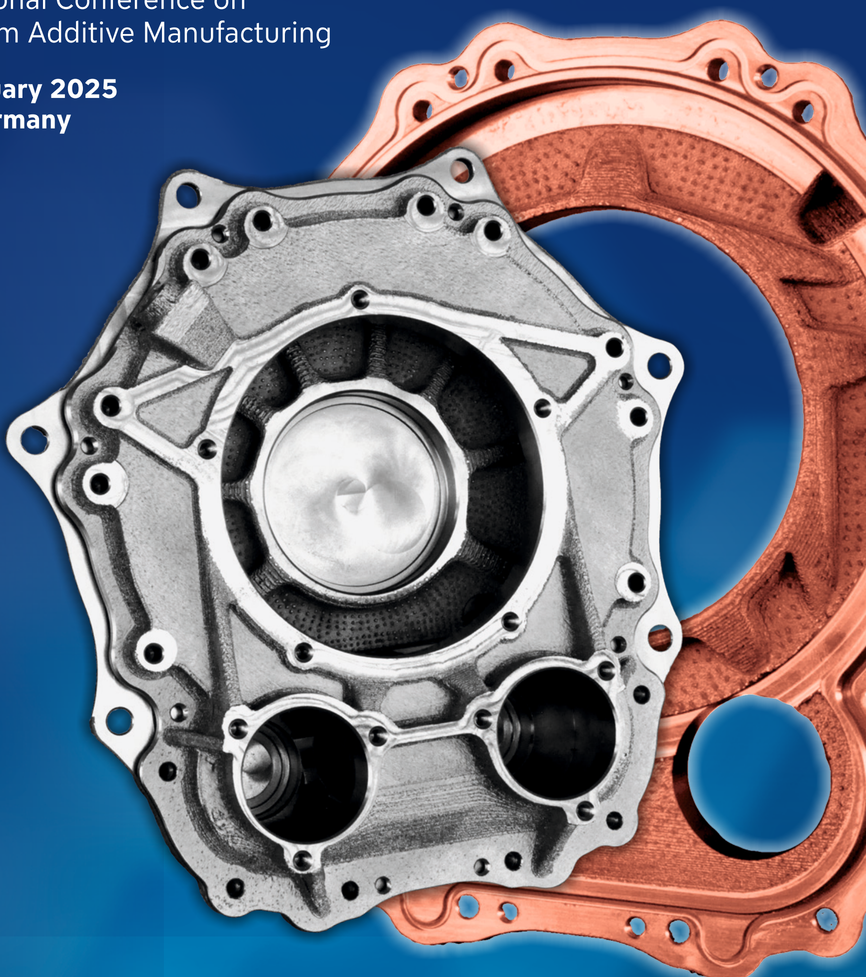
FAU

Friedrich-Alexander-Universität
Erlangen-Nürnberg

EBAM 2025

5th International Conference on
Electron Beam Additive Manufacturing

26 - 28 February 2025
Erlangen, Germany



WTM

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Welcome

It is our pleasure to announce the **5th International Conference on Electron Beam Additive Manufacturing EBAM 2025**, which will take place from 26 – 28 February 2025 in Erlangen, Germany. EBAM 2025 is organized by the Chair of Materials Science and Engineering for Metals with support of the FAU Competence Center Engineering of Advanced Materials (EAM) at the Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU).

The conference aims to discuss specific challenges and opportunities offered by the electron beam. EBAM 2025 will bring together researchers and industrial users in person to achieve improvements in this technology. Keynote presentations from academics as well as industry will give high-level insight into this fabrication technology.

Since the first EBAM conference in 2016, interest in this topic has been increasing, which is reflected in an enormous number of contributions for EBAM 2025 from all over the world. We hope that the wide range of inspiring talks, including the keynote presentations, in combination with high-quality poster presentations and the exhibition area initiates various fruitful discussions and future cooperation. Warm thanks go to our organization team for the help and support during preparation and the following three intense days.

We are looking forward to the scientific program full of expertise from all over the world.

Carolin Körner
Conference Coordinator

Matthias Markl
Head of the Local Organization Committee

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Table of Contents

General Information 2

Keynote Speakers 4

Exhibitors & Media Partner 9

Organization 14

Program 15
- Wed, 26 February 15
- Thu, 27 February 17
- Fri, 28 February 19

Abstracts for Oral Presentations 20
- Wed, 26 February 20
  - 9:40 · Refactory Metals 20
  - 11:30 · Materials 24
  - 14:30 · Technology 1 29
  - 16:10 · Process Monitoring 33
- Thu, 27 February 38
  - 9:00 · Technology 2 38
  - 10:40 · Iron 42
  - 13:40 · Process 46
  - 15:50 · Nickel 51
- Fri, 28 February 55
  - 9:00 · Titanium & Copper 55
  - 11:10 · Process Chain 60

Abstracts for Poster Presentations 64

Conference Venue

Kreuz+Quer
Haus der Kirche Erlangen

Bohlenplatz 1
91054 Erlangen

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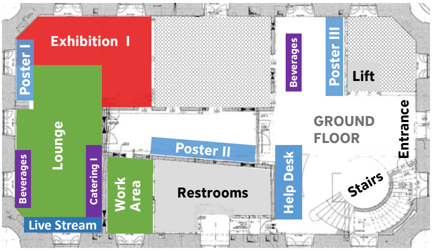

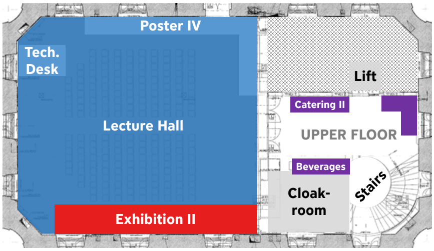

Registration & Help Desk

The registration and help desk is located in the lower foyer. Registration starts on Wed, 26 Feb, 9:00 and is open during the whole conference.

Oral Presentations

All oral presentations take place in the lecture hall and are streamed to the lounge area on the ground floor. They are limited to a total of 20 minutes; keynote speakers have 30 minutes. This time includes a short discussion of about 5 minutes on the presented topic.

Speakers are expected to respect the schedule, to keep the time of their presentation and to present themselves to their session chair in advance to the session.

Speakers are requested to provide their presentation at least 15 minutes before the beginning of the session at the technical desk in the lecture hall. If necessary, speakers can use their own laptops for their presentation. Please inform the technical desk accordingly.

We would like to provide PDF documents of all presentations to all participants after the conference. Please inform the technical desk, if we are allowed to share your presentation.

Conference Publications

All authors are invited to publish a peer-reviewed journal publication within the collection **Advanced Electron Beam Additive Manufacturing** in *Progress in Additive Manufacturing* (Springer, impact factor of 4.4 in 2023).

Poster Presentations

Posters are displayed in the lecture hall surrounding the presentation area as well as on the ground floor. Please mount your poster immediately after registration. The poster boards are marked by contribution ID, presenting author and title. The poster session starts on Wed, 26 Feb, 18:00. Posters should be displayed until the end of the conference.

Poster Awards

All attendees are invited to vote for the best poster presentation until Thu, 27 Feb, 14:00. The three posters with the most votes will be awarded with a poster prize sponsored by Wiley during the concluding remarks of the conference.

10 YEARS ADVANCED MATERIALS INTERFACES Open Access

Exhibition

The exhibition is located behind the lower foyer on the ground floor as well as surrounding the presentation area in the lecture hall. The exhibition is accessible during the whole conference. The main exhibition times are parallel to the poster session and lunches.

Lunches, Coffee Breaks & Refreshments

Lunch, beverages and light refreshments will be served in the lower and upper foyer. There are several tables and bar tables located in the lecture hall, the lounge, the work area and the upper and lower foyer to enjoy the breaks and to exchange ideas.

Conference Dinner

The conference dinner starts on Thu, 27 Feb, 18:00.

Hotel Bayerischer Hof
Schuhstraße 31
91052 Erlangen

©Hotel Bayerischer Hof, Erlangen 2024

Keynote Speakers

Pär Arumskog
VBN Components AB
Uppsala, Sweden

Carbide size control using EBM process parameters and extreme layer thickness variations in high-speed steels and cemented carbide

Thu, 27 Feb, 10:40 - 11:10

Pär Arumskog earned his Master of Science in Engineering in Applied Physics from Linköping University, Sweden, before moving to Japan to do industrial research into hard coatings for cutting tools, in particular working on ceramic Physical Vapor Deposition coatings. Moving from coatings into Additive Manufacturing, he has been working with Electron Beam Melting (EBM) since 2017 when he joined Arcam AB, now Collibirum Additive, as an Application Engineer. At GE Additive, he gained extensive knowledge of EBM, in particular working on customer-focused process development for new alloys and supporting medical device manufacturers with Equipment Qualification and Process Validation topics. He is qualified to teach material development with EBM and has experience of EBM connected to a wide range of materials, such as Ti alloys, pure Cu, Ni alloys, stainless steel, and refractory metals. At VBN Components since 2022, currently with the title Senior AM Development Engineer, he now works with EBM of high-speed steels and hybrid cemented carbides. Since 2024, he devotes the majority of his time to qualifying large-scale L-PBF for aerospace applications at GKN Aerospace Sweden. Pär speaks fluent Swedish, English and Japanese. He currently holds six patents with several additional applications pending.

Dr. Agustin Diaz
Advanced Manufacturing and Innovation Manager
REM Surface Engineering
2107 Longwood Drive, Brenham, TX 77833 US

Post-processing of metal additive manufactured components: Powder removal and surface finishing of internal channels and external surfaces through chemically-assisted technologies

Fri, 28 Feb, 11:10 - 11:40

Dr. Agustin Diaz is the Advanced Manufacturing and Innovation Manager at REM Surface Engineering, where he leads cutting-edge research and development efforts to optimize the surface properties of additive manufacturing (AM) components. He has pioneered several innovative processes that enhance the mechanical performance and corrosion resistance of AM surfaces, earning him widespread recognition in the field. Dr. Diaz is at the forefront of developing novel technologies that address the challenges of surface finishing in AM, significantly advancing the capabilities and applications of AM materials. Dr. Diaz actively contributes to advancing industry standards and best practices through his involvement in numerous technical committees and professional organizations. He has authored numerous peer-reviewed papers, holds several patents, and contributed to multiple book chapters on the surface optimization of AM components. He is also a highly regarded principal investigator, having led various high-profile research projects, including multiple NASA and US Air Force Small Business Innovation Research (SBIR) awards.

Dr. Michael Kirka
Manufacturing Demonstration Facility
Deposition Science and Technology Group
Materials Science and Technology Division
Oak Ridge National Laboratory, US

Processing of refractory metals through electron beam melting

Wed, 26 Feb, 9:40 - 10:10

Dr. Michael Kirka is a Senior Research Staff and the Group Leader of the Deposition Science and Technology Group at Oak Ridge National Laboratory, where his research interests are on evaluating the suitability and limitations of high temperature materials for use in extreme environments for processing via additive manufacturing routes. Combining interdisciplinary disciplines encompassing metallurgy, data science, computational materials modeling, and process simulation, the necessary processing science to overcome many non-weldability challenges of nickel-base superalloys and refractories to enable materials of ever-increasing operational capabilities has been achieved. These advancements have allowed the team to demonstrate the suitability of additively manufactured materials in some of the harshest environments including hot section rotating components of turbine engines and fusion plasma environments.

In 2020 Michael was the recipient of the TMS Young Innovator Award in Additive Manufacturing. Michael received his B.S. in Materials Science from The University of Michigan in 2007 and M.S. and Ph.D. degrees from the Georgia Institute of Technology in Mechanical Engineering in 2010 and 2014 respectively.

Prof. Feng Lin

Department of Mechanical Engineering (DME), Tsinghua University, China
Council Member of Chinese Mechanical Engineering Society (CMES)
Vice Chairman of Additive Manufacturing and 3D Printing Institute of CMES

Efforts to reduce thermal stress, surface roughness, and powder consumption in powder bed melting additive manufacturing technology

Wed, 26 Feb, 11:30 - 12:00

Prof. Lin started his research on Rapid Prototyping technique in early 1990, when he was a graduate student in the Department of Mechanical Engineering at Tsinghua University and developed the first laminated object manufacturing (LOM) system in China. From 1998 to 2002, he became a post-doctoral fellow and research assistant professor at Drexel University, and began research on computer aided tissue engineering. Since 2002, Prof. Lin joined the department of Mechanical Engineering of Tsinghua University and initiated the research and development of electron beam selective melting (EBSM) in China, which possessed active precise powder supply system and the capacity of dual metal gradient structure manufacturing. Recently, he is devoted to improving the function and performance of EBSM process through introducing the multi-scale computational simulation technique into EBSM process and inventing the EB-laser hybrid selective melting processes with an integrated laser in EBSM. He invented the floated powder bed technique and is dedicated to refining and promoting this innovative technology. He won the Program for New Century Excellent Talents by Ministry of Education in 2006, the second prize of National Science and Technology Progress Award twice in 2015 and 2002, and the Highly Commend Award for Outstanding Paper by the Literati Club of Emerald Publishing in 2001.

Prof. Greta Lindwall

Department of Materials Science and Engineering
KTH Royal Institute of Technology, Sweden

Real-time tracking of electron beam additive manufacturing using synchrotron x-ray techniques

Wed, 26 Feb, 16:10 - 16:40

Greta Lindwall is an Associate Professor at the Department of Materials Science and Engineering at the KTH Royal Institute of Technology in Sweden. Her research focuses on materials design for metal additive manufacturing and combines computational approaches with advanced material characterization techniques to increase the understanding and predictability of structure evolution during additive manufacturing.

Andrea Palumbo
Additive Technology Life Cycle Engineering
Additive Manufacturing Principal Engineer
Avio Aero - a GE Aerospace Business
Cameri (NO), Italy

EBM TiAl blades production at Avio Aero - An overview

Fri, 28 Feb, 9:00 - 09:30

Andrea Palumbo is currently the Principal Engineer for Additive Manufacturing at AvioAero Additive Technology Life Cycle Engineering. Based in the 9X TiAl blades Cameri shop, his role involves providing technical guidance on the development of additive parts and technologies, with a particular focus on EBM and GE9X LPT blades.

In this role, he also mentors emerging talents in AvioAero Additive Technology and contributes to the consolidation of additive technical knowledge.

Andrea holds a master's degree in Aeronautical Engineering from the Turin Polytechnic. He began his career working as a mechanical designer and structural analyst at an engineering company. In 2002, he joined AvioAero, relocating to Turin to work in Engineering on Low Pressure Turbine component and system design. After graduating as a Six Sigma Black Belt, he spent two years working on various product and process improvement projects. In 2008, he was appointed Technical Leader for the Low Pressure Turbines of the EJ200 (Eurofighter), PW308, and for the development of the PW814-815 Exhaust Case.

In 2014, he began working on Additive Manufacturing technology, moving to the Cameri shop to oversee the development and industrialization of GE9X Electron Beam Melting LPT TiAl blades up to their certification. Andrea enjoys skiing, hiking, photography, reading, and playing with his 11-year-old son and 5-year-old daughter.

Dr.-Ing. habil. Anja Weidner
Local Deformation and Damage Group
Institute of Materials Engineering
Faculty of Materials Science and Technology
TU Bergakademie Freiberg, Germany

Ultrasonic fatigue testing of additively manufactured high temperature materials at RT and elevated temperatures

Thu, 27 Feb, 15:50 - 16:20

Anja Weidner has been researcher at the Institute of Materials Engineering at the University Bergakademie Freiberg, Germany, since 2009. She studied Materials Science at the University Bergakademie Freiberg where she received her doctorate in 1998 and her habilitation in 2019. She has been the leader of the group “Local deformation and damage mechanisms” since 2011. Her research includes plasticity and fatigue as well as additive manufacturing with particular focus on in situ characterization techniques and micromechanics. She was awarded the “Galileo price” in 2020 and the DGM society award “DGM Pioneer” in 2024.

Prof. Wentao Yan
Applied Mechanics
Department of Mechanical Engineering
National University of Singapore, Singapore

High-fidelity modeling of multi-material additive manufacturing: from particle reinforced composites to in-situ alloying

Thu, 27 Feb, 13:40 - 14:10

Dr. Wentao Yan has been an assistant professor in the Department of Mechanical Engineering, National University of Singapore (NUS) since 2018. Supported by multi-million grants, his research group with 20+ students focuses on multi-scale multi-physics modeling, experimental investigation and data analysis of additive manufacturing. His team was the biggest winner in the 2022 NIST AM-Bench Simulation Challenges by winning 9 awards in the total 25 tests. He has published 120 papers on flagship journals, such as Nature Communications, and Acta Materialia, which have received over 5600 citations. He has delivered more than 80 invited talks at international conferences and prestigious universities. Over 20 of his former students have got faculty positions, including all the 10 former postdocs. Before joining NUS, Dr. Yan was a postdoctoral fellow at Northwestern University and also a guest researcher at the National Institute of Standards and Technology in the USA. He received his Ph.D. degree jointly at Tsinghua University, Beijing and Northwestern University, USA. He got his Bachelor degree from the Department of Mechanical Engineering, Tsinghua University, Beijing in 2012.

Exhibitors

ALD Vacuum Technologies GmbH

Otto-von-Guericke-Platz 1
63457 Hanau, Germany

ALD Vacuum Technologies GmbH, based near Frankfurt am Main, is one of the world's leading manufacturers of vacuum systems for vacuum metallurgy and heat treatment. ALD supplies plant technology for the thermal and thermochemical treatment of metallic materials in solid and liquid form. The company's expertise lies in its mastery of vacuum process technology and its know-how in designing customized system solutions for these fields.

ALD is the supplier of EBuild®, the world's largest E-PBF system, which can produce parts up to 850 x 850 x 1000 mm. EBuild® complements ALD's inert gas atomisers, which are market leaders in the production of high quality spherical metal powders. The combination of large scale powder production and EBuild® systems establishes E-PBF as an economically viable process on an industrial scale.

Colibrium Additive – a GE Aerospace company

Freisinger Landstrasse 50
85748 Garching bei München, Germany

Colibrium Additive – a GE Aerospace company – is a trusted leader in providing metal 3D printers, powders, and services for industrial scale metal additive manufacturing. We are the pioneers in Electron Beam Powder Bed Fusion technology, and our advancements, including the new Point Melt melting scan strategy, have kept us at the forefront of metal additive EBM At Colibrium Additive, we empower our customers to design and build innovative new products that solve manufacturing challenges and improve business outcomes.

Freemelt AB

Bergfotsgatan 5A
43135 Molndal, Sweden

Founded in 2017 by a team of experienced engineers, Freemelt develops advanced 3D printers for metal components, based in Gothenburg, Sweden. Freemelt primarily serves companies in the defense, energy, and medical technology sectors in Europe and the U.S., helping them innovate and improve production efficiency. Our modular 3D printers use E-PBF (Electron Beam Powder Bed Fusion) technology, offering significantly higher efficiency compared to other machines on the market, while being independent of the type of metal used. To maximize customer flexibility, we use an open source software solution. Our primary materials are tungsten, with a melting point of 3400°C, making it ideal for advanced defense applications and fusion reactors in the energy sector, and titanium, which is perfect for implants.

By supporting the full development journey, we position ourselves as a long-term partner, ensuring smooth transitions and faster time-to-market for industrial customers in sectors like defense, energy, and medical technology. We support the full development journey from concept to serial production through our three 3D printers:

Freemelt® ONE · For open materials research
e–MELT®-iD · For efficient product development
e–MELT®-iM · For optimized for serial production

Hipercone Ltd.

14 Ezrat Israel st.
Jerusalem, Israel

Hipercone Ltd. specializes in the field of computational material science and industrial processes modeling. In close cooperation with industry leaders, we develop and market software tools as well as provide research and development services for prediction of material properties and modeling of physical and chemical processes in additive manufacturing and other industrial applications. Our software tools span a wide range of spatial and temporal scales: from ab initio quantum chemistry simulations of atomic and molecular structure of materials to simulation of device behavior on the macroscale. Hipercone Headquarters are in Jerusalem, Israel.

We have developed a high-throughput GPGPU-enabled simulation package for additive manufacturing (KiSSAM) which accurately captures the diverse physical phenomena occuring during powder bed fusion (PBF) process at the mesoscale: powder layer formation, energy absorption, melt pool dynamics and solidification. The high performance of KiSSAM enables multilayer simulations without compromising the accuracy of the description of the PBF process, helping gain insights into how evolution of single-track morphology affects the morphology and microstructure of entire parts.

JEOL Ltd.

3-1-2, Musashino, Akishima
Tokyo, 196-8558, Japan

Advancing Manufacturing Capabilities through Electron Beam Melting Technology.

Electron Beam Powder Bed Fusion (EB-PBF) stands out as a cutting-edge additive manufacturing technology which enables rapid printing speeds with minimal post processing requirements.

JEOL proudly introduces the JAM-5200EBM which is the only EB-PBF machine that harnesses over 70+ years of electron beam innovation, guaranteeing exceptional reliability in manufacturing environments.

Discover how the JAM-5200EBM and JEOL can help revolutionise your production processes and bring unparalleled manufacturing capabilities to your organisation.

Leybold GmbH

Bonner Strasse 498
50968 Köln, Germany

As a pioneer in vacuum technology, Leybold offers a wide range of state-of-the-art vacuum pumps, standardized and fully customized vacuum solutions and services, complemented by well suited vacuum equipment.

We are able to meet even the most demanding requirements of highly complex applications, helping our customers to succeed. From heavy-duty processes in metallurgy, clean room conditions in world-renowned research and development institutes to coating applications on the smallest scale, Leybold offers top performance. Vacuum technology is used in numerous areas of our everyday lives, such as air conditioning systems, flat screens and automotive applications. However, it is also used in high-tech processes such as the coating of microchips, CDs and DVDs as well as in the manufacture of optical glass and analytical equipment.

We have been at the forefront of vacuum innovation since our foundation in 1850, and our dedicated employees are at the heart of our company's success. Their ability to innovate, their commitment and their know-how are the reasons why customers all over the world place their trust in us.

pro-beam additive GmbH

Zeppelinstr. 26
82205 Gilching, Germany

pro-beam additive GmbH is part of the pro-beam Group, a global leader in the field of electron beam technology. The company enables two additive manufacturing processes for metal components – EBM (Electron Beam Melting) and WEBAM (Wire Electron Beam Additive Manufacturing) – as well as corresponding machines.

EBM is especially suitable for compact as well as highly detailed metal components. With the company's efficient EBM system PB EBM 30S customers can build parts from a batch size of 1 up to serial production in a powder bed. The process is reproducible and ensures high-quality and fast production. At the same time, processes are parallelized so that users benefit from maximized productivity.

WEBAM is suitable for large components made of high-performance metals as well as reactive metals. With the wire-based PB WEBAM 100 customers can manufacture their components in a flexible, quick and material-efficient manner, while multi-material components are possible. The process is reproducible and leads to very good surface qualities.

REM Surface Engineering

325 West Queen Street
Southington, CT 06489, US

REM Surface Engineering is a global provider of surface engineering solutions. REM's Extreme ISF® Process is a suite of subtractive, isotropic superfinishing processes tailored to the metal additive manufacturing industry. The technology can reduce the extreme surface roughness associated with metal AM while removing/remediating surface and near-surface defects. Applicable alloys include titanium, nickel-based, copper, steel, stainless steel, and refractory alloys. Some key benefits for AM components include increase bending fatigue resistance, reduced pressure drop, improved corrosion resistance, and improved cleanliness. REM's processes can remove support structures and accommodate complex geometries such as internal channels and lattices. REM offers the Extreme ISF Process as an outsourced solution or as a complete technology installation.

REM's ISF Technologies have been used to enhance the performance of parts in many industries, including Aerospace, Space, Medical, Heavy Equipment, and many others. REM locations are ISO 9001:2015 and AS9100:2016 Rev. D certified.

Wayland Additive Ltd.

Unit 7, Park Valley Court
Huddersfield, HD4 7BH, UK

Wayland Additive was founded in 2019 to bring to market a new generation of electron beam additive manufacturing machines. Wayland's objective is to simplify the electron beam process and machine operation whilst increasing the breadth of process capability thereby increasing the technological and market reach for electron beam AM. Wayland's hot part process, as opposed to a hot bed process, creates stress free parts with less structural scaffolding, higher productivity and lower total part costs. With a strong heritage in electron beam systems, charged particle physics and additive manufacturing Wayland has created a new technology, NEUBEAM®, that builds on the best of electron beam's capabilities whilst taking away the constraints. With machines now in the field and in production Wayland is looking for pioneers and innovators to join them in their AM journey.

Media Partner

Metal Additive Manufacturing magazine

Inovar Communications Ltd
11 Park Plaza, Battlefield Enterprise Park
Shrewsbury SY1 3AF, UK

Metal Additive Manufacturing magazine is a global publication that showcases the latest commercial and technical advancements in the world of metal 3D printing. We cut out the hype, kill the buzzwords and discuss a range of topics from the industry, including market insights, applications, materials, equipment, research, events, and software.

Published quarterly in print and online, each issue features a number of exclusive in-depth articles and special features on metal Additive Manufacturing, as well as our extensive industry news rundown. Each new issue of Metal AM, and the complete archive, is available to download free of charge.

Scientific Advisory Board

Ulf Ackelid	Freemelt AB, Sweden
Akihiko Chiba	Tohoku University, Japan
Paolo Gennaro	GF Machining Solutions, Italy
Ola Harrysson	North Carolina State University, US
Greta Lindwall	KTH Stockholm, Sweden
Feng Lin	Tsinghua University, China
Thorsten Löwer	pro-beam GmbH & Co. KGaA, Germany
Ulric Ljungblad	Freemelt AB, Sweden
Guilhem Martin	Université Grenoble Alpes, France
Lars-Erik Rännar	Mid Sweden University, Sweden
Anders Snis	GE Additive - Arcam EBM, Sweden
Iain Todd	University of Sheffield, UK

Local Organization Committee

Carolin Körner	Conference Coordinator
Matthias Markl	Head of the Local Organization Committee
Angelika Mach	Technical Organization

9:00 - 9:30 Registration

9:30 - 9:40 Welcome
Carolin Körner · FAU Erlangen-Nürnberg, Germany

Wed, 26 Feb **Refractory Metals**
Chair: Paolo Gennaro · GF Machining Solutions, Italy

9:40 - 10:10 **Processing of refractory metals through Electron Beam Melting**
Michael Kirka · Oak Ridge National Laboratory, US 20

10:10 - 10:30 Challenges for realization of dense, crack-free pure tungsten components in electron beam powder bed fusion
Satoshi Ono · JEOL Ltd., Japan 21

10:30 - 10:50 Densification and microstructural engineering of pure tungsten in electron beam powder bed fusion
Kenta Yamanaka · Tohoku University, Japan 22

10:50 - 11:10 High power spot melting of pure tungsten – an enabler for high productivity in manufacturing dense and crack-free tungsten parts
Camilo Medina Viramontes · Freemelt AB, Sweden 23

11:10 - 11:30 Break

Wed, 26 Feb **Materials**
Chair: Ola Harrysson · North Carolina State University, US

11:30 - 12:00 **Efforts to reduce thermal stress, surface roughness, and powder consumption in powder bed melting additive manufacturing technology**
Feng Lin · Tsinghua University, China 24

12:00 - 12:20 A numerical study of the morphology and microstructure of thin walls manufactured using PBF depending on process and material parameters
Sergei Belousov · Hipercone Ltd., Israel 26

12:20 - 12:40 Microstructure and mechanical behavior of a NiAl-CrMo eutectic in-situ composite processed via electron beam powder bed fusion
Katharina Titz · FAU, Germany 27

12:40 - 13:00 Machinable and high-temperature strong Nb-silicide intermetallic composites by Electron Beam Powder Bed Fusion
Bo Wei · Tsinghua University, China 28

13:00 - 14:30 Lunch

Wed, 26 Feb **Technology 1**

Chair: Feng Lin · Tsinghua University, China

14:30 - 14:50 Wire electron beam technology: The key to resource efficiency and scalable additive manufacturing
Alejandro Zamorano Reichold · pro-beam additive GmbH, Germany 29

14:50 - 15:10 Investigation and simulation of thermo-mechanical distortion of parts made by wire-based electron beam additive manufacturing
Johannes Käsbauer · Technische Hochschule Deggendorf, Germany 30

15:10 - 15:30 Optimization of processing strategies in WEBAM with simulation
Tobias Geiger · Neue Materialien Fürth GmbH, Germany 31

15:30 - 15:50 Influence of different additive manufacturing processes on the mechanical properties of Ti-6Al-4V
Fernando Gustavo Warchomicka · Graz University of Technology, Austria 32

15:50 - 16:10 Break

Wed, 26 Feb **Process Monitoring**

Chair: Ulric Ljungblad · Freemelt AB, Sweden

16:10 - 16:40 **Real-time tracking of electron beam additive manufacturing using synchrotron x-ray techniques**
Greta Lindwall · KTH Royal Institute of Technology, Sweden 33

16:40 - 17:00 In-situ synchrotron radiography of melt pool dynamics in electron beam powder bed fusion
Nick Semjatov · FAU, Germany 34

17:00 - 17:20 In-Melt electron analysis (IMEA) approach for process optimization and quality control in EB-PBF
Jinghao Xu · Linköping University, Sweden 35

17:20 - 17:40 In-situ monitoring of melt pool dynamics during electron beam melting and sintering
Ivan Zhirnov · Wuppertal University, Germany 36

17:40 - 18:00 Exploring the potential of a Multi-Detector Electron-Optical system in Electron Beam Powder Bed Fusion
Timo Berger · FAU, Germany 37

18:00 - 20:00 **Poster and Exhibition**

Poster presentations and exhibition including light refreshments

Thu, 27 Feb **Technology 2**

Chair: Greta Lindwall · KTH Stockholm, Sweden

9:00 - 9:20 Electron beam powder bed fusion for mass production
Ulric Ljungblad · Freemelt AB, Sweden 38

9:20 - 9:40 NeuBeam E-PBF enabled build strategies
Martyn Hussey · Wayland Additive, UK 39

9:40 - 10:00 Increased productivity in EBM
Sebastian Pohl · pro-beam additive GmbH, Germany 40

10:00 - 10:20 EBM point melt – A new level of serial production for titanium components in the medical industry, as well as an enabler for high-temperature materials production in the aerospace industry
Markus Ramsperger · Colibrium Additive, Sweden 41

10:20 - 10:40 Break

Thu, 27 Feb **Iron**

Chair: Michael Kirka · Oak Ridge National Laboratory, US

10:40 - 11:10 **Carbide size control using EBM process parameters and extreme layer thickness variations in high-speed steels and cemented carbide**
Pär Arumskog · VBN Components AB, Sweden 42

11:10 - 11:30 Microstructural and mechanical properties of high-alloy austenitic CrMnNi steels with different nickel contents produced by electron beam melting
Christina Burkhardt · TU Bergakademie Freiberg, Germany 43

11:30 - 11:50 Effect of sulphur addition on the processability of a metastable stainless steel X2CrMnNi 16-7-4.5 in EB-PBF/M
Stefan Langenhan · TU Bergakademie Freiberg, Germany 44

11:50 - 12:10 EB-PBF of wear resistant FeCr-10V for resource efficient tools
Alexander Kirchner · Fraunhofer IFAM, Germany 45

12:10 - 13:40 Lunch

Thu, 27 Feb **Process**

Chair: Akihiko Chiba · Tohoku University, Japan

13:40 - 14:10 **Design of alloys for additive manufacturing by efficient combination of experiments, simulation and machine learning**
Wentao Yan · National University of Singapore, Singapore 46

14:10 - 14:30 Part-scale thermal simulation of EB-PBF
Jonas Böhm · FAU, Germany 47

14:30 - 14:50 In-situ monitoring of heat propagation in EB-PBF
Marco Luigi Giuseppe Grasso · Politecnico di Milano, Italy 48

14:50 - 15:10 The investigation on the evolution of smoking phenomenon in electron beam powder bed fusion process
Dongfang Wang · Tsinghua University, China 49

15:10 - 15:30 Correlating outgassing and smoke phenomenon in EB-PBF
Jihui Ye · FAU, Germany 50

15:30 - 15:50 Break

Thu, 27 Feb **Nickel**

Chair: Andrea Palumbo · Avio Aero, Italy

15:50 - 16:20 **Ultrasonic fatigue testing of additively manufactured high-temperature materials at RT and elevated temperatures**
Anja Weidner · TU Bergakademie Freiberg, Germany 51

16:20 - 16:40 The study of the relationship between the melting strategy and the microstructure formation during EB-PBF process
Ren Hao Lu · North Carolina State University, US 52

16:40 - 17:00 Microstructural analyses and defects investigation of Inconel 738 processed by electron beam powder bed fusion (EB-PBF)
Serena Lerda · Politecnico di Torino, Italy 53

17:00 - 17:20 3D Point patterns for material design in EB-PBF
Yannic Westrich · FAU, Germany 54

18:00 - 21:00 **Conference Dinner**
Hotel Bayerischer Hof, Schuhstraße 31, 91052 Erlangen

Fri, 28 Feb **Titanium & Copper**
Chair: Anja Weidner · TU Bergakademie Freiberg, Germany

9:00 - 9:30 **EBM TiAl blades production at Avio Aero – An overview**
Andrea Palumbo · Avio Aero, Italy 55

9:30 - 9:50 Crystal plasticity finite element method virtual laboratory for EB-PBF microstructural properties
Paolo Antonioni · Politecnico di Torino, Italy 56

9:50 - 10:10 Graph-based Spot Sequences in EB-PBF
Tobias Kupfer · FAU Erlangen-Nürnberg, Germany 57

10:10 - 10:30 Powder bed fusion of pure copper using an electron beam – A comparative study on the material properties obtained using vector- and spot-based exposure
Robert Ortmann · Ruhr University Bochum, Germany 58

10:30 - 10:50 Role of high oxygen content on the process-structure-property relationship of copper produced in EB-PBF
Prithwish Tarafder · Linköping University, Sweden 59

10:50 - 11:10 Break

Fri, 28 Feb **Process Chain**
Chair: Lars-Erik Rännar · Mid Sweden University, Sweden

11:10 - 11:40 **Post-processing of metal additive manufactured components: powder removal and surface finishing of internal channels and external surfaces through chemically-assisted technologies**
Agustin Diaz · REM Surface Engineering, US 60

11:40 - 12:00 Evaluation of infrared thermography for the defects detection in Components manufactured by EB-PBF
Silvio Defanti · University of Modena and Reggio Emilia, Italy 61

12:00 - 12:20 In-situ powder alloying via Powder2Powder ultrasonic atomization tailored for electron beam melting
Jakub Ciftci · Amazemet, Poland 62

12:20 - 12:40 Sustainability in Metal AM: The EBuild® 850 and its Role in metal powder recycling
Alexander Klassen · ALD Vacuum Technologies GmbH, Germany 63

12:40 - 12:50 Concluding Remarks
Carolin Körner · FAU Erlangen-Nürnberg, Germany

12:50 - 14:00 Lunch

Processing of refractory metals through electron beam melting

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Refractory metals have many advantageous uses over other materials families due to there ability to operate in extreme high temperature and damaging applications such as fusion energy among others. However, refectory metals are among the most challenging metals to process in the world through conventional and advanced manufacturing routes such as electron beam melting (EBM). This is due to their high melting points, and sensitivity to defect formation upon liquid-to-solid phase transition, as well as in the solid state due to linkages between ductility and temperature. Leveraging the ability to control localized thermal gradients during the processing of refractory metals, significant advancements have been made in the processing of the tungsten and molybdenum alloys, as well as refractory high entropy alloys (RHEAs). To be discussed is the progress to date in the processing of refractory metals into relevant geometries in case study energy applications where refractories are necessary to unlock increases in energy efficiency. Further, the lessons learned and perceived limitations to the processing of refractory metals with current EBM technology will be considered.

Figure 1: Tungsten plasma facing component mock-up for fusion energy first wall application.

Challenges for realization of dense, crack-free pure tungsten components in electron beam powder bed fusion

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The manufacturing of tungsten parts is challenging due to its high melting point and brittleness, resulting in difficulty producing complex geometries. Methods such as laser powder bed fusion (LPBF) and powder metallurgy encounter limitations. LPBF struggles with tungsten's high melting point and thermal management, resulting in cracks and low density. Powder metallurgy is effective for simple geometries but lacks flexibility for intricate shapes.

Electron beam melting (EBM) technology utilizes the electron beam's preheating capability to create a stable thermal environment on the powder bed prior to melting of metal powder. This approach ensures consistent powder densification, producing high-quality tungsten parts. The robust preheating capabilities of the EBM process enable the successful manufacturing of complex geometries with excellent mechanical properties, overcoming the challenges associated with alternative methods.

This presentation will highlight advances in achieving dense, crack-free tungsten components, focusing on the technology's application and performance benefits. Further, we will discuss ongoing work aimed at scaling up build volumes to increase production rates, making EBM a practical and efficient solution for high-performance applications. Future developments will emphasize optimizing the process for larger components and implementing real-time in situ process monitoring systems for enhanced quality control, broadening the potential applications of tungsten in industrial environments.

Densification and microstructural engineering of pure tungsten in electron beam powder bed fusion

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Tungsten is an attractive metal for the additive manufacturing community due to its potential applications in nuclear, aerospace, defense, and medical industries [1]. However, its high melting point and inherent low-temperature brittleness make fabricating bulk components challenging [2, 3]. In this study, using a JEOL electron beam powder bed fusion printer (JAM-5200EBM), we systematically investigated the densification behavior and microstructural evolution of pure tungsten by varying energy input and hatch spacing. The state-of-the-art electron beam control capability enabled a superior build surface temperature at 1400°C, mitigating thermal cracking. However, we discovered that high energy density results in unique intragranular cracking occurring on the {001} planes (Figs. 1(a, b)), suggesting that the solidification microstructures underwent cleavage failure at temperatures below the ductile-to-brittle transition temperature. Nevertheless, we successfully eliminated cleavage failures by managing thermal conditions, thereby determining the process window for crack-free builds. The obtained specimens exhibited columnar microstructures with notable substructural evolution (Fig. 1(c)), showing a well-defined <100> + <110> texture along the building direction (BD). We also demonstrated the manipulation of the grain morphology through the precise control of building conditions.

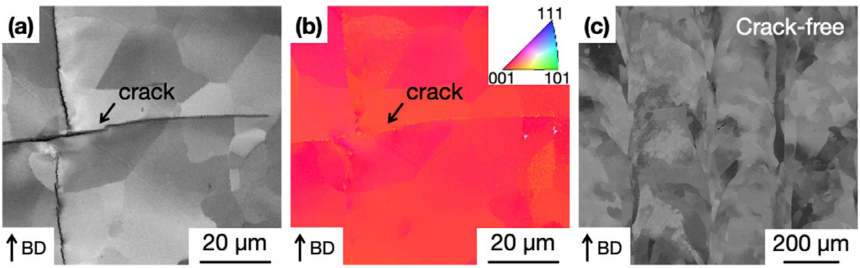

Figure 1: (a) Image quality map and (b) inverse pole figure map showing cleavage cracking along {001} planes. (c) Backscattered electron image of the specimen prepared under the optimal conditions.

[1] A. Talignani et al., 2022, *Addit. Manuf.* **58**, 103009.
[2] A. Iveković et al., 2018, *Int. J. Refract. Met. Hard Mater.* **72**, 27-32.
[3] A.V. Müller et al., 2019, *Nucl. Mater. Energy* **19**, 184-188.

High power spot melting of pure tungsten – an enabler for high productivity in manufacturing dense and crack-free tungsten parts

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Electron Beam Powder Bed Fusion (EB-PBF) of pure tungsten has gained significant research interest in recent years as it has enabled manufacturing of dense and crack-free bulk parts [1]. EB-PBF has two distinct advantages useful for tungsten: an elevated powder bed temperature reducing the residual stress levels and a high vacuum environment preventing oxygen pickup [2,3]. Inertia-free high deflection speed of the electron beam facilitates unique scanning strategies for thermal management, site-specific microstructure control, etc.

In this study, we demonstrate a variety of spot melting strategies for manufacturing of dense and crack-free parts in pure tungsten. Process-microstructure-properties relationships for different scanning strategies and post-processing are investigated. The influence of grain morphology and texture on deformation behaviour are discussed. Video material will be used for illustration.

We will present parts with geometries suitable for plasma facing walls in fusion reactors showing the capability of printing defect free, low oxygen, bulk parts made at high production rate enabled by high beam power processing and spot melting.

[1] Ledford, C. et al., 2023, *Int J Refract Metals Hard Mater* **113**, 106148.

[2] Wright, J., 2020, *PhD thesis* , Univ. of Sheffield.

[3] Yang, G. et al., 2019, *Int J Refract Metals Hard Mater* **84**, 105040.

Efforts to reduce thermal stress, surface roughness, and powder consumption in powder bed melting additive manufacturing technology

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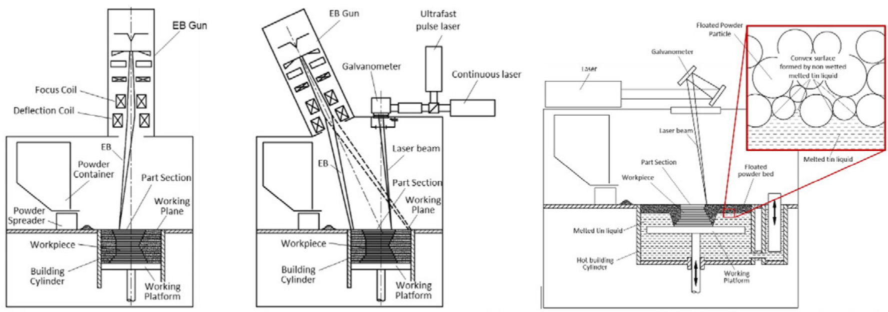
The powder bed fusion (PBF) technology has been the most common additive manufacturing process, especially for complex metal parts. But it is still subject to several barriers such as the thermal stress, the limited material, the rougher surfaces, the higher cost and the overstock powder. Multiple efforts made in Tsinghua University to overcome the barriers will be presented in this speech.

Since 2004, electron beam (EB) has been adopted in powder bed fusion technology in Tsinghua University (Fig.1(a)). Due to the high power and high energy absorption ratio of electron beam, the electron beam based powder bed fusion (EB-PBF) process has a preheated powder bed with the temperature up to 1000°C or even higher, in which the thermal stresses in the workpiece can be controlled to a very low level. By this advantage, the dense crack free parts of several difficult-to-process metals, such as high strength aluminum alloy (Al2024), intermetallics (TiAl alloy), non-weldable superalloys (IN738) and refractory metals (pure tangent) have been successfully fabricated by EB-PBF, which expands the suitable material of PBF technology to the metals with low plasticity, prone to hot/liquid cracking, and very high melt point.



(a) EB-PBF process (b) EB-LHM process (c) PBF process with floating powder bed

Figure 1: Schematics of the processes developed to upgrade the PBF technology

After that, based on the EB-PBF, a novel lower stress additive-subtract hybrid PBF process with the combination of continuous laser and ultrafast pulse laser was invented, called as EB-laser hybrid melting (EB-LHM) process (Fig.1(b)). In EB-LHM, the powder bed is preheated by the EB to a temperature up to 1000°C, and selectively melted by the continuous laser to form the cross sections of parts, of which the contour is trimmed and smoothed by the ultrafast laser ablation.

Furthermore, an originative powder bed technique named floated powder bed is proposed recently, in which the powder bed is composed of a powder layer with a constant thickness around 10 mm floating on the metal liquid (such as melted tin) (Fig.1 (c)). Because no powder is needed to fill the space below the top 10mm powder layer, and hot melted tin can heat the powder bed and the workpiece, the supply of powder and thermal stress in PBD process can be greatly reduced by the floating powder bed.

A numerical study of the morphology and microstructure of thin walls manufactured using PBF depending on process and material parameters

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In this work, a number of three-dimensional multilayer numerical simulations have been carried out using detailed three-dimensional setup taking into account unsteady melt pool dynamics with free surface and evaporation effects, directly resolving powder particles during the selective melting process, powder spreading at each layer and introducing accurate energy deposition by using ray tracing with multiple reflections in case of L-PBF and Monte Carlo method taking into account electron backscattering in case of EB-PBF. GPU-accelerated KiSSAM simulation software for additive manufacturing [1] is used for that. Temperature free surface lattice Boltzmann method is used in KiSSAM as the melt pool dynamics solver in the vicinity of the melt pool, while on a larger scale domain the heat equation is solved. Powder spreading is modeled using the discrete element method, cellular automata model is implemented in KiSSAM for the grain structure simulation. Most simulations have been carried out using the 3 micrometer grid and taken 1-2 hours per layer or 1-2 days per wall to complete.

A thin wall morphology and microstructure dependence on powder characteristics have been considered. Previously it was shown in [2] that powder wetting can be a crucial factor defining the thin wall morphology on par with the recoil pressure and Marangoni convection well-known for the formation of spatters, pores and denudation zone for single tracks [3]. Mechanisms of powder influence on thin wall microstructure are investigated in the current research. In addition to that, conventional process maps using scanning speed and power for the thin wall morphology and microstructure parameters have been built.

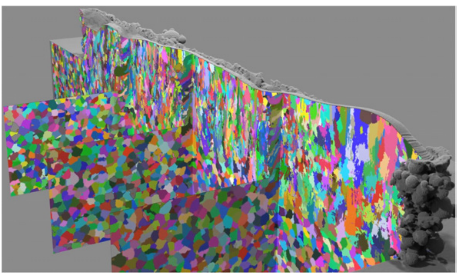

Figure 1: 3D simulation of thin wall morphology and microstructure of a thin wall in KiSSAM.

[1] A. Zakirov et al., 2024, *Prog. in Add. Manuf.* **1-18**.

[2] B. Korneev et al., 2023, *Add. Manuf.* **74**, 103705.

[3] S.A. Khairallah et al., 2016, *Acta Mater.* **108**, 36-45.

Microstructure and mechanical behavior of a NiAl-CrMo eutectic in-situ composite processed via electron beam powder bed fusion

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NiAl-based alloys are promising high-temperature materials due to their high melting point, excellent oxidation resistance, and low density. However, limited fracture toughness and ductility at room temperature restrict their applications. A eutectic microstructure with fine cellular-lamellar phases can address these challenges [1]. Our newly developed Ni30.6Al36Cr31.4Mo2 (at.%) alloy, processed via electron beam powder bed fusion (PBF-EB), achieves this microstructure due to its eutectic composition and high cooling rates in additive manufacturing [2]. The elevated process temperature in PBF-EB enables in-situ heat treatment, inducing spinodal decomposition and discontinuous precipitation, which modify the microstructure (see Figure 1). By adjusting the microstructure, the mechanical properties can be changed according to the requirements. This study presents dense, crack-free specimens of Ni30.6Al36Cr31.4Mo2, alongside detailed creep tests at elevated temperatures of 750 °C. These insights highlight the link between process, microstructure, and mechanical properties offering pathways for new applications.

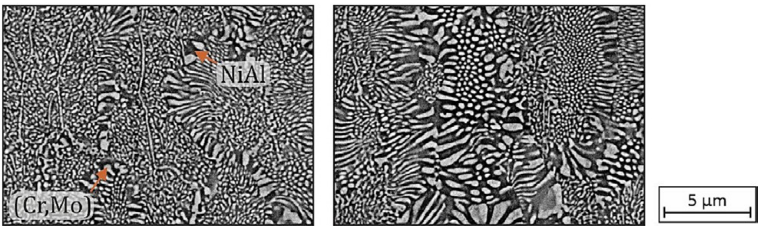

Figure 1: Microstructure of the eutectic NiAl-(Cr,Mo) in-situ composite with a low area of discontinuous precipitated (DP) regions (left) and a high amount of DP regions (right).

This work is funded by German Research Foundation (Project number 491441582).

[1] A. Förner, J. Vollhüter, A. Krapf, A. Jamjoom, D. Hausmann, B. Wahlmann, Z. Fu, C. Körner, S. Neumeier, M. Göken, 2023, *Adv. Eng. Mater.* **25**, 15.

[2] K. Titz, J. Vollhüter, P. Randelzhofer, S. Neumeier, M. Göken, B. Wahlmann, C. Körner, 2024, *Adv. Eng. Mater.* **26**, 9.

Machinable and high-temperature strong Nb-silicide intermetallic composites by electron beam powder bed fusion

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As a refractory metal-intermetallic composite, Nb-silicide based alloys possess the higher melting points of >1750 °C, about 300 °C higher than that of single-crystal Ni-based superalloys, and moderate densities of 6.6–7.2 g/cm^3, lower than that of Ni-based superalloys. Meanwhile, its service temperature is expected up to 1350 °C, which is about 80 % of its absolute melting point. Achieving the balance between the high-temperature functionality and room-temperature ductility is an unresolved challenge as usual. Solving the confliction between obtaining nanocrystals and preventing cracks becomes the key to achieve crack-free Nb-silicide based alloys with ultrafine grains.

In this paper, EB-PBF with the powder bed preheated to 1200 °C, a temperature higher than the DBTT of Nb-silicide based alloys, is introduced first time to additively manufacture the Nb-silicide based alloys with a composition of Nb-16Si-10Zr-10Ti-3Al-3Hf-3Cr (at.%) modified to stabilize a stable silicide (H-phase). Crack-free dense bulks sized 118 × 22 × 50 mm and near net shaped blade with a length of 114 mm and height of 38 mm were successfully fabricated, which were machined into standard specimens for tensile tests and the final blade part. The ultrafine-grained silicides were observed in the as-built samples, and the average room-temperature tensile elongation is 2 % with a tensile strength of 644 MPa. Besides the upgraded room-temperature ductility and machinability, an excellent high-temperature tensile strength of 169 MPa was measured at 1400 °C from vacuum heat-treated (VHT) samples. The results indicated that the process route of EB-PBF+VHT is efficient to control the impact of silicide brittleness, and provides a way to balance the machinability and high-temperature performance of Nb-silicide alloy, which may be a promising route to realize the engineering application of Nb-silicide alloys.

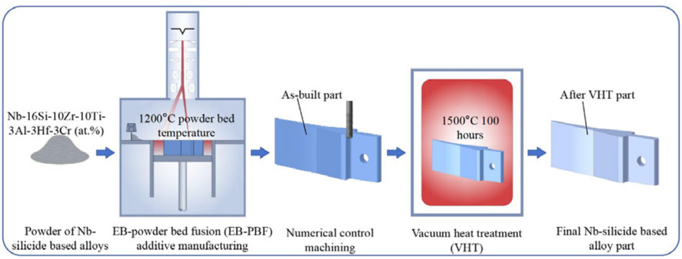

Figure 1: The process route of EB-PBF+VHT proposed for Nb-silicide based alloys

Wire electron beam technology: The key to resource efficiency and scalable additive manufacturing

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A major aspect of effectively integrating additive manufacturing into industrial production processes is ensuring satisfactory productivity and material efficiency. Wire Electron Beam Additive Manufacturing (WEBAM) delivers improved productivity levels compared to alternative methods by taking advantage of its unique characteristics.

WEBAM is particularly resource efficient, using only a third of the electrical energy of laser based directed energy deposition (DED), eliminating the need for inert gas and drastically reducing material waste, especially in the case of powder based laser DED.

Exceptionally high deposition rates can be achieved due to the availability of a high power electron beam source and the superior energy absorption of the electron beam. For example, deposition rates reach 13 kg/h for pure copper, 12 kg/h for IN718 and 6 kg/h for Ti64.

Using WEBAM also minimises thermal distortion of the baseplate through precise temperature and energy control. This allows thinner base plates to be used, reducing material waste and the need for extensive milling.

By utilizing a hybrid approach that combines WEBAM and electron beam welding (EBW) within a single system, semi finished parts can be welded together with EBW, while features are added using WEBAM. This method also enables the substrate to be constructed from simple sheets welded together, optimizing material usage and minimizing waste. As a result, material loss is minimized, additive manufacturing time is reduced, and machine changeover times are shortened.

WEBAM is an innovative and sustainable technology that significantly increases material, energy and time efficiency in modern industrial production.

Investigation and simulation of thermo-mechanical distortion of parts made by wire-based electron beam additive manufacturing

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Wire-based electron beam additive manufacturing (WEBAM) is a highly productive method for the creation of large parts using a wide range of materials. WEBAM is especially beneficial for additive manufacturing of materials prone to hot cracking such as Inconel IN718, a material widely applied in aeronautics.

Additively manufactured components may experience thermo-mechanical distortions. During the build-up process, the uneven temperature distribution causes local inelastic deformation, leading to complex residual stress and strain fields within the built and the base plate.

Numerical simulations of the build-up process can predict the final component geometry before manufacturing and help develop measures to compensate for shape deviations from thermo-mechanical distortions. The accuracy of these simulations heavily relies on the quality of thermo-mechanical material data. Due to the lack of reliable data for high-temperature ranges, calibration and validation of the numerical simulations are often necessary.

In this study, sample geometries are used for in-situ investigation of transient heat transfer and distortion. A multilayer wall structure (IN718) is deposited on a substrate plate clamped on one side. Figure 1 (a) illustrates the experimental setup with the clamped sample. The dynamic effects during the build-up are monitored using thermocouple temperature measurements and distortion evaluations with a displacement sensor. The experimental results are used to calibrate and validate the WEBAM process simulation (Figure 1b).

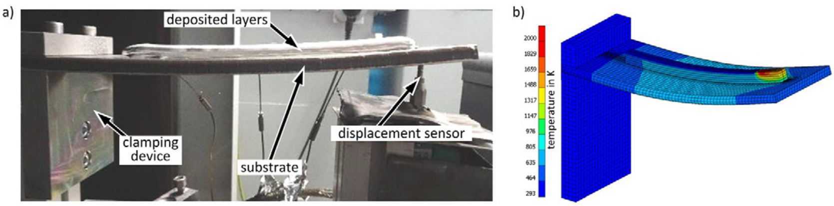

Figure 1: Experimental setup (a); Exemplary image obtained by the process simulation (b).

This work is funded by the Bavarian Ministry of Economic Affairs, Regional Development and Energy (MW-2112).

Optimization of processing strategies in WEBAM with simulation

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Wire-based additive manufacturing with the electron beam (WEBAM) enables the production of near-net-shape parts at high deposition rates. The process offers higher material efficiency compared to machining processes, making it attractive to the aerospace industry for processing high performance materials such as TiAl6V4. In this presentation the near-net-shape production of low-distortion components is examined and implemented. The thermomechanical behavior and fluid flow in the melt pool are investigated numerically and experimentally to gain a better understanding of the process and to support the production of a demonstrator part of a structural component used in aerospace applications. Thermomechanical calculations are used to optimize the layering structure and sequence in terms of thermal insulation, preheating and process parameters after validation of the models. Fluid mechanics analysis is employed to study fundamental effects on the shape of the melt pool in stationary point exposures and to optimize the weld bead at the beginning or end of a layer. The results successfully supported the production of a demonstrator part with a minimal distortion (see Figure 1).

Figure 1: Final demonstrator with low distortion

The project „Qualitätssicherung durch Datenanalyse und Simulation für das WEBAM-Verfahren QSDS-WEBAM“ was kindly funded by the Bayerisches Staatsministerium für Wirtschaft, Landesentwicklung und Energie.

Influence of different additive manufacturing processes on the mechanical properties of Ti-6Al-4V

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Ti-6Al-4V is the most used alloy for aerospace applications. In general, components are produced by thermomechanical processes, followed by machining to the final shape. If the geometry of the component is complex, the subtraction of material and final finishing is considerable and costly. In this case, additive manufacturing brings an alternative to producing net-shaping components. Wire-based direct energy deposition for additive manufacturing processes has the advantage of printing volumetric structures with high deposition rates. Within these processes, electron beam (EB) is suitable to work with reactive alloys such as titanium alloys due to the vacuum condition used during the printing. However, techniques like Cold Metal Transfer (CMT) and Plasma Metal Deposition (PMD) can also be used for titanium alloys with a shielding environment. This work analyses the three wire-based DED processes, EB, CMT and PMD, using the same Ti-6Al-4V wire feedstock to produce the same component. Specimens for tensile and impact tests and hardness measurements along the building height help to determine the mechanical properties of the material. Metallographic observations helped to compare the microstructural features in as-build conditions and after a post-heat treatment to relieve internal stresses and to correlate with the obtained mechanical properties. The findings show that materials produced by EB have better ductility and higher impact energy than the other studied materials.

Furthermore, thermal cycling was applied to all the as-build materials to promote dynamic globularization of the alpha phase.

Real-time tracking of electron beam additive manufacturing using synchrotron x-ray techniques

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In situ synchrotron x-ray characterization techniques enable real-time observation of the rapid transient phenomena that occur in and around the melt pool during additive manufacturing (AM). To facilitate high-speed in situ x-ray imaging, diffraction, and small-angle x-ray scattering during electron beam powder bed fusion, the sample environment MiniMelt [1] has been developed. This work describes the characteristics of MiniMelt and its implementation at two different beamlines at the synchrotron facility PETRA III at DESY, Hamburg, Germany [1]. The measurement capabilities of MiniMelt are demonstrated, including observations of powder behavior, melt pool dynamics, and phase transformations during processing. In particular, we present the use of in situ diffraction and scattering to reveal solidification behavior, solid-state phase transformations, and precipitation during printing, and discuss how this data contributes to the validation and development of modeling approaches.

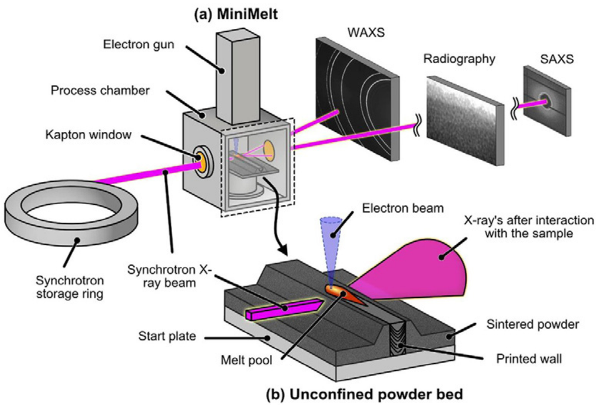

Figure 1: Schematic of (a) the MiniMelt experimental setup for x-ray imaging, Wide-Angle X-ray Scattering (WAXS) and Small-Angle X-ray Scattering (SAXS) in the synchrotron, and (b) the powder bed interacting with x-ray beam.

[1] H.-H. König et al., 2023, *Review of Scientific Instruments* **94**, 125103.

In-situ synchrotron radiography of melt pool dynamics in electron beam powder bed fusion

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The development of processing strategies and special alloys for electron beam powder bed fusion (PBF-EB) depends on a fundamental understanding of the phenomena involved in melt pool formation - from thermal diffusion, over evaporation, to fluid dynamics. However, empirical studies of these phenomena are rare due to a lack of experimental techniques that can operate with enough spatial and temporal resolution. Consequently, studies of melt pool dynamics have relied almost entirely on numerical methods, which themselves are predominantly validated through post-mortem studies.

To uncover some of the melt pool dynamics during PBF-EB, we conduct high-speed synchrotron radiography experiments using MiniMelt [1], a new PBF-EB machine, purpose built for in-situ process investigations using synchrotron diffraction and radiography. Our studies empirically reveal several mechanisms involved in melt pool dynamics for the first time (Fig. 1), from oscillations, caused by the relaxation of surface tension during particle fusion over a new balling formation mechanism to various types of spatter formation mechanisms. Finally, we show how improved energy distribution during melting can lead to significantly more stable melting conditions [2] and utilize radiography to visualize the underlying change in melt pool dynamics that enables this improvement.

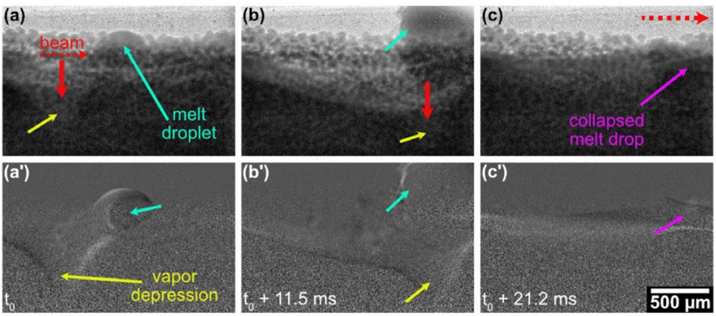

Figure 1: CMSX-4 melt pool formation in the vicinity of a vapor depression, showing the formation (a/a'), growth (b(b') and collapse of a melt droplet, isolated from the melt pool in scan direction by the present recoil pressure.

[1] H.-H. König et al, 2023, *Review of Scientific Instruments* **94**, 125103.

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In-Melt electron analysis (IMEA) approach for process optimization and quality control in EB-PBF

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To enhance the versatility and efficiency of electron beam powder bed fusion (EB-PBF), a widely used additive manufacturing technique for metallic materials, we introduce a novel in-melt electron analysis (IMEA) approach. This technique facilitates the exploration and optimization of process parameters for challenging materials, such as ceramics. Due to ceramics' high melting points and poorly understood thermal properties, their melting behavior has been difficult to comprehend. In this study, titanium diboride (TiB_2) sintered bodies were spot melted under varying electron beam currents and exposure times. The IMEA method successfully identified different stages of melting and aligned with experimental observations on the spot-melted TiB_2 surface.

Additionally, IMEA's potential extends to monitoring the melt pool characteristics of 316L stainless steel. The interaction of electrons with matter provides valuable in-melt information, with thermionic electrons proving highly correlated to the temperature and area of the hottest spot. Single-track melting experiments conducted on both bare plates and powder beds of 316L stainless steel demonstrated that the intensity of emitted electrons correlates with the melt pool width. Furthermore, IMEA was applied to monitor melt pool dynamics, such as surface depression, during an 80-layer print on a stainless steel powder bed.

The IMEA approach offers a promising pathway for real-time process window optimization and quality assurance in EB-PBF, especially for novel and challenging materials. This method establishes a new, reliable paradigm for process monitoring and quality control, enhancing print quality and broadening the scope of EB-PBF applications.

In-situ monitoring of melt pool dynamics during electron beam melting and sintering

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Electron Beam Melting (EBM) offers significant advantages in additive manufacturing, including efficient energy use, rapid production times, and the capability to fabricate complex geometries with high-melting-point metals, which find applications, particularly in aerospace and medical fields [1,2]. Despite these benefits, achieving consistent part quality and effective real-time defect detection remains challenging [3]. This research introduces a novel approach for in-line process monitoring of the EBM melt pool using backscattered electron (BSE) signals. By utilizing high-resolution BSE imaging, we examine the correlation between BSE signals and the stability and quality of the melt pool, focusing on both the melting and sintering stages of the process. Initial findings suggest that BSE data may serve as a valuable metric for assessing melt pool stability, which is critical for successful builds, particularly with materials where process parameters are not yet established. Our findings aim to support the development of robust quality assurance strategies in EBM, potentially leading to more efficient process optimization, early defect detection and minimized waste.

Funding from the DFG (Deutsche Forschungsgemeinschaft) via INST 218/90-1 (Project-ID 510085108)

[1] S. Rouf, A. Malik, N. Singh, A. Raina, N. Naveed, 2022, *Sustainable Operations* **3**, 258-274.

[2] A. Nouri, A. Sola, 2020, *Processing and Medical Device Manufacturing* **271-314**.

[3] M. Grasso, B. Colosimo, 2024, *Progress in Additive Manufacturing* **9**, 591-609.

Exploring the potential of a multi-detector electron-optical system in electron beam powder bed fusion

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The electron-optical (ELO) system serves as a robust and versatile process monitoring tool in electron beam powder bed fusion (PBF-EB). During PBF-EB, the ELO system can be utilized at different process steps, providing crucial information to control and ensure the quality of the manufactured parts. The most common application, referred to as in-situ mode, describes the use of a focused low-power electron beam for a rapid line-by-line scanning of the surface immediately before and after the melting step. In addition, the operando mode leverages the ELO system during the melting itself. We outline the unique capabilities of utilizing a self-developed multi-detector ELO system, featuring a high resolution and flexible measurement chain, in all process steps. This includes the evaluation of powder application quality as well as the extraction of quantitative information about surface topography during PBF-EB. Furthermore, we demonstrate the potential of a novel material contrast framework that even enables the detection of changes in chemical composition due to evaporation using the in-situ ELO imaging. Furthermore, we present basic investigations into how a bias voltage contributes to the signal differentiation in the operando mode.

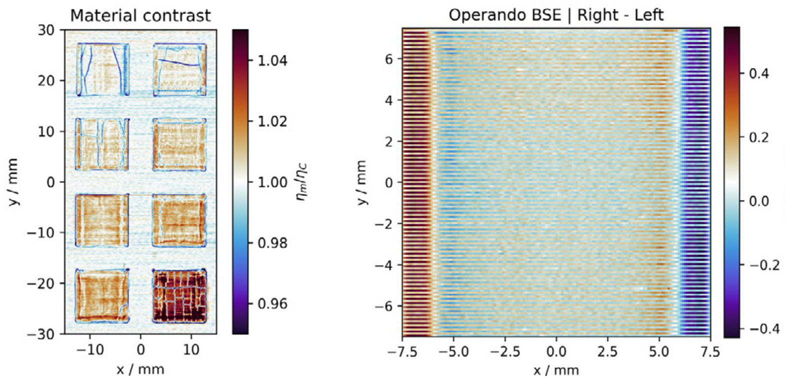

Figure 1: Left: Material contrast image of titanium aluminde plate depicting changes in the chemical composition due to evaporation. Right: Operando BSE difference image of left and right detector.

This work is funded by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program

Electron beam powder bed fusion for mass oroduction

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We will present our version of electron beam powder bed fusion (E-PBF) technology which differs on crucial points to enable higher production rate, not only as compared with laser powder bed fusion, but also compared with other E-PBF solutions currently on the market.

The benefits of our in-house developed high beam power electron gun which is an integral and crucial part of our systems will be shown. Our electron gun maintains an excellent beam spot size throughout the entire beam power range 0-6kW. This opens up for extremely fast and accurate printing in many powder materials.

We will also show our innovative cooled build tank technology. It enables the continuous use of high beam power throughout each and every build layer. The controlled cooling function acts to balance high power input of the build to achieve very fast printing at the correct build temperature, also for the relatively small build areas in our systems.

These features are incorporated in our system for mass production, eMELT®, together with our novel roaming build modules that enables very fast turnaround between the builds and no powder handling in the area of the factory where the printing takes place which will be shown. We will also present further design benefits of the eMELT system, as well as some examples of spot melting material build processes that have been developed for eMELT.

Figure 1: The eMELT iD with roaming build tank for fast turnaround

NeuBeam E-PBF enabled build strategies

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Electron beam additive manufacturing was developed as a process over 20 years ago, along with its competing technology, selective laser melting. Both have advanced and developed significantly in that time. Wayland Additive is a relatively new entrant to the metal additive market, offering a 3rd way with a new technology 'NeuBeam' that has electron beam melting at its core. At the heart of NeuBeam is a process that mitigates against excessive electron charge accumulation on the surface of the metal powder particles. In a standard electron beam PBF process, excessive charge accumulation will initiate build limiting 'smoke events' as a result of repulsive electrostatic forces between adjacent powder particles. A traditional E-PBF process overcomes the smoke issue by employing a wide-area sinter to fuse the powder layer into a mechanically stable conductive layer before melting. In the NeuBeam E-PBF process stability is maintained without the requirement to wide-area sinter. Details of the NeuBeam Charge Neutralisation mechanism have previously been presented (EBAM 2023). This paper presents details on the NeuBeam AM build strategy – preheat and melt - that are made possible by the charge neutralisation mechanism at the core of NeuBeam, and how these differ from standard E-PBF. Effects of the NeuBeam AM process on the electron beam and the interaction of the neutralising mechanism with the powder bed will also be discussed in detail. Implications of the NeuBeam mechanism for complementary in-process monitoring techniques such as back scatter electron detection will also be presented.

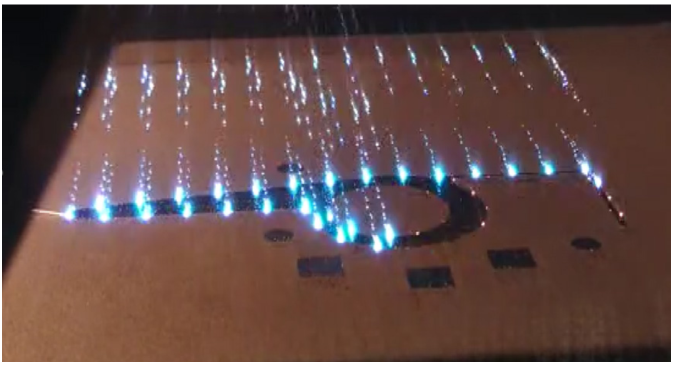

Figure 1: Contour point melt strategy in Wayland's Calibur3 NeuBeam E-PBF Process

Increased productivity in EBM

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The low productivity rate of many additive technologies still limits their widespread industrial application. In the case of metal powder bed fusion, many efforts have been made to increase productivity, like using multiple lasers in LB-PBF.

Electron Beam Melting (EB-PBF, EBM), with its high deflection speeds combined with high available beam power, generally offers the best prerequisites for a highly productive process. However, additional process steps such as pre- and post-processing, evacuation, preheating, cooling and limited acceleration voltage significantly slow down the overall process time on many conventional EBM machines.

Many of these limitations can be overcome with pro-beam's PB EBM30S machine, allowing an application in an industrial series production thanks to the following features:

Pro-beam has introduced a machine concept with an air lock system that eliminates non-productive times inside the build chamber, allowing a high beam-on time of the machine. Non-productive steps such as setup, evacuation, dismantling, and cooling of build jobs are separated from the build chamber, allowing parallelization of different process steps.

Another advantage of the pro-beam concept is the use of high acceleration voltage of up to 150 kV. This offers many advantages, one of which is the potential to significantly increase the preheating and melting speed.

The process window for dense parts is typically larger and shifted toward lower required energy and faster scanning speeds [1], therefore the time needed for melting can be reduced.

The preheat time can also be reduced by increasing the acceleration voltage, as fewer electrons are required to achieve stable preheating at increased energy inputs without smoke generation.

In this presentation, the pro-beam machine concept, which allows EBM processes of highest productivity, will be discussed in detail.

[1] M. Reith, M. Franke and C. Körner, 2024, *Prog Addit Manuf* **9**, 1425-1436.

EBM point melt – A new level of serial production for titanium components in the medical industry, as well as an enabler for high-temperature materials production in the aerospace industry

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Colibrium Additive is continuously working on expanding its Electron Beam Melting (EBM) capabilities to meet current and prospective customer needs. The nature of electron beam deflection makes EBM well-suited for implementing advanced melt strategies. Point Melt is elevating EBM to the next level of additive manufacturing (AM) serial production, with a focus on components for the medical and aerospace industries.

Over the past two years, Colibrium Additive has been developing and qualifying the Point Melt process for Titanium-based alloys for the medical industry. Continuous improvements to our EBM machine hardware and software have been key enablers. Moreover, by utilizing in-house developed simulation software, we have gained a deeper understanding of the process and significantly reduced the amount of experimental efforts. We are now producing components with excellent material properties and performance, showcasing a new level of feature resolution and surface roughness quality. These advancements include unique EBM capabilities such as building parts without solid supports and without a solid build platform. These new features, combined with the high stacking capability of EBM, are true differentiators for AM.

In addition to EBM Point Melt for medical applications, processing of high-temperature materials for production on an industrial quality scale requires even tighter process and temperature control. This is mainly to overcome cracking issues and to meet the material requirements of the components. The ability to use the electron beam for both heating and melting are crucial for processing "non-weldable" high-temperature materials, such as the Ni-based Superalloy Alloy 247. Utilizing novel EBM point melt strategies, in-situ temperature monitoring capabilities, and simulation tools are key factors for successful component production and for tailoring the microstructure to a state suited for high-temperature performance. In this work, we present our journey to enable EBM Point Melt for the serial production of medical components. We also demonstrate EBM manufacturing capabilities for producing crack- and defect-free components in Alloy 247, a material ideal for applications in the High-Pressure Turbine (HPT) of turbine.

Carbide size control using EBM process parameters and extreme layer thickness variations in high-speed steels and cemented carbide

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Major developments towards microstructure control in EBM includes variation between columnar and equiaxed grains using traditional line melting [1] and point melting [2], as well as printing single crystals [3]. However, to our knowledge, controlling the size of carbides within a material has not been shown before. Having worked on this topic for several years, VBN Components is now able to produce actuals parts with varying carbide sizes. By adjusting the energy input locally, it is possible to tailor the carbide size, allowing the creation of different domains where average carbide sizes may differ more than 10 times. These domains may be as small as a few millimeters, e.g. making it possible to print a wear part with large carbides on selected wear surfaces. Possible carbide sizes vary depending on materials and examples of size and domain shapes from high-speed steels (Vibenite® 150, 280 and 290) and cemented carbide (Vibenite® 480) will be shown. In the second part of the talk, a series of experiments with extreme variations in layer thickness will be shown for the high-speed steel Vibenite® 150. As layer thickness is such a fundamental parameter, it is usually fixed at an early stage in the development process. However, we developed rough process parameters for layer thicknesses from 50 to 1000 μm to investigate the impact on productivity, microstructure and mechanical properties. Using the same powder, test coupons were printed in 50, 160, 250, 500, 750 and 1000 μm in a single build, along with demonstrator parts containing all six layer thicknesses.

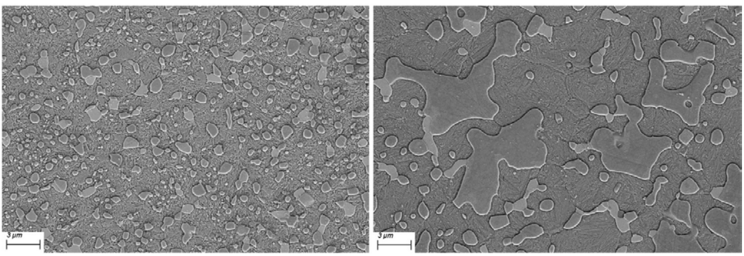

Figure 1: Example of carbide size variation in the high-speed steel from finer (left) to coarser (right).

This work was partially supported by the Wallenberg Initiative Materials Science for Sustainability (WISE) funded by the Knut and Alice Wallenberg Foundation, as well as by the Vinnova project AMjord.

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[3] C. Körner et al., 2018, *Metal. Mat. Trans. A* **49A**, 3781-3792.

Microstructural and mechanical properties of high-alloy austenitic CrMnNi steels with different nickel contents produced by electron beam melting

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A change in the microstructural and mechanical properties of EB-PBF manufactured materials is usually carried out by varying the beam parameters and seldom by adjusting the alloying concept. The present study shows the changes in microstructure (grain shape, texture) as well as of the mechanical properties by varying the nickel content with 3 %, 6 % and 9 % in a high-alloy austenitic CrMnNi steel. The resulting properties can be explained by the ratio of chromium and nickel equivalent (Cr_{eq}/Ni_{eq}) of the individual steel variants because the Cr_{eq}/Ni_{eq} ratio influences the solidification behaviour and, thus, the resulting microstructure (columnar or fine-grained grains) of the steel variants [1]. Furthermore, the mechanical properties and the mechanisms for enhanced strength and/or ductility under load (TRIP/TWIP effect) can be explained by the changes in the stacking fault energy as a function of the nickel content [2]. For these investigations three different CrMnNi steel alloys were atomised by using the EIGA process. In addition, the steel powders with 3 % and 9 % nickel were mixed in a specific ratio to get a fine-grained microstructure after the EB-PBF process again.

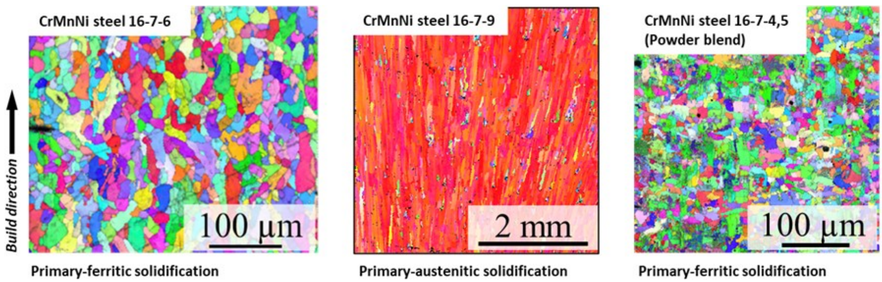

Figure 1: Change between columnar and fine-grained microstructure of CrMnNi steels through differend nickel contents.

[1] C. Burkhardt et al., 2023, *Addit. Manuf.* **69**.

[2] M. Seleznev et al., 2021, *Addit. Manuf.* **47**.

Effect of sulphur addition on the processability of a metastable stainless steel X2CrMnNi 16-7-4.5 in PBF-EB/M

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Sulphur is traditionally viewed as an impurity in steels that can cause problems such as embrittlement and hot cracking. For welding applications, minor changes in the elements concentration can drastically affect the weld pool behaviour, since it acts as a surface active element and is able to change the surface tension gradient and weld pool penetration depth [1]. Therefore, the element offers several interesting properties for applications in powder bed fusion additive manufacturing. It was already shown that altering the sulphur content in SS316L powder can significantly affect the melt behaviour during PBF-LB/M, resulting in different melt pool geometries [2]. Furthermore, adjusting the penetration depth of the melt pool [1] and lowering the surface tension of the liquid metal [3] might allow for a reduction in process-induced lack-of-fusion defects due to enhanced flowability.

In the present study, the impact of different sulphur concentrations (30 and 300 ppm, respectively) on a X2CrMnNi 16-7-4.5 stainless steels printability during PBF-EB/M are presented and discussed. Originally, the base material was designed based on thermodynamic calculations to obtain a fine-grained and equiaxed microstructure. The powder feedstock was created by blending of X2CrMnNi 16-7-9 and X2CrMnNi 16-7-3 powders, but without sulphur adjustments yet. After PBF-EB/M processing, the steel showed excellent mechanical properties and a promising microstructure. After these initial tests, the material was atomized directly with the modified sulphur content, which will also be the focus of the study. To evaluate the influence of sulphur content on printability, process parameters have been deliberately set in a way that encourages the formation of defects. Those samples will be compared to parts built with more optimized settings. All samples were analyzed with regard to their microstructure and defect distribution and size. Additionally, mechanical properties were determined on selected samples.

[1] B. Keene and K. Mills, 1985, *Mat. Sci and Tec.*. **1**, 559-567.

[2] T.-N. Le and Y.-L. Lo, 2019, *Mat. and Des.*. **179**, 107866.

[3] . Korobeinikov and A. Perminov, 2021, *Metals.* **11**, 521.

PBF-EB of wear resistant FeCr-10V for resource efficient tools

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Additive processing of wear-resistant materials to near-net-shape parts is attractive for applications in tooling or recycling equipment since the machining of hard materials is problematic. PBF-EB processing of pre-alloyed FeCr-10V powder at 850 °C preheat temperature results in crack-free material. As-built material contains ferrite and a high fraction of vanadium carbide and chromium carbide. The microstructure is fine grained with the majority below one micrometer. The hardness is 52 HRC. Heat treatment increases hardness to over 60 HRC and bending strength above 2000 MPa [1]. Durability in a custom jet wear test proved above hard facing reference material.

For application in industrial shredder machines an innovative hybrid concept combining PBF-EB fabricated cutting knives and recyclable carriers is explored. Joining is realized by screw coupling and adhesive bonding. Several geometrical variants were tested. Despite the severe loads while shredding, a service life of three million cuts was reached. In comparison to standard knives, edge retention of the PBF-EB processed FeCr-10V was superior.

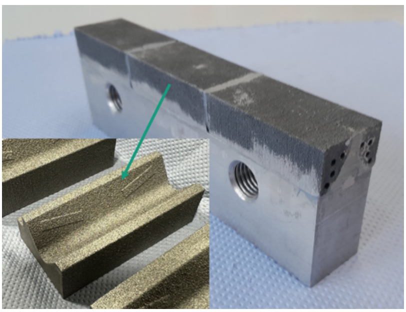

Figure 1: TEM/BF over-view images of microstructure of scales formed on: a) MC/ air oxidized, b) PBF-EB / air oxidized, c) MC/ steam oxidized and d) PBF-EB / steam oxidized.

The financial support of the Federal Ministry of Education and Research for the research project ReHaRecy (grant numbers 02P22K020 through 02P22K022) is gratefully acknowledged.

[1] M. Franke-Jurisch, M. Mirz, T. Wenz et al., 2022, *Materials* **15**, 1679.

High-fidelity modeling of multi-material additive manufacturing: from particle reinforced composites to in-situ alloying

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Additive manufacturing possesses promising capabilities of fabricating new materials by mixing multi-material powders and manipulating chemical compositions. In this talk, we will present our latest work on high-fidelity modeling of the complex additive manufacturing process: from powder spreading to melting. To evaluate the mixture uniformity of the powder layer, we employ the discrete element method (DEM) method to simulate the powder spreading processes of mixed multi-material powders. To thoroughly understand the material composition distribution in the melting procedure, we develop a multi-physics thermal-fluid flow model to simulate the different melting/flow/solidification behaviors of different powders as well as the interactions between solid powders and molten pool. Various scenarios are simulated from micro-/nano-particle reinforced composites to in-situ alloying for new materials. All these models are validated against experiments, and show appealing potentials to provide guidance for additive manufacturing of mixed powders.

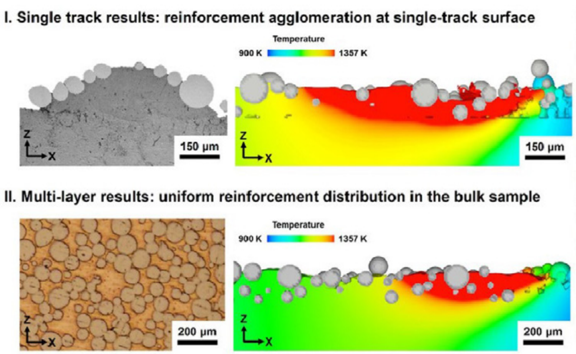

Figure 1: EBAM of W particle reinforced Cu composites: experiments and simulations.

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Part-Scale thermal simulation of electron beam powder bed fusion

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Powder bed fusion employing the electron beam (PBF-EB) distinguishes itself as an excellent method to process crack-susceptible, high-performance alloys and metals, e.g. ni-base superalloys, TiAl and tungsten. This capability is mainly due to the high operating temperatures, which mitigate the apparent thermal gradients and reduce the corresponding mechanical stresses. Consequently, controlling the emerging thermal conditions is a key factor for efficient process management and obtaining optimal results, particularly with these challenging materials.

In order to resolve and comprehend the prevalent thermal conditions, a numerical model is presented, which depicts the thermal evolution of entire build volumes over multiple layers in a scan-resolved manner (see Figure 1). Being able to reconstruct the process as a digital twin opens the possibility of analysing the different process steps in detail and address possible shortcomings effectively. Additionally, the model allows for systematic investigations of process stages on the macroscale, such as the preheating phase, to develop a comprehensive database for parameter selection.

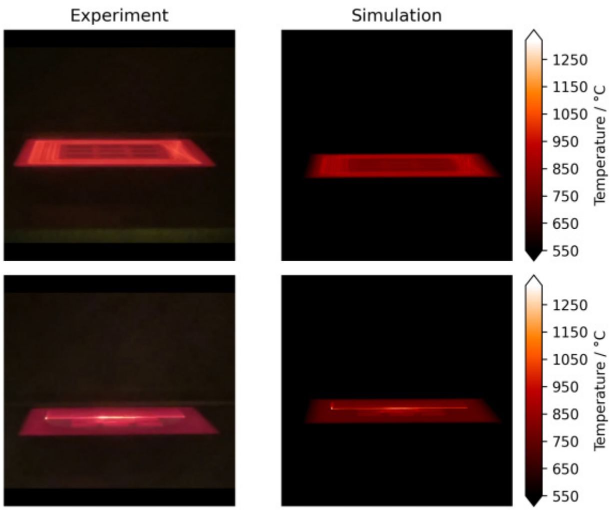

Figure 1: Qualitative comparison between images captured through the observation window of the machine and the corresponding results of the thermal numerical simulation

This project received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program (grant agreement No 101018634).

In-situ monitoring of heat propagations in electron beam powder bed fusion

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In-situ sensing and monitoring techniques for characterizing heating and cooling patterns in powder bed fusion have attracted significant attention in the additive manufacturing community. Studies on thermal gradients and heat accumulation aim to detect local anomalies and predict the quality characteristics of fabricated parts [1 - 3]. Most existing methods focus on spatial and temporal heat maps within the exposed layer area. However, heat dissipation into the surrounding powder is also critical. Indeed, variations in heat transfer between the part and the surrounding powder can adversely affect surface quality, dimensional accuracy, and microstructural uniformity of the final product. In electron beam powder bed fusion (EB-PBF), the heat transfer and dissipation in the pre-sintered powder shall be maintained as homogenous and uniform as possible to achieve the target quality and mechanical performance.

We explore opportunities and methods in the field of in-situ monitoring of the EB-PBF thermal history. We also present a novel approach for in-line monitoring of the heat propagation beyond the exposed area. It integrates a spatio-temporal model of the thermal history with a non-linear low-dimensional learning technique to effectively distinguish between normal and anomalous heat propagation patterns. A case study on pure copper in EB-PBF is presented. Pure copper, with its contrast in thermal conductivity between the consolidated material and the surrounding powder, is prone to defect formation and underscores the need for advanced in-situ thermal monitoring approaches.

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The investigation on the evolution of smoking phenomenon in electron beam powder bed fusion process

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Smoking is a unique phenomenon in the electron beam powder bed fusion (EB-PBF) process, which stems from the area of interaction between the powders and the electron beam and then rapidly expands outward in an explosive type [1,2]. The far-field effect and rapid expansion of smoking can destroy the powder bed and result in process failure or even equipment damage, which seriously restricts the adoption of EB-PBF. Therefore, it is necessary to investigate the smoking evolution and reveal its mechanism.

Because of the strong randomness and rapid occurrence, it is difficult to obtain quantitative evaluation indicators for smoking phenomenon, which makes the study of smoking difficult to quantify. In this work, a DEM-FEM numerical model was established to describe the charge distribution and particle dynamics during smoking process, while "limited smoking experiments" were obtained to quantitatively evaluate the intensity of smoking for the validation of model results. Partial decoupling between process parameters and physical quantities has been achieved in this model. The secondary electronic signal can reflect the state of the powder bed and was used as a basis for identifying the occurrence of smoking by detecting the formation of small powder clouds. A deep learning method called autoencoder was employed for smoking anomaly detection. This self-supervised deep learning method requires only normal scanning data to train the neural network, which could be applied to real-time detection of smoking during forming processes.

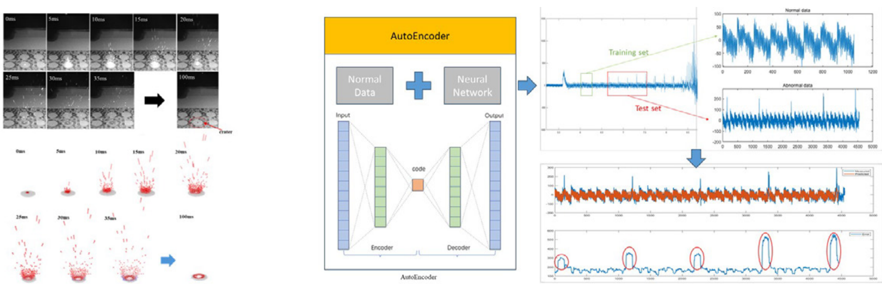

Figure 1: (a) High-speed photographic images and simulation results of smoking evolution (b) Illustration of smoking detection using AE method

[1] MF. Zäh and M. Kahnert, 2006, *Euro-uRapid2006* **27**.

[2] Milberg and M.Sigl, 2008, *Prod. Eng. Res. Devel.* **2**, 117-122.

Correlating outgassing and smoke phenomenon in electron beam powder bed fusion

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Maintaining high vacuum quality is crucial in Electron beam powder bed fusion (PBF-EB) to prevent feedstock contamination. However, the inherent nature of the PBF-EB process introduces a gas load into the system[1], potentially affecting process stability and product quality. This study utilizes a residual gas analyzer to investigate experimentally outgassing associated with various process activities, including electron beam radiation, rake movement, and powder outgassing. The findings indicate that hydrogen, water, nitrogen, oxygen, argon and carbon dioxide are the predominant gases present during PBF-EB processes. Moreover, rapid outgassing is identified as a likely trigger for powder movement, marking the initial stage of the Smoke phenomenon. These results contribute fundamental insights into the gas atmosphere in PBF-EB processes.

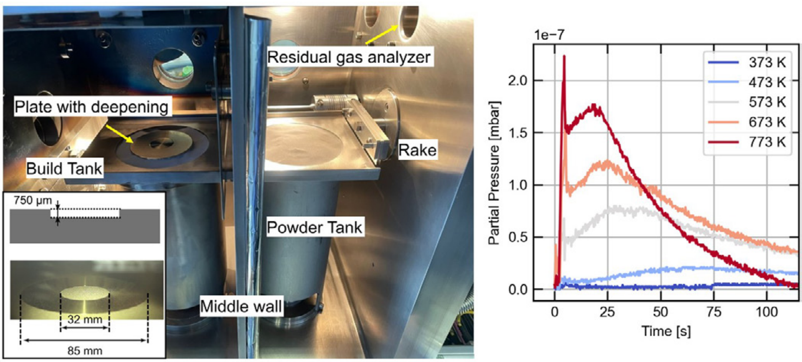

Figure 1: Left) Freemelt ONE machine setup used for investigating the outgassing phenomenon. Right) Development of water partial pressure after raking a fresh powder layer onto a specific start plate at various temperatures. Images are adapted from [2] under the CC-BY license.

The financial support provided by the German Research Foundation (DFG) for the project (FU 1283/2 1) is gratefully acknowledged.

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Ultrasonic fatigue testing of additively manufactured high temperature materials at RT and elevated temperatures

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Additive manufacturing (AM) gained an increased interest during the last decade due to unprecedented design freedom arising from the related novel production technologies. However, drawbacks of the layerwise processing are both the anisotropic microstructure with columnar grains and strong textures as well as several building defects such as lack of fusion and porosity. Fatigue properties of materials processed by additive manufacturing are of high interest, in particular both for components designed for high-temperature applications as well as in the range of high fatigue lives. The presentation gives first a review on ultrasonic fatigue tests on various AM materials in particular at elevated temperatures, and challenges related to the this technique. In the second part, the talk will focus on own results obtained on titanium alloys (Ti6Al4V, γ-TiAl [1]) and the nickel-base superalloy IN718 at RT as well as at application-relevant high temperatures up to 700°C in range up to 10^9 cycles. The analysis of the fatigue fracture surfaces provides the failure-relevant microstructural features of AM states and conventionally manufactured reference materials. In general, it can be concluded that a fine grain e d, equiaxed and texture-free microstructure without residual stresses and with low density of building defects will have enhanced fatigue properties.

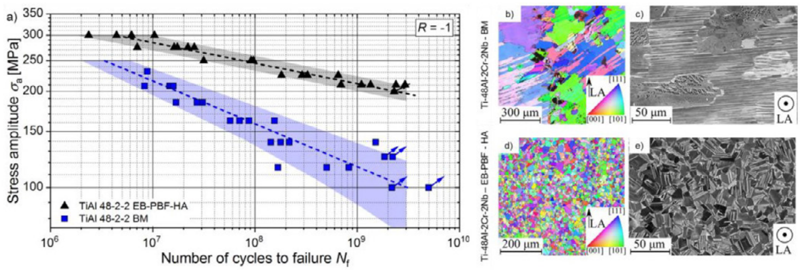

Figure 1: Results of ultrasonic fatigue tests (a) obtained on γ -TiAl manufactured via EB-PBF in comparision to conventional material (BM) and their related microstructures (b-e) [1]

[1] A. Schmiedel et al., 2023, *Mater. Sci. Eng. A* **862**, 144507.

The study of the relationship between the melting strategy and the microstructure formation during electron beam powder bed fusion process

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MAR-M247 is a nickel-based superalloy widely used in high-temperature, high-stress environments, such as gas turbines. Despite its desirable properties, high gamma prime nickel superalloys are considered non-weldable due to their susceptibility to solidification cracking. Residual stresses and steep thermal gradients aggravate this issue during solidification.

Variations driven by scanning strategies impact the microstructure formation and affect crack susceptibility. Recent advances in spot melting and alternative scanning strategies coupled with detailed thermo-mechanical finite element analysis of the melt pool have enabled specific site control during processing to control and manage residual stresses and solidification rates [1,2]. These techniques have been extended to other Nickel-based super alloys such as CM247 and Haynes 282, exploring whether site-specific cooling can enable the fabrication of crack-free geometries [1–3]. However, a gap remains in understanding how varying energy inputs or melting strategies by controlled cooling rates affect crack susceptibility in high gamma prime nickel superalloys.

In this study, we are investigating different melting strategies, including raster and spot melting, using a Freemelt ONE machine. The goal is to analyze how changes in melting strategy can impact microstructure evolution and defect formation in a hot-cracking alloy while maintaining constant energy input. Additionally, we aim to systematically integrate computational models to predict how localized cooling rates - altered by varying the jump sequence in spot melting - affect solidification behavior. By focusing on the influence of processing conditions, this work seeks to provide deeper insights into reducing cracking tendencies in high gamma prime nickel superalloys.

[1] S. S. Babu, N. Raghavan, J. Raplee, S. J. Foster, C. Frederick, M. Haines, R. Dinwiddie, M. K. Kirka, A. Plotkowski, Y. Lee, R. R. Dehoff, 2018, *Metall Mater Trans A* **49**, 3764.

[2] Y. S. Lee, M. M. Kirka, S. Kim, N. Sridharan, A. Okello, R. R. Dehoff, S. S. Babu, 2018, *Metall Mater Trans A* **49**, 5065.

[3] P. Fernandez-Zelaia, M. M. Kirka, A. M. Rossy, Y. Lee, S. N. Dryepondt, 2021, *Acta Materialia* **216**, 117133.

Microstructural analyses and defects investigation of Inconel 738 processed by electron beam powder bed fusion (EB-PBF)

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Ni-based superalloys represent a class of high-performance alloys showing good to excellent mechanical properties, coupled with corrosion and oxidation resistance between 540°C and 1000°C. In particular, Inconel 738 (IN738) guarantees safe service conditions up to 1000°C, thanks to the strengthening effect induced by γ′ precipitation. Due to these considerations, IN738 is generally employed in the aerospace industry for turbine blade production [1]. The interest in additive manufacturing (AM) showed rapid growth due to the severe forming and machining conditions requested by IN738 shaping. However, the high percentages of γ′ induce crack susceptivity to the alloy, making the AM processability of IN738 challenging. The use of an AM hot process, such as electron beam powder bed fusion (EB-PBF), represents a valuable way to overcome crack formation during the building step [2-3].

The work deals with the effect of the preheating temperature on the phases precipitation and their impact on defect formation in the EB-PBF production of IN738. Dense and crack-free samples were obtained (Figure 1) after a deep defects investigation and process parameters optimization. The tailored building conditions avoided the formation of cracks along the grain boundaries, thus resulting in the formation of columnar grains along the building direction with the reduced presence of γ′ and carbides.

Figure 1: Cross-section view of built samples.

[1] R.C. Reed, 2006, *CUP.* **25-50**.

[2] O.A. Ojo, N.L. Richards, M.C. Chaturvedi, 2003, *Scr. Mater.* **50**, 641-646.

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3D Point patterns for material design in electron beam powder bed fusion

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Spot melting has finally arrived in electron beam powder bed fusion (PBF-EB), offering a great degree of design freedom, suitability for complex geometries and the ability to control the local microstructure [1, 2]. By capitalizing on the fast deflection capabilities of the electron beam (km/s), spot melting strategies have introduced a broad and complex parameter space which must be considered from two separate perspectives: the underlying geometric information, namely the lattice structure, and the spot sequence that governs the order in which locations are visited by the electron beam [3]. This contribution is the first of its kind to solely investigate the influence of the underlying spot pattern in three dimensions and assess its influence on efficiency, grain morphology and texture. Using IN718 on the novel, freely programmable 150 kV PBF-EB system AMELI (PB-EBM 30S), the experiments reveal unique microstructural and mechanical characteristics through Electron backscatter diffraction (EBSD) analysis. These range from isotropic to anisotropic properties, demonstrating the ability to tailor the texture to suit specific application requirements.

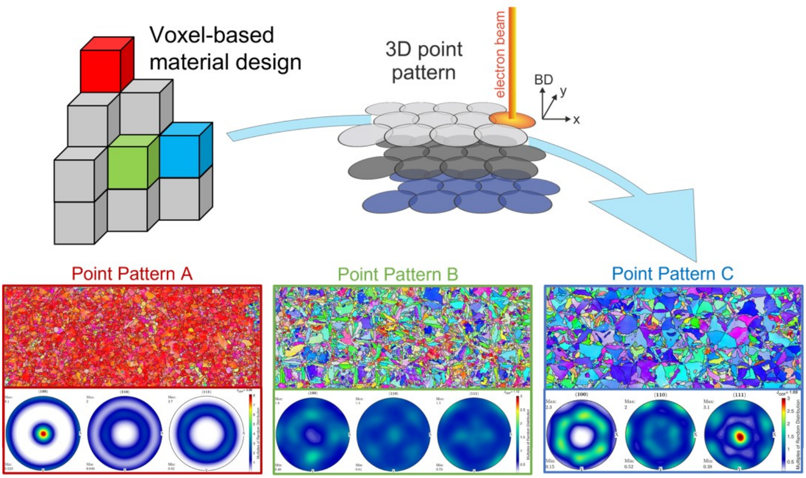

Figure 1: Voxel-based material design by controlling the 3D point pattern in spot melting of IN718.

[1] K. N. Chaithanya Kumar, 2024, *Metals* **14**, 1278.

[2] S.T. Nabil, 2024, *Journal of Manufacturing and Materials Processing* **8**, 241.

[3] T. Kupfer, 2024, *Additive Manufacturing* **91**, 104321.

EBM TiAl blades production at Avio Aero – An overview

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Avio Aero has been the first aerospace company to adopt Electron Beam Melting (EBM) technology for producing additively manufactured aeroengine components, specifically the TiAl blades for the Low Pressure Turbine of the GE9X commercial engine. Compared to the Nickel-based alloys typically used in lower temperature LPT stages, TiAl offers significant weight advantages while maintaining comparable mechanical properties. The choice of EBM manufacturing is driven by its suitability for materials that are difficult to cast and prone to cracking, such as TiAl.

Avio Aero's journey with EBM TiAl blades has encompassed the maturation of the manufacturing technology, material, and product, from early feasibility studies and initial machine adaptation for high-temperature applications in collaboration with Arcam AB, to more recent entry in production at Avio Aero's Cameri plant. With the GE9X TiAl blades, Avio Aero has also pioneered the certification of additive manufacturing for commercial aviation.

The discussion will cover Avio Aero's journey, highlighting key milestones and challenges encountered during product development, certification, and preparation for regime production. Additionally, recent focus on introducing new generation EBM machines to leverage process enhancements and optimize production will be addressed. Specifically, the development of point melt as an alternative to the current line melt production standard will be presented. This will include an analysis of the advantages, disadvantages, and challenges of the new strategy, along with a high-level comparison of the point melt and line melt processes, focusing on internal defects and microstructure – microstructure conformity representing the keystone of TiAl alloy parameters development.

Further hints into the challenges of operating a high-volume additive manufacturing production site will be offered. Topics will include machine and process qualification, machine-to-machine and build-to-build variability, in-process monitoring, and process data analytics. Additionally, general topics relevant to the sustainability and competitiveness of additive production, with special focus on parts inspection, will be addressed.

Crystal plasticity finite element method virtual laboratory for PBF-EB microstructural properties

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Powder bed fusion with electron beam (PBF-EB) is a distinctive additive manufacturing process enabling rapid adjustments in conditions like beam power or speed for precise control over microstructure and material properties. However, predicting final component properties, especially mechanical ones, remains challenging. Macroscale and microscale mechanical behaviors of polycrystalline aggregates require testing, as they cannot be predetermined. Local variations in microstructure - such as size, grain orientation, and phase distribution - add complexity, making experimental characterization costly, time-consuming, or impractical.

To this purpose, this work presents an analysis using the Crystal Plasticity Finite Element Method (CPFEM) to determine the material response in a virtual environment. For a given microstructure obtained by processing Ti6Al4V by PBF-EB, a controlled domain was simulated under tensile load. The domain considered the typical bimodal microstructure of the material consisting of columnar β grains growing along the build direction due to thermal gradients during solidification and α-phase laths within prior β grains. The simulation considered a specific hardening model in which the effect of the main descriptor, such as slip resistance, on the final measured mechanical properties was also analyzed. The construction of such a model may also consider the effect of the presence of porosities and process-induced defects in the material.

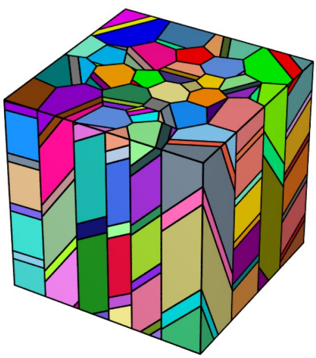

Figure 1: Powder bed fusion with an electron beam synthetic microstructure

Graph-based spot sequences in electron beam powder bed fusion

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Spot melting in electron beam powder bed fusion is a current research focus. It exploits the ability of the electron beam to almost instantaneously jump between individual spots. The increased degree of freedom compared to line melting opens up a wide range of possibilities to influence the thermal history and thus the mechanical properties of the built part. However, each layer of a part consists of thousands of spots ending up in an almost infinite number of possibilities to order them in a spot melting sequence. This issue necessitates efficient algorithms for sequence planning, which is the core of this research work.

In this work, the goal is to achieve homogeneous material properties in arbitrary complex parts. The spot melting sequence controls the temperature field, thereby influencing the microstructure and mechanical properties. Consequently, the main challenge is to develop a spot melting sequence that ensures thermal independence of all spots. We developed a new graph-based, heuristic algorithm to generate a spot melting sequence. This method is based on the subdivision of complex geometries into consecutive melt groups and communities. They are transformed into graphs connecting the spots with all possible jumps that met certain machine restrictions, e.g. maximum jump distances. The heuristic algorithm identifies Hamiltonian paths on these graphs determining the final spot-melting sequence. We demonstrate the applicability of the heuristic algorithm to different complex geometries.

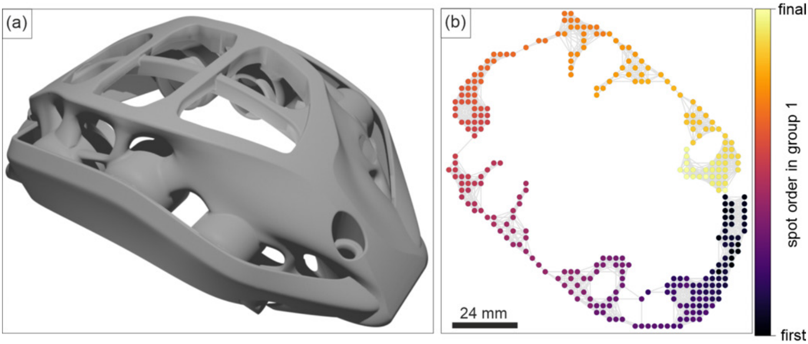

Figure 1: (a) CAD-model of a brake caliper (b) Spot order in group 1 in an exemplary layer

This work is funded by the German Research Foundation - Project ID 61375930 SFB 814 - "Additive Manufacturing" TP T07.

Powder bed fusion of pure copper using an electron beam - A comparative study on the material properties obtained using vector- and spot-based exposure

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Additive manufacturing of pure copper is of interest due to the material's thermal and electrical conductivity, corrosion resistance and ductility, as well as the possibility of creating value through the production of complex structures [1]. Powder bed fusion of copper using an electron beam (PBF-EB/M) is considered promising due to the vacuum atmosphere preventing oxidation [2] and the scalable beam power to overcome the high heat dissipation capability of the material.

Spot-based exposure strategies are considered a promising approach to overcome issues resulting from vector-based processing with variable vector length such as lack of fusion, local temperature accumulation, and surface swelling [3]. However, the processing of pure copper using spot-based exposure strategies is widely uncovered.

This study investigates the transfer of exposure parameters from vector- to spot-based processing of pure copper and compares the relative density (Fig. 1 a), microstructure (Fig. 1 b) and physical properties. The applicability of spot-based PBF-EB/M for the production of complex geometries is shown using a heat exchanger with sinusoidal fins (Fig. 1 c).

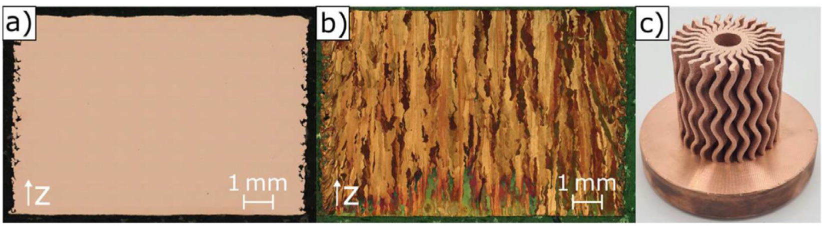

Figure 1: Spot-based PBF-EB/M of pure copper: Metallographic cross-sections displaying relative density (a) and microstructure (b) and a heat exchanger wit sinusoidal fins and a height of 60 mm (c).

Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – 508745195 and 426714296.

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[2] R. Guschlbauer, S. Momeni and C. Körner, 2018, *Mater. Charact.* **143**, 163-170.

[3] T. Kupfer, C. Breuning and M. Markl, 2024, *Addit. Manuf.* **91**, 104321.

Role of high oxygen content on the process-structure-property relationship of copper produced in electron beam powder bed fusion

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Pure copper with low oxygen content is known to produce wide columnar epitaxial grains when processed by raster scans with high scan rotation angles via electron beam powder bed fusion. However, oxygen, commonly found as non-passivating surface copper oxide in otherwise pure precursor copper powder, can restrict the grain growth and hence, can lead to a different microstructure. Previous studies, albeit limited to laser powder bed fusion, showed insignificant effect of the oxides on the electrical properties, while an improved strength properties are often reported for copper with high oxygen content. In this study, copper powder was furnace treated to increase its oxygen content and processed under similar conditions to the processing of pure copper. Initial microstructural results show differences in grain morphology as oxygen content increases. Further characterization of the specimens with regard to the undercooling conditions and nucleation events aided by detailed microscopic routines will elaborate the mechanism of grain evolution during the process. Physical and mechanical properties are expected to show trends similar to laser processed oxidized copper powder, as the process induced porosity is limited to negligible amounts in this study. This approach can demonstrate the feasibility of using oxidized copper powder in a favourable way instead of undergoing the recycling process for the need of high purity virgin powder.

Post-processing of metal additive manufactured components: powder removal and surface finishing of internal channels and external surfaces through chemically-assisted technologies

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Metal additive manufacturing (AM) has revolutionized the production of complex components across various industries. However, the as-built surfaces of metal AM parts often exhibit roughness and residual powder, compromising their mechanical properties and performance. Effective post-processing is essential to enhance surface quality and ensure component reliability. This study investigates the post-processing of metal AM components, focusing on powder removal/declogging and surface finishing of complex internal channels in PBF-EB components. We studied three methods: chemical polishing (CP), abrasive flow machining (AFM), and combining both techniques. A design chemical formulation capable of reacting with the metals in a self-limiting penetration depth targeted residual/clogged/caked powder was produced to remediate blockages and clean the channels. CP and AFM were used to smooth the internal surface textures and refine internal geometries. The combined approach aimed to leverage the advantages of each technique, achieving superior surface finishes and thorough powder removal. Results demonstrated that the combined method significantly improved surface roughness and fluid flow characteristics. However, CP is the most efficient and self-sustained option if just one method should be selected due to project, manufacturing, or budgetary constraints.
This work was supported by the US Air Force [1].

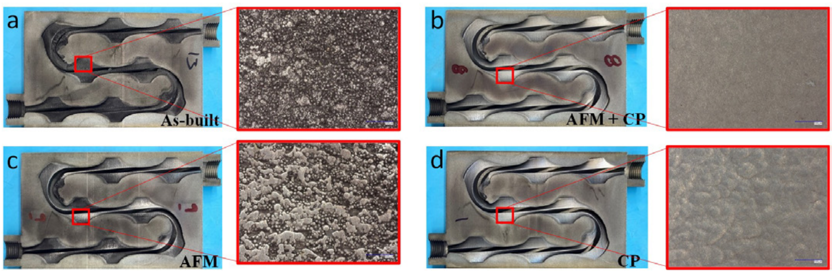

Figure 1: EDM cut of testing block exposing internal channel of a PBF-EB/Ti-6Al-4V with an optical micrograph of the internal surface in their as-built (a); AFM followed by CP (b); AFM only (c); and CP (d).

[1] AM Heat Exchanger and Channel Fabrication Optimization via Chemical Powder Blockage RemovalSurface Roughness Reduction, and Wall Thickness Optimization/Component Lightweighting, (US Air Force SBIR:, *#FA8649-22-P-0969)* , .

Evaluation of infrared thermography for the defects detection in components manufactured by powder bed fusion with electron beam

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This study investigates the use of infrared thermography as a cost-effective alternative to computed tomography for detecting subsurface defects in parts produced by powder bed fusion with an electron beam (PBF-EB). Ti6Al4V specimens were produced with designed defects that mimic subsurface pores or discontinuities whose size and depth are typical of PBF-EB. The accuracy of the samples was measured using computed tomography (CT-scan) to collect information on the defect dimensions and coordinates accurately. The same samples were therefore analysed using Joule heating infrared thermography, applying electric current while an infrared camera recorded the temperature development on the surface of the sample.

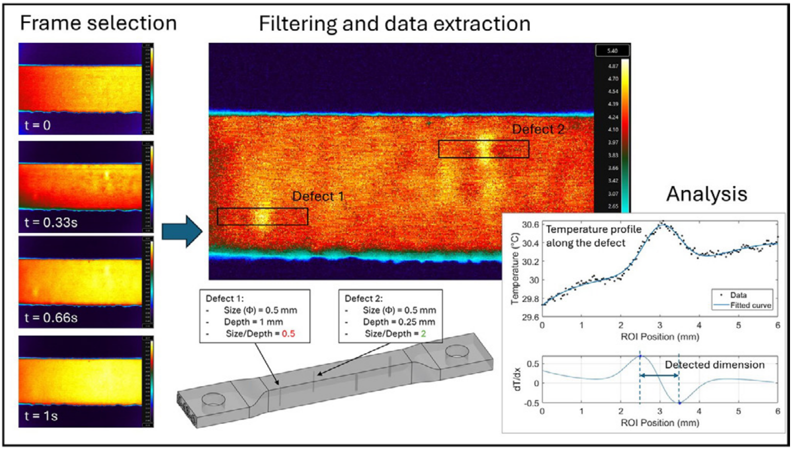

Figure 1: Example of IR data processing.

The joint analysis of CT scan and thermography data provided a comprehensive study on the limits of the inspection technologies, PBF-EB process, and measuring system in terms of defect size, depth, and the size-to-depth ratio. The results showed that the surface characteristics of the PBF-EB are critical for thermography. A new test protocol is provided to maximise the signal-to-noise ratio.

This study was founded by the MUR (Italian Minister of University and Research), PRIN Project, Grant N. 2022WA5TJ4. Project title: INTACT.

In-situ powder alloying via Powder2Powder ultrasonic atomization tailored for electron beam melting

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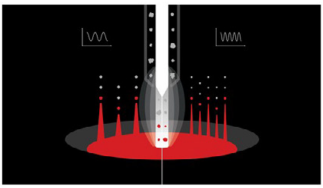
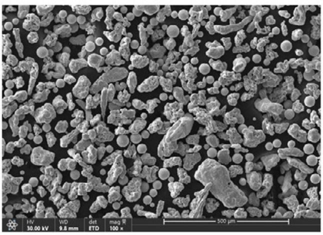
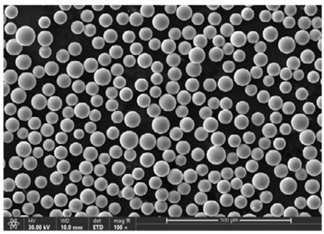
Current methods for the production of spherical powders restrict the development of custom particles with tailored chemical composition. The proposed Powder2Powder ultrasonic atomization process enables in-house powder production for alloy development. Ultrasonic atomization is a process in which a liquid, in contact with a surface vibrating at ultrasonic frequencies, forms standing capillary waves that lead to the ejection of fine droplets. As the amplitude of these waves increases, the wave crests can reach a critical height where the cohesive forces of the liquid are overcome by the surface tension, leading to the ejection of small droplets from the wave tips [1]. Material in the form of powder including post-processing material was used to atomize new alloy from powder blend which was melted in the plasma stream (Figure). The reatomization capabilities were inspected by particle size distirubtion analysis, chemical analysis including oxygen content in the final powder. Additional case studies in which irregular and other out-of-spec feedstocks were used will be presented.



(a)



(b)



(c)

Figure 1: Powder2Powder ultrasonic atomization: (a) diagram, (b) feedstock and (c) final powder.

[1] A, Priyadarshi, S. Bin Shahrani, T. Choma, L. Zrodowski, L. Qin, C.L.A. Leung, S.J. Clark, K. Fezzaa, J. Mi, P.D. Lee, D. Eskin, I. Tzanakis , 2024, *Addit. Manuf.* **83**, 104033.

Sustainability in metal AM: The EBuild® 850 and its role in metal powder recycling

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ALD is a leading manufacturer specializing in vacuum equipment for vacuum metallurgy and heat treatment applications. In response to evolving industry needs, ALD expanded its product line to include the world's largest electron beam PBF system specifically designed for the fabrication of large-scale 3D metal components – the EBuild®.

The EBuild® 850, the first iteration of our EBuild® AM system, features a build capacity of up to 850 x 850 x 1000 mm^3 and maximum beam power of 45 kW. This system takes advantage of electron beam technology to enable significantly faster build rates of 1000 cm^3 per hour and higher, making it economically viable for sectors traditionally hindered by the limitations of conventional manufacturing processes. The capability to produce sizable parts without the need for welding or assembly significantly enhances design flexibility and reduces lead times, opening new avenues for industries such as aerospace and energy & power.

In our EBAM 2025 presentation we showcase how the manufacturing capabilities of the EBuild® 850 contribute to the critical aspect of sustainability through an efficient recycling process for unused metal powder. This pathway not only reduces material waste but also promotes cost efficiency, thereby expanding the economic feasibility of large-scale AM applications.

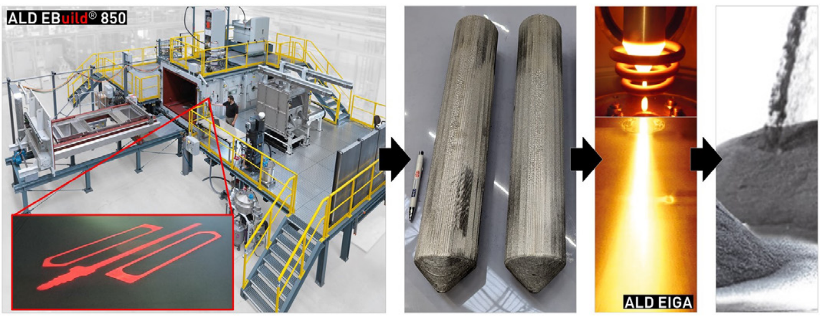

Figure 1: ALD's EBuild® 850 AM system and the recycling of metal powder using E-PBF and ALD's EIGA process.

Abstracts for Poster Presentations

ID 115: *A. Kirchner* · Corrosion Behavior of PBF-EB processed RNT650 Titanium Aluminide 66

ID 117: *X. Liang* · TiAl4822 fabricated by electron beam and laser powder bed hybrid manufacturing: feasibility and characteristics 68

ID 122: *K. Kadali* · Towards sustainable additive manufacturing of refractory tungsten using polygon powder via electron beam powder bed fusion process: A study of geometrical and microstructural characteristics of single-tracks 69

ID 125: *N. Tsutagawa* · Development of the detecting defects application by BSE monitoring 70

ID 126: *W. Sjöström* · Reduced Tungsten process development by a dual-gradient parameter approach in PBF-EB 71

ID 129: *M. Madeja* · Effect of process parameters on dimensional accuracy of Ti-55511 parts in electron beam melting 72

ID 130: *R. Dziedzic* · High manganese steel produced with electron beam melting technology 73

ID 131: *N. Boone* · In-Process monitoring on Wayland Calibur 3 74

ID 136: *S. Belousov* · Monte-Carlo model for electron scattering in molten pool and detection of backscattered electrons 75

ID 139: *C. Li* · Modeling columnar to equiaxed transition of Ni-based superalloys during additive manufacturing 76

ID 141: *M. Riaz* · A Novel method to obtain the constitutive equation of EBM produced Ti6Al4V lattice structure 77

ID 153: *G. Graf* · Exploring the formation of γ′ in Ni-based superalloys during electron beam powder bed fusion using in-situ SAXS and WAXS 78

ID 162: *D. Bruson* · Surface-based structures through 3D thickness variation using electron beam powder bed fusion: a way to enhancing performance and functionality 79

ID 163: *G. Rizza* · Thermal conductivity of sintered powder during the PBF-EB: comparison between analytical and finite element calculation in a randomly packed powder bed 80

ID 164: *Y. Chen* · Microstructural analysis of Mo-Si-B alloy processed using electron beam powder bed fusion 81

ID 166: *J. Weidinger* · Mimicking Microstructures & Evaluating Processability via Successive Electron Beam Remelting - A new approach for AM focused alloy development 82

ID 173: *J. Renner* · AI-assisted surface porosity detection for complex parts in electron beam powder bed fusion 83

ID 174: *R. Baseer* · High power PBF-EB processing of dense, crack-free tungsten 84

ID 179: *C. Torrent* · Grain Size Adjustment by (unexpected) Thermal Changes in PBF-EB/M 85

ID 180: *P. Bidola* · Leveraging the Capabilities of Synchrotron White Beam Imaging for Real-Time Studies of Electron Beam Powder Bed Fusion . 86

Corrosion Behavior of PBF-EB processed RNT650 Titanium Aluminide

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The RNT650 titanium aluminide alloy with a chemical composition of Ti-48Al-2Nb-0.7Cr-0.3Si (at.%) has been developed specifically for increased oxidation resistance and enhanced creep strength. With these properties RNT650 is suitable for application in automotive turbochargers. As an alternative to the conventional casting route, for complex shaped parts especially, PBF-EB processing has been developed [1]. This facilitates the fabrication of optimized parts such as hollow turbocharger wheels. The early stages of oxide scale formation by exposure to both dry air and steam at 650 °C for 1000 h were characterized using Transmission Electron Microscopy (TEM) [2]. A three-layered scale is formed in dry air, consisting of corundum, rutile, and a combination of both. Water vapour not only promoted the scale formation, but also changed the surface morphology of the rutile plates into whiskers. Silicon is the most mobile alloying element and diffuses to the outermost layer. The subtrate underneath the scale showed enrichment in Niobium (Nb), Chromium (Cr) and Nitrogen (N).

In comparison of the results to mould cast (MC) RNT650, the finer PBF-EB microstructure leads to a denser oxide layer compared to the more porous scale on mold cast material. This study allows to elucidate the difference in corrosion behavior caused by the powder bed fusion route.

Fraunhofer IFAM acknowledges the funding from the European Union's Seventh Framework Programme under grant agreement FP7-SME-2012-315226 and Collaboration with Łukasiewicz - Krakow Institute of Technology (KIT). The work was partly financially supported by the Institute of Metallurgy and Materials Science of the Polish Academy of Sciences within the statutory work "Optimization of materials properties via dynamic microstructure observations" (Z-14/2022).

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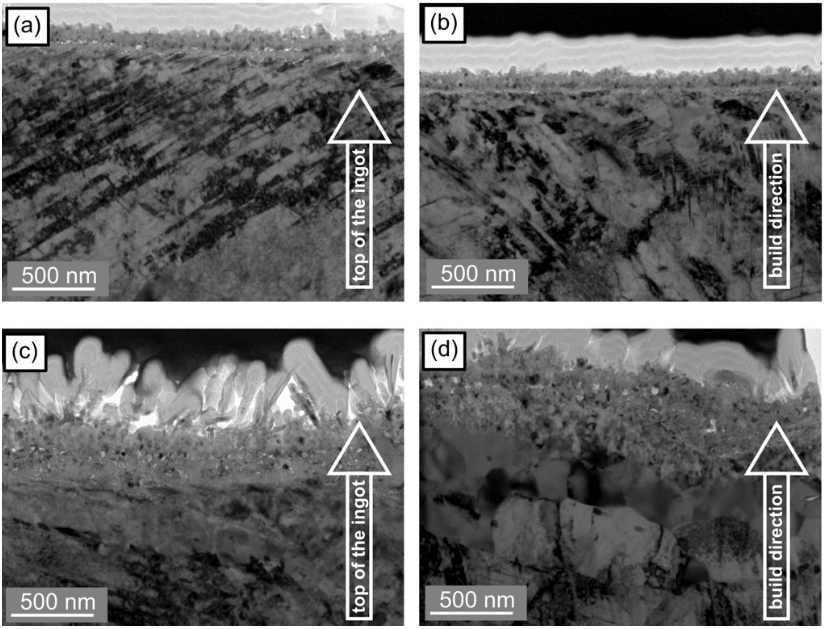

Figure 1: TEM/BF over-view images of microstructure of scales formed on: a) MC/ air oxidized, b) PBF-EB / air oxidized, c) MC/ steam oxidized and d) PBF-EB / steam oxidized.

TiAl4822 fabricated by electron beam and laser powder bed hybrid manufacturing: feasibility and characteristics

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Given the technical characteristics of Laser Powder Bed Fusion(LPBF) and Electron Beam Powder Bed Fusion(EB-PBF) processes, this study proposes an Electron Beam-Laser Hybrid Melting (EB-LHM) process. By integrating a laser beam with good focus, small spot size, and high precision with an electron beam with high penetration energy and high forming efficiency, efficient, low-stress forming of TiAl alloys are achieved. This study investigates the effects of different powder bed preheating temperatures and laser energy densities on the formation defects and density of TiAl4822 bulk under continuous preheating with a defocused electron beam and reveals the impact of powder bed temperature on microstructural evolution behavior and mechanical properties.

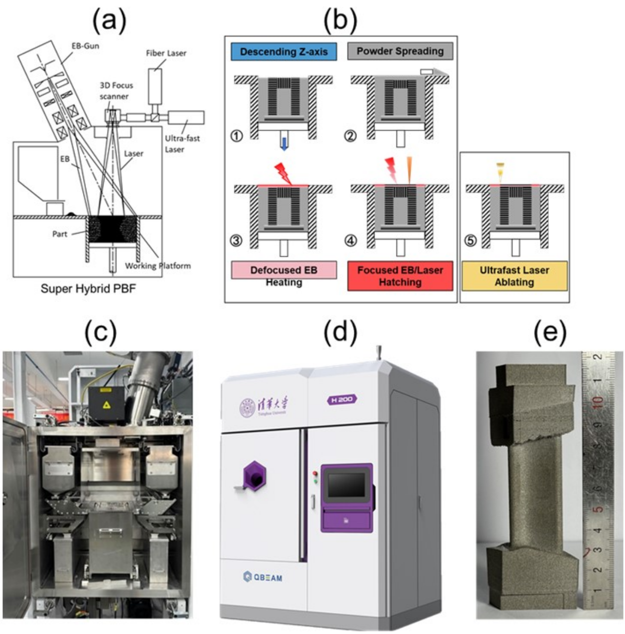

Figure 1: (a) Schematic design of super Hybrid PBF; (b) Schematic procedure of super Hybrid PBF; (c) Photo of super Hybrid PBF machine; (d) Commercialized model THU-Qbeam H200; (e) a Ti-Al blade fabricated via electron beam in-situ heating and laser beam hatching

Towards sustainable additive manufacturing of refractory tungsten using polygon powder via electron beam powder bed fusion process: A study of geometrical and microstructural characteristics of single-tracks

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The use of economically produced polygon shape (non-spherical) refractory tungsten powder in additive manufacturing (AM) processes has gained significant attention in recent times [1], [2]. The current state-of-the-art powder bed fusion AM processes predominantly utilize spherical refractory tungsten powder produced via plasma spheroidization process, associated with significant cost implications for building high-quality tungsten parts [3]. However, exploiting polygon shape refractory tungsten powder in AM is more challenging due to poor flowability and increased susceptibility to defect formation during the powder-bed fusion process [1]. To establish polygon shape refractory tungsten powder as a viable feedstock for powder-bed fusion AM processes, optimization of single tracks by deploying a process strategy is essential for ensuring process stability, dimensional accuracy, defect reduction, process scalability and attaining overall build quality with tailored properties. This study explores the use of polygon refractory tungsten powder in the electron beam powder-bed fusion (EB-PBF) process by depositing single-layer single-tracks. The process map was established for single-track depositions, followed by an in-depth study focusing on the geometrical and microstructural characterization. The evolution of track morphology, melt pool characteristics and the process-induced defects were investigated systematically by a precise control over volumetric energy density and bed pre-heating conditions. The process conditions of keyhole, transition, and conduction modes, as well as the associated cracking behaviors were characterized by cross-sectional analysis. Further, high-fidelity thermo-mechanical finite element method simulations of single-tracks were performed to predict the temperature distribution and residual stresses occurring during the melt pool formation. Based on integrated results, comprehensive mechanisms responsible for stable and unstable single tracks in the EB-PBF process were proposed. This study highlights the feasibility of using polygon shaped powder for sustainable AM of refractory tungsten by EB-PBF process.

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Development of the detecting defects application by BSE monitoring

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In industrial additive manufacturing (AM), ensuring product quality by inspecting the properties of 3D-printed parts is critical prior to shipment. For instance, detecting and evaluating the internal defects of 3D printed parts through X-ray computed tomography (CT) imaging is often indispensable to ensure defects are detected. However, there are two drawbacks associated with the post-inspection process. One is the challenge in inspecting defects in heavy metals such as tungsten and pure copper. Due to the limited penetration of X-rays, it makes defect analysis infeasible. Another issue is that defect analysis and 3D data reconstruction require significant time and resources. Production delays occur if unacceptable defects are found after the 3D parts have been printed, resulting in time and financial losses.

To address this challange, JEOL has developed a real-time defect detection using Backscatter Electron (BSE) monitoring. This application integrates artificial intelligence(AI) to identify defects, allowing users to detect unacceptable defect sizes and elevated levels of porosity during the build process promptly. Furthermore, the application also offers the capability to halt printing or isolate problematic parts automatically if issues arise, minimizing waste of resources and ensuring efficiency in the production workflow.

We will introduce the features and principles of this application in presentation, emphasizing its role in enhancing productivity and mitigating time and financial losses in AM processes.

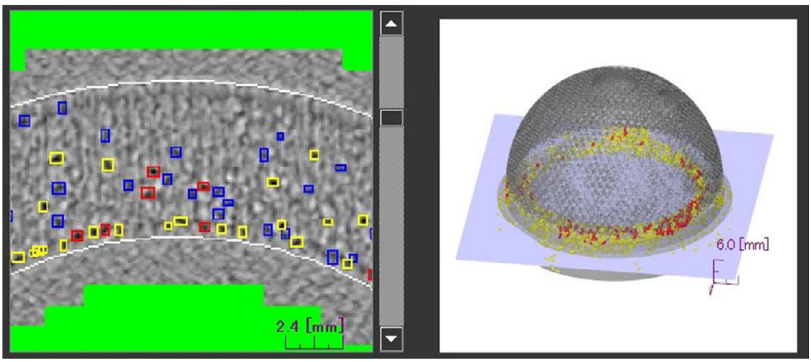

Figure 1: The application image of detecting defects by BSE monitoring

Reduced Tungsten process development by a dual-gradient parameter approach in PBF-EB

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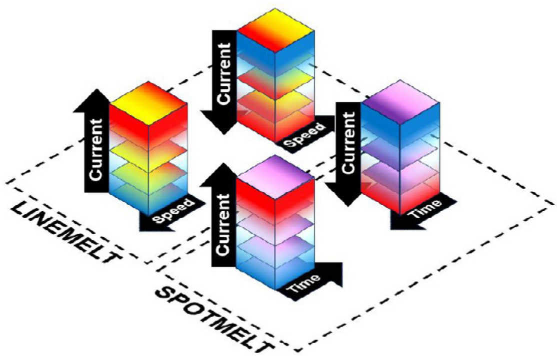
This study introduces an innovative approach for optimizing the process development in electron beam powder bed fusion (PBF-EB). Chemically reduced tungsten powder is processed using both line and spot melting strategies. A gradient-based variation of the main processing parameters, i.e. beam current and scanning speed (line melting) / dwell time (spot melting), is applied across both the XZ and XY planes (respectively) on prismatic specimens. In doing so, the transition in the consolidated material with increasing energy, from porous to swelling, can be mapped within one specimen. The same approach is inverted within the same build file to expose effects of changing the direction of the gradient in beam current, speed and dwell time. Microscopical analysis of XZ cuts of the specimens allows for identifying the parameter window in regions with dense material free of swelling, which are then selected for detailed characterization. Microstructural and compositional analysis of selected zones is carried out by SEM, EDX and EBSD, whereas variation in local micromechanical properties is assessed trough nanoindentation cartography. Further steps on the development include building of larger specimens under fixed parameters for macroscopic mechanical characterization.



Effect of process parameters on dimensional accuracy of Ti-55511 parts in electron beam melting

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The successful transition of additive manufacturing processes from research to industrial production often relies on the ability to forecast the geometric quality of fabricated components. In the case of PBF-EB and PBF-L processes, commonly observed geometric defects include side loss and warping. Side loss typically results from uneven shrinkage between layers, leading to variations in layer length and subsequent changes in the final geometry. Warping is usually characterized by the curved shape of the first overhang layers. This type of defect is caused primarily by the lower heat dissipation in the powder bed, which is less conductive than the solid material. Heat dissipation occurs more rapidly in the upper layers than in the lower ones, resulting in compressive stresses on the upper layers and tensile stresses on the lower layers.

In EBM control system 3.2 and later, to mitigate issues related to geometric accuracy, parameters that modify the beam speed (Speed factor, Thickness factor, and Exponent factor) are applied, depending on the melted cross-section and part geometry. In these studies, the impact of these parameters on geometric accuracy was analyzed by creating a series of test samples with different geometries and various sets of Speed factor, Thickness factor, and Exponent factor parameters. Based on the obtained results, an empirical model was developed and validated, which was then used to determine the final parameter values. The determined values of individual parameters significantly reduced and eliminated the phenomena of side loss and warping.

Work supported by the Polish National Centre for Research and Development within the project: INNOLOT/I/6/NCBR/2013 - AMpHOra "Research on Additive Manufacturing Processes and Hybrid Operations for Development of Innovative Aircraft Technology".

[1] S. Ghaoui , Y. Ledoux, F. Vignat, M. Museau et al., 2020, *Addit. Manuf.* **36**, 1-12.

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High manganese steel produced with electron beam melting technology

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The article presents the results of research on processing high manganese-chromium-nitrogen steel (HMnCrHN) using Electron Beam Melting (EBM) technology. High-manganese steels are increasingly used in the automotive industry; however, they remain largely unexplored and untested in additive manufacturing applications. Although high-manganese steels have been widely utilized since the 19th century, advancements in new manufacturing technologies provide a fresh perspective on their application. The high work-hardening capacity of high-manganese steels presents a considerable challenge in producing complex geometric parts, yet additive technologies appear promising in addressing these difficulties.

The research led to the development of several optimized EBM parameter sets aimed at minimizing porosity. It was observed that increased energy input resulted in a reduction in manganese and chromium content within the samples. Analysis using electron microscopy and X-ray diffraction revealed that the samples predominantly exhibited a highly directional austenitic structure. Microstructural analysis further identified the presence of eutectic-like carbide structures in two distinct forms: firstly, carbides located along the boundaries of austenitic columns, and secondly, discontinuously precipitated carbides. The presence of these carbides was confirmed through Thermo-Calc software calculations. Additionally, a significant increase in metallization was observed within the EBM fabrication chamber, with the resulting metallization products appearing in flake form. EDX analysis indicated that these flakes were composed almost exclusively of manganese. Examination of the area around the hardness indentation confirmed the presence of a TWIP (Twinning Induced Plasticity) strengthening mechanism in the processed steel.

The work was funded by the "Excellence Initiative - Research University" (IDUB) program to enhance the level of scientific activity in 2022.

In-Process monitoring on Wayland Calibur 3

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In-process monitoring in Additive Manufacturing is becoming more of a relevant tool at all stages of the process, from material development to part qualification. OEM and third party monitoring solutions are becoming common and seeing more use. These solutions are mostly based around visible light cameras, but infrared cameras and electron imaging systems are also in use. Wayland Additive's Calibur 3 incorporates 2 camera-based in-process monitoring systems: a structured light system (SLS) which can be used to capture powder bed images and surface topography, and an infrared (IR) camera that can capture high resolution images and high speed video at any point during the build process.

With Wayland's View software these in-process monitoring data sources can be reviewed post process along with all other machine data sources. It's ability to overlay and align all of Calibur 3's in-process monitoring and build data allows the user insight that can be hard to get with other less integrated systems. An example use case could be using the in-process monitoring systems to optimise a build file with difficult-to-support parts. Here the IR camera would be used to look for heat accumulation around overhanging geometry, suggesting inappropriate support geometry. The SLS system may also show evidence of overheating-related swelling, pointing to similar problems. This analysis could be completed post build or in real time with the in-process monitoring data available to the user on the machine's HMI. When used in this way proactive changes can be made to build parameters when problem signs start to occur, increasing the chance of build success. This real time functionality has also been used to expedite the new material development process. Allowing real time decisions on melt parameters to be made and measured. Therefore, the operating window of a material could be found quicker, leading to fewer builds than without in-process monitoring.

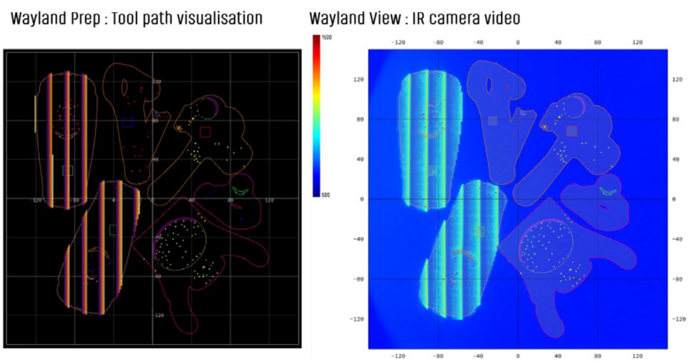

Figure 1: IR Camera and toolpath visualisation in Wayland View

Monte-Carlo model for electron scattering in molten pool and detection of backscattered electrons

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KiSSAM [1] is a software package for detailed simulation of particle bed fusion at mesoscale, from single tracks to small parts. The fluid dynamics of the melt pool is simulated in 3D with the free surface thermal lattice Boltzmann method (LBM), where the powder particles are resolved on the mesh, and the whole simulation domain can cover several centimetres. KiSSAM uses the latest GPU acceleration methods, so that such simulations are possible on desktop workstations. Here, we present the recent developments in the model for tracing electrons in the simulation.

We trace each ray as it is scattered inside the material, reducing its kinetic energy along the path. Both elastic and inelastic scattering processes are taken into account [2]. In the Monte-Carlo model, the electron trajectory in the material is approximated by a series of straight line segments with a randomly chosen length. The energy loss is modelled by reducing the electron energy at each line segment between two collisions. In the scattering events, the energy is deposited as a volume heat source at the corresponding cells for the LBM temperature model. The electrons can be fully absorbed in the material, if all energy is deposited, or leave the material otherwise.

We have implemented the detectors of back scattered electrons [3]. To reduce noise in the detected voltage, the number of electrons traced in the model is increased. Such calculations are readily accelerated with CUDA GPU, and the impact on the overall performance is low.

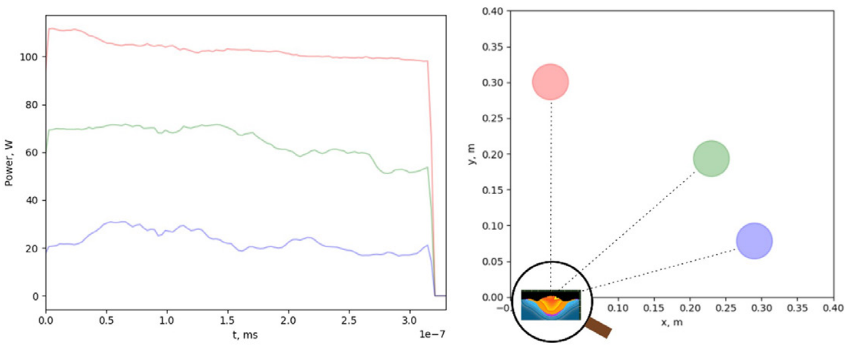

Figure 1: Electron voltage on the simulated detectors (left). Detectors position relative to the meltpool (right).Line colours on the left correspond to the circle colours, representing the detectors, on the right.

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[3] Renner, J., Grund, J., Markl, M., Körner, C., 2023, *Jour. of Man. and Mat. Proc.* **7(3)**, 87.

Modeling columnar to equiaxed transition of Ni-based superalloys during additive manufacturing

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The ability to control grain structure during additive manufacturing is critical for getting tailored properties and mitigating cracks in the products. In the present work, we present a model for columnar to equiaxed transition of Ni-based superalloys during additive manufacturing, considering the process condition, local alloy composition and the number density of nucleation sites. Thermal condition during solidification is modeled considering different beam conditions or scanning strategies. The rapid solidification is considered by a multicomponent non-equilibrium model for dendrite tip kinetics with full coupling to CALPHAD database for thermodynamic and diffusion mobility descriptions. Finally, columnar to equiaxed transition is modeled assuming heterogenous nucleation in constitution undercooled region in front of the columnar dendrite. The framework presented can be used to assist design in alloy composition and process condition to control the grain morphology in additive manufacturing components.

A Novel method to obtain the constitutive equation of EBM produced Ti6Al4V lattice structure

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Ti6Al4V alloy lattice structures fabricated using Electron Beam Melt (EBM) generally exhibit a brittle behavior. The layer-by-layer build-up of struts which are mostly angular results in partially melted powder stuck to the surface of the strut, reducing the build accuracy. The rough surfaces of struts with sharp edges and corners act also as "stress-raisers" resulting in reduced mechanical properties as compared with the bulk built samples. It also results in the difficulty of finding the correct mechanical behavior of the material under study as the Finite element models usually consider a body as totally perfect dense material. A novel method is suggested here which can easily predict the constitutive model of the EBM produced Ti6Al4V. The proposed method named "double-shear strut test" can allow to predict the stress-strain behavior of a strut. Additionally, the microstructure of the 1 mm as built struts was studied and compared to the bulk specimen. Their microstructures show that the grain boundaries were aligned parallel to the build direction with varying α platelet size. The α plate thickness for a smaller strut was lesser than the bulk specimen which resulted in a lower ductility of a lattice structure. The offered test setup can be very useful in correctly predicting the mechanical behavior of a design for a particular set of processing parameters no matter how complex the geometry is. The ease of use and straight forwardness of this setup can make it beneficial for predicting, designing and implementing the properties of EBM produced products in aerospace, medical and automotive sector.

Exploring the formation of γ′ in Ni-based superalloys during electron beam powder bed fusion using in-situ SAXS and WAXS

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Ni-based superalloys are widely used as hot section components such as turbine blades for jet engines due to their exceptional mechanical properties at high temperatures. Those alloys are strengthened by $Ni_3(Al,Ti)$ precipitates (γ′) and are conventionally manufactured by casting. Processing Ni alloys by additive manufacturing (AM) is very attractive as it opens the way for new hot gas path designs and more efficient turbines. This ultimately reduces fuel consumption and lowers emission levels. However, AM of high volume fraction γ′ alloys generally results in a large amount of cracks in the material, due to the high cooling rate and metallurgical phenomena involved in the process, especially in laser powder bed fusion (PBF-LB). Electron beam powder bed fusion (PBF-EB) is more promising, due to the higher build temperature and lower thermal gradients. However, the production of crack-free parts by PBF-EB remains challenging. Since the underlying mechanisms of crack formation during cooling of Ni-based superalloys are linked to precipitation of secondary phases and residual stress formation, simultaneous in-situ small- and wide-angle X-ray scattering (SAXS and WAXS) experiments at high acquisition rates were performed at DESY to study the influence on crack formation. These experiments are enabled by the unique sample environment developed in collaboration between KTH, FAU, Hereon, DESY and Freemelt. This sample environment is fully representative of the industrial machine developed by Freemelt, replicating the PBF-EB process while being able to acquire scattering measurements [1]. The results gained from this study accurately depict the precipitation kinetics of secondary phases during the PBF-EB process and can be used to optimize processing conditions to obtain crack-free parts.

[1] H.-H. König, N. Semjatov, G. Spartacus, P. Bidola, C. Ioannidou, J. Ye, J. Renner, U. Lienert, G. Abreu Faria, B. Wahlmann, M. Wildheim, U. Ackelid, F. Beckmann, P. Staron, P. Hedström, C. Körner and G. Lindwall, 2023, *Review of Scientific Instruments* **94**, 125103.

Surface-based structures through 3D thickness variation using electron beam powder bed fusion: a way to enhancing performance and functionality

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Lightweight structures, including struts and surface-based designs, are increasingly popular across applications. While ordered patterns provide significant performance, tuning geometric features (e.g., surface thickness) in 3D offers new possibilities to address multi-directional, multi-intensity loads. However, literature typically reports unidirectional feature variation. Challenges in structure design, continuity, homogeneity, and testing remain critical. Powder bed fusion with an electron beam (PBF-EB) enables 3D complexity due to reduced support constraints.

This study examines 3D gradation patterns' effects on the compressive strength of surface-based structures. Four gradient configurations were designed using gyroid and diamond triply periodic minimal surfaces (Figure 1): (i) along the loading direction (Vertical), (ii) along 45 degrees with respect to the load direction (Diagonal), (iii) along 45 degrees and 135 degrees with respect to the load direction in a cross configuration (Cross), and (iv) in compliance with a spherical field located in the center of the samples (Core). Wall thickness varied between 1 mm and 2 mm. Uniform 1 mm and 2 mm thick geometries served as controls. Samples (n=15) were manufactured in Ti−6Al−4V using an Arcam A2X system and tested under quasi-static compression. Computed tomography assessed thickness variation, accuracy, and defects. Digital image correlation analyzed deformation mechanisms. Results revealed that 3D gradation enhances stiffness and strength for localized loading, minimizing material use while maintaining performance. Thicker zones reinforce stress-prone areas, while thinner regions reduce weight in low-stress zones.

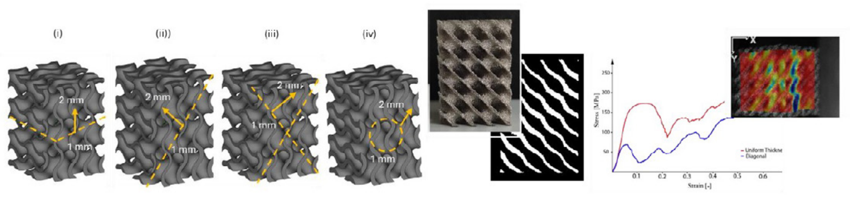

Figure 1: Gyroid CAD specimens in the (i) vertical, (ii) diagonal (45°), (iii) cross (45°/135°), and (iv) spherical (core) with tomography, compression test and DIC results.

Thermal conductivity of sintered powder during the PBF-EB: comparison between analytical and finite element calculation in a randomly packed powder bed

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The thermal conductivity of powder critically influences heat transfer in the powder bed fusion with an electron beam (PBF-EB) process. The high temperatures in PBF-EB lead to progressive powder sintering, affecting thermal conductivity, which varies with sintering degree and temperature. Microscopically, the powder bed is a complex, anisotropic network of particles whose thermal conductivity depends on particle-particle contact resistance and directional particle orientations. To address these complexities, Rizza and Galati [1] proposed a new analytical formulation incorporating tortuosity to evaluate thermal conductivity.

This study compares and validates the results of the analytical model result with those from finite element (FE) heat transfer simulations. Using a phase field model, a 150 μm cubic domain with 13 particles (45–150 μm diameter) was simulated during sintering. CAD models of the sintered geometry were extracted at four time steps. Each geometry was subsequently subjected to a thermal gradient applied alternately along three orthogonal directions to calculate directional thermal conductivity using Fourier's law. The FE values closely matched the analytical result, with a slight overestimation due to modelling uncertainties and domain discretisation. While FE captures the heat flow through the geometry, the analytical model offers a faster, resource-efficient method to explore parameter influences like particle and neck size on thermal conductivity.

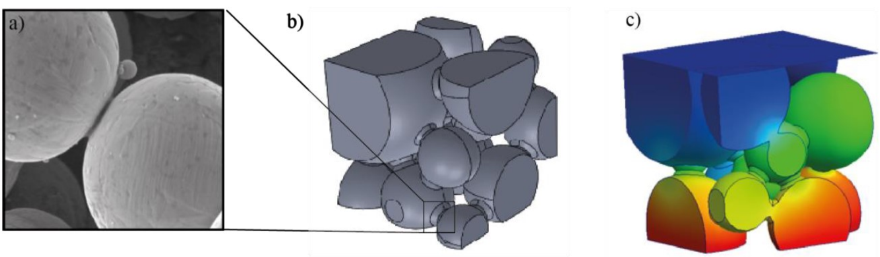

Figure 1: Evaluation of thermal conductivity with FE model. a) SEM image of neck among particles. b) Structure under consideration. c) Heat flow inside the structure

[1] G. Rizza and M. Galati, 2024, *Int. J. Heat Mass Transf.* **234**, 126055.

Microstructural analysis of Mo-Si-B alloy processed using electron beam powder bed fusion

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Mo-9Si-8B (at.%) exhibits excellent structural properties at temperatures exceeding 1200 °C, making it a promising material for ultra-high temperature applications in turbine engines. The combination of Mo-Si-B with additive manufacturing (AM) enables the single-step production of complex near-net-shape bulk materials (e.g., turbine blades). However, the high brittle-to-ductile transition temperature (BDTT, > 1000 °C) of the Mo-Si-B presents challenges in producing crack-free samples. Electron beam powder bed fusion (PBF-EB), characterized by high powder bed temperatures (i.e., above the BDTT of Mo-Si-B), can reduce thermal stress and the risk of cracking. In this study, we developed the processing window of Mo-9Si-8B using novel strategies combining high-throughput thermal modeling and electron-optical monitoring. We investigated the solidification path and phase composition of Mo-Si-B alloy during AM. Furthermore, we analyzed the microstructure and texture of as-built samples, focusing on the effects of processing parameters (e.g., lateral velocity). Finally, we established the relationship between process parameters and microstructure of Mo-Si-B processed using PBF-EB.

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Mimicking Microstructures & Evaluating Processability via Successive Electron Beam Remelting - A new approach for AM focused alloy development

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Nickel-based superalloys are extensively utilized in demanding environments characterized by elevated temperatures and corrosive atmospheres. In recent years, the application of additive manufacturing (AM) techniques, especially electron-beam powder bed fusion (PBF-EB), has gained significant attention due to their potential to enable design freedom, weight reduction, and advanced geometries. However, a major limitation of high γ′-strengthened nickel-based superalloys lies in their pronounced crack susceptibility when transitioning from casting to additive manufacturing processes [1]. To address this challenge, new alloys must be developed, or existing ones modified to reduce cracking tendencies and ensure the production of dense, defect-free components. The development of nickel-based superalloys tailored for AM remains a time-intensive and costly challenge. The large number of constituents and their complex interactions impedes identifying simple cause-effect relationships regarding processability as well as mechanical properties and makes alloy development very challenging. Experimental alloy development is further complicated by the fact that atomizing powder of each potential alloy composition would be extremely time-consuming, expensive and, hence, impractical.

This study introduces Successive Electron Beam Remelting (SEBR) as a possible new and cost-effective approach for alloy development for additive manufacturing. The SEBR process involves iterative remelting of bulk alloy samples, wherein the melt pool depth is progressively reduced during successive remelting steps. The intention is to mimic the layer-wise solidification and microstructural evolution characteristic of PBF-EB processes, including the occurrence of AM-relevant cracking phenomena. Precise control of process parameters is critical for the success of the SEBR technique. Thermal simulations are employed to identify and refine process parameters, ensuring accurate control over melt pool depth and melt pool regime. The microstructures produced via SEBR were systematically compared with those produced via PBF-EB in terms of grain size, carbide distribution, and crack density. Preliminary results indicate that SEBR successfully replicates key features of AM microstructures, including the formation of fine, elongated grains typical for PBF-EB. Furthermore, cracking can be observed within the remolten zone and the crack morphology and density correlates with those observed in actual PBF-EB builds. Hence, the evaluation of crack susceptibility through SEBR appears feasible and the method offers a rapid and cost-efficient pathway to assess the processability of novel nickel-based alloys for additive manufacturing without the need for powder.

[1] Chauvet et al., 2018, *Acta Mater.* **142**, 82-94, doi: 10.1016/j.actamat.2017.09.047 .

AI-assisted surface porosity detection for complex parts in electron beam powder bed fusion

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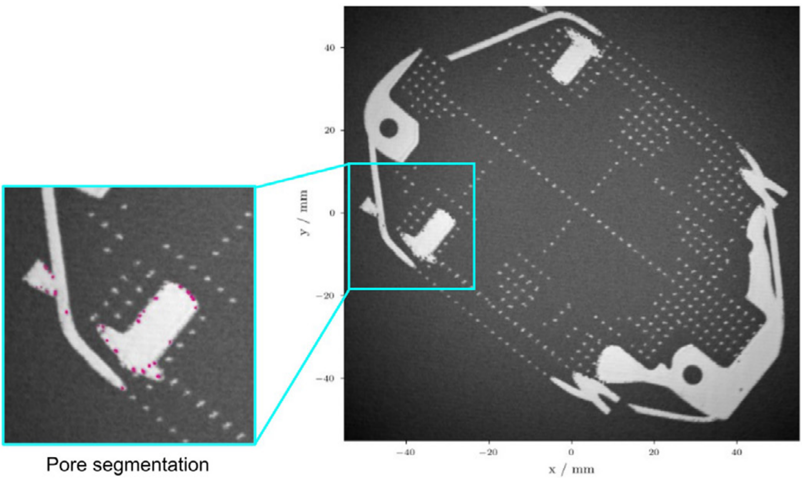
Single-detector (SD) Electron Optical (ELO) imaging systems are able to detect local part porosities in the interior of parts reliably by analyzing surface porosities in SD-ELO images of melt surfaces using classical thresholding algorithms [1]. However, overhang regions or part borders in complex parts borders represent a major challenge for histogram-based or other classical segmentation algorithms. The specific issue is that the generally good contrast between part and powder areas is locally lowered, due to the influence of uneven local melt surface topographies. This contribution highlights the usage of a U-Net [2], which has been trained using an expert-labeled surface porosity training data set containing ELO images of several complex parts. The trained U-Net can clearly identify local surface porosities in part borders and overhang regions of complex parts which allows to conduct in-depth surface porosity data analysis and enables the development of part-specific scanning strategies.



[1] Arnold, 2022, *Fundamental Investigation of Electron-Optical Process Monitoring in Electron Beam Powder Bed Fusion, FAU, Doctoral Thesis.*

[2] Ronneberger, 2015, *Lecture Notes in Computer Science* **9351**, 234–241.

High power PBF-EB processing of dense, crack-free tungsten

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Tungsten's exceptional properties, including its high melting point, high density, excellent thermal conductivity, low thermal expansion, and outstanding resistance to thermal shock and acids, make it a highly suitable material for a wide range of applications. These include heating elements, plasma-facing materials in fusion reactors, thermocouples, rocket engines, spacecraft, and radiation shielding in medical devices. However, tungsten's poor machinability presents significant challenges in fully realizing its potential.

To address these limitations, there is increasing interest in fabricating tungsten components using powder-based additive manufacturing techniques. While Laser Powder Bed Fusion (PBF-LB) often results in cracking due to tungsten's high ductile-to-brittle transition temperature, Electron Beam Powder Bed Fusion (PBF-EB) has demonstrated the ability to produce crack-free, dense tungsten parts. However, the low build rates limit its suitability for industrial applications.

In this study, E-PBF was utilized to fabricate dense, crack-free tungsten components using high power (5 kW) with scan speeds up to 4.2 ms, an unprecedented level of power in the field. The effects of preheating and localized heating on porosity and crack formation were thoroughly investigated. Tungsten samples with dimensions of up to 10 × 10 × 80 mm³ were successfully fabricated using a Freemelt ONE machine, achieving geometrically accurate, dense, crack-free overhang structures.

Figure 1: 10 × 10 × 80 mm³ and overhang Tungsten structures fabricated using 5kW power

Grain Size Adjustment by (unexpected) Thermal Changes in PBF-EB/M

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Highly complex thermal paths are inherent to electron beam powder bed fusion (EB-PBF) processes, exerting a significant influence on the resulting microstructural and mechanical properties of the material. The intricate geometries often produced with EB-PBF exhibit varying cross sections, leading to fluctuating energy inputs during the build process. These variations impact the thermal history and, consequently, the material's final properties. This study investigates how thermal history variations during EB-PBF processing affect the properties of built components. To this end, the number of specimens on the build plate was varied while maintaining constant process parameters to evaluate the impact of scan area on overall process temperature and microstructure. Additionally, the preheat step was altered using a consistent build layout to further assess its effects on the microstructure. Results demonstrate that the number of specimens significantly affects energy input, build chamber temperature, grain size, and material strength, whereas variations in preheat produce less pronounced effects. This study highlights the critical importance of understanding and managing thermal conditions in EB-PBF processes to ensure consistent material properties and mitigate risks of unexpected component failures.

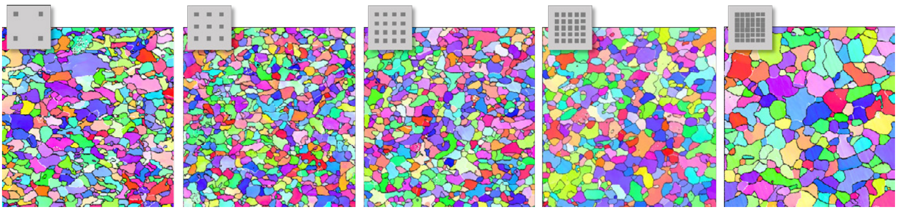

Figure 1: EBSD IPF maps of the samples processed with different packing densities.

Leveraging the Capabilities of Synchrotron White Beam Imaging for Real-Time Studies of Electron Beam Powder Bed Fusion

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In-situ synchrotron X-ray imaging offers unparalleled capabilities for real-time visualization of dynamic processes in electron beam powder bed fusion (PBF-EB), a pivotal additive manufacturing technique for high-performance materials [1, 2]. This study highlights the unique attributes of synchrotron white beam imaging, particularly its ability to achieve sub-microsecond temporal resolution and micrometer-scale spatial resolution [3]. By resolving fringes at short propagation distances using a partially coherent synchrotron beam, the imaging system enables efficient visualization of critical phenomena, including crack formation and pore evolution, in high-Z materials such as nickel-based superalloys during the PBF-EB process. These advancements allow for in-situ observation of melt pool dynamics, powder consolidation, and solidification behavior, offering new insights into defect formation mechanisms and process optimization. This work demonstrates the transformative potential of synchrotron white beam imaging in advancing the understanding of PBF-EB processes and improving additive manufacturing outcomes for demanding engineering applications.

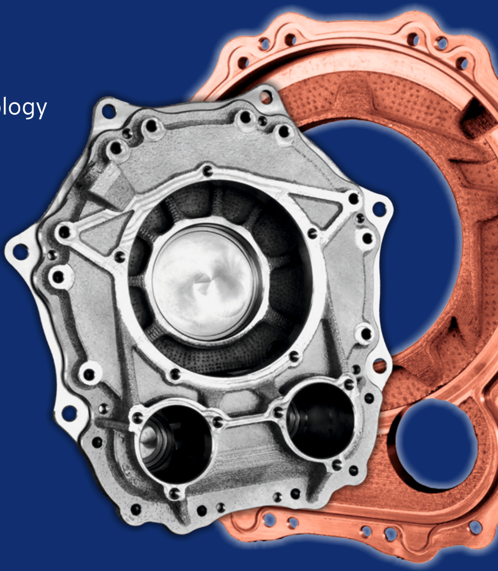
This work is funded by the Bundesministerium für Bildung und Forschung (BMBF) project number 0520CGA via the Röntgen-Angstrom Cluster (RÅC).

[1] L. Escano, S. Chuang and et L. Chen, 2022, *Addit. Manuf. Lett.* **3**, 100094.

[2] H. H. König, N. Semjatov and G. Lindwall, 2023, *Rev. Sci. Instrum.* **94**.

[3] . Bidola, G. Abreu-Faria and F. Beckmann, 2023, *Advances in X-Ray/EUV Optics and Components XVIII.* **12694**, SPIE.

Key Visual	**Formula Student Gearbox**
Design	High-Voltage Motorsports e.V. c/o Inst. of Manufacturing Technology
Manufacturing	PBF-EB of Ti-6Al-4V Neue Materialien Fürth GmbH
Postprocessing & Graphics	Chair of Materials Science and Engineering for Metals (WTM)



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