Metal Additive Manufacturing Conference - MAMC 2023

Tuesday 17 October 2023 - Thursday 19 October 2023

WKO Vienna

Book of Abstracts

Contents

Laser Melting, Electron Beam Melting & Direct Energy Deposition Processes / 3

Wire based DED processes for large scale industrial applications

Author: Rainer Beccard[1]

[1] *LUNOVU GmbH*

Corresponding Author: beccard@lunovu.com

Wire-based DED/LMD promises some unique advantages compared to powder-based DED. Most relevant are the low cost of the starting material and the reduced health and safety risks. In the recent years, wire DED was mainly used for R&D purposes. In this study, however, we will present the adoption of wire DED to industrial requirements using Inconel 625 and 718 materials. By optimizing the system hardware and processes, deposition rates up to 3 kg/h were achieved using wire diameters up to 1.6 mm. Using direct diode lasers, a maximum power of 6 kW could be used. By carefully adjusting process parameters and build strategies, very smooth surfaces could be achieved. Build height deviations which often occur at edges or when the deposition direction is changed could be reduced to a minimum in the same manner. A special focus was on maximum process stability and continuous operation. A detailed description of individual measures to achieve this will be presented. Furthermore, we will compare industrial powder based and wire-based processes with respect to material performance, cost/throughput, reproducibility, and ease of use. Finally, we will present examples for wire-based DED machine systems and CAM based toolpath generation for wire processes.

Speaker Country:

Germany

Plenary Talks / 4

Progress in multi-material design

Author: Rudolf Gradinger[1]

[1] *LKR Leichtmetallkompetenzzentrum Ranshofen GmbH*

Corresponding Author: rudolf.gradinger@ait.ac.at

The Horizon Europe project MULTi-FUN was creating novel solutions which shall enable multi-functional performance through multi-material additive manufacturing. In the years 2020-2023, successful developments were performed with respect to wire-arc AM machinery, customized materials as well as improved multi-material processing.

The three use cases contain demonstrators related to aerospace & automotive structures, moulds & dies for aluminium & CFRP processing as well as components for fuel cell testing. All of these 7 demonstrators feature unique multi-material designs, leading to added functionalities. These multi-functionalities are covering the combination of structural strength, complex geometries, integrated sensing of temperate/strain, embedded conductors (thermal, electrical) as well as novel materials.

This presentation is providing the first complete insight into the key results of MULTI-FUN, covering successful developments, major findings, important learnings, recent innovations as well as open challenges.

Speaker Country:

Austria

Laser Melting, Electron Beam Melting & Direct Energy Deposition Processes / 5

Real-time Modelling and ML Data Training for Digital Twinning of Additive Manufacturing Processes

Author: Amir Horr[1]

[1] *senior Scientist*

Corresponding Author: amir.horr@ait.ac.at

Reduced and real-time modelling is one of the main pillars of digital "process models" for twining of manufacturing processes. Starting from the data processing and model building, a digital twin of additive manufacturing (AM) processes involves creating virtual replica where predictions and corrections can be made in real-time. Developing such fast predictive/corrective digital models involve data training and machine learning (ML) routines, where dynamic and accurate models can be employed for process optimisation and control. In this research work the overview of the real-time modelling and ML data training have been presented for AM processes using hybrid and reduced order modelling (ROM) techniques. Hence, variations of processing parameters (e.g., temperature, power and feeding speed) for wire arc AM processes are considered to develop a tailored process data base and its associated snapshot matrix. Furthermore, the accuracy and reliability of these digital models for monitoring and optimizing AM processes are investigated using a real-world case study. The performances of different reduced model building and data interpolation techniques have subsequently been scrutinized to create the most accurate and efficient solver-interpolator combinations for integration of real-time models into digital twins for AM processes.

Speaker Country:

Austria

Post-Processing of AM parts / 6

Method for improved electrical conductivity of integrated thermally sprayed copper layers

Authors: Daniel Hohm[1]; Rudolf Gradinger[2]

[1] *Leichtmetallkompetenzzentrum Ranshofen*

[2] *LKR Leichtmetallkompetenzzentrum Ranshofen GmbH*

Corresponding Author: daniel.hohm@ait.ac.at

This presentation introduces a new method for a significant improvement of the electrical conductivity of thermally sprayed copper layers in multi-material designs. Within the MULTI-FUN project, thermally sprayed coatings are used to create integrated electrical conductors, which are insulated by ceramic layers and subsequently embedded into metallic structures by Wire Arc Additive Manufacturing. The use case for this novel multi-material design is a motorcycle handlebar featuring integrated electrical conductors as well as hydraulic channels.
A recurring problem is the poor electrical conductivity of the thermally sprayed copper coatings, which can be up to 5 times lower than pure copper as a drawn wire.
A new method for a post-treatment of these electrical conductors is introduced, which significantly increases the conductivity without negatively affecting the joint to the insulating stacks or influencing the mechanical properties of the adjacent structural part.

Speaker Country:

Österreich

Plenary Talks / **7**

R&D and industrial perspectives of metal additive manufacturing in Japan

Author: Hideki Kyogoku[1]

[1] *Kindai University*

Corresponding Author: kyogoku@hiro.kindai.ac.jp

Additive Manufacturing (AM) technology has been dramatically attracting attention as a breakthrough technology in advanced manufacturing. However, Japan lags behind Europe and the U.S.A. in addressing this technology. Therefore, the Ministry of Economy, Trade and Industry (METI) of Japanese Government established a new research association, "Technology Research Association for Future Additive Manufacturing (TRAFAM)"in 2014 in order to implement the national project on the development of innovative metal Additive Manufacturing systems that will meet the world's highest standards (FY2014-FY2018). Consequently, two PBF-EB type machines, two DED hybrid type machines and a PBF-LB machine were developed together with software and powder production technology. At next stage (FY2019-FY2023), TRAFAM develops a real-time monitoring and feedback control technology to assure the final product quality and process repeatability in the NEDO project. In this talk, TRAFAM activities are mainly introduced. In addition, current R&D and industrial perspectives of metal additive manufacturing in Japan are mentioned.

Speaker Country:

Japan

Mixed Topics / **8**

Fatigue behaviour of an additively manufactured drive wheel made of Ti6Al4V

Author: Deborah Kaschube[1]

Co-author: Berend Bohlmann [2]

[1] *University of Southern Denmark*

[2] *Fachhochschule Kiel*

Corresponding Author: dek@sdu.dk

This study investigates the fatigue behaviour of a specially designed drive wheel made of Ti6Al4V using cold metal fusion. In addition to its actual task, the drive wheel also serves as a spring element to cushion force peaks caused by the application and thus protect surrounding components. The special design with integrated spokes and stop points allows for a rotation within the drive wheel of 2.9°. The entire wheel was subjected to shape, strength, weight, and function optimisation by means of topology optimisation and specially designed for additive manufacturing using cold metal fusion. Previous tests on small specimens provide the necessary material parameters to carry out a strain life fatigue strength simulation. The simulation is validated by means of component tests on the test bench and in the vehicle.

Speaker Country:

Germany

Process- and Quality Control & Sustainability / **9**

The impact of minor changes in the chemical composition on the properties of an additively manufactured nickel-based superalloy and its response to hot isostatic pressing

Author: Manfred Stadler[1]

[1] *voestalpine BÖHLER Edelstahl GmbH & Co KG*

Corresponding Author: manfred.stadler@voestalpine.com

Alloy-X is a well-established nickel-based superalloy that is extensively used in petrochemical- and aerospace industry due to its outstanding combination of corrosion resistance and high temperature performance. Since additive manufacturing is more and more establishing itself as a capable method for producing components with complex geometries, also the properties of 3D-printed samples must be investigated.
Therefore, samples of three different chemical compositions of alloy-X were additively manufactured via LPBF, examined and compared regarding their microstructure and mechanical properties. A particular focus was laid on the susceptibility to hot cracking in the as-built condition, which seems to increase with increasing impurity, namely sulfur content, and negatively affects the impact toughness of the material. This was manifested, by dendrites on the fracture surface. Consequently, hot isostatic pressing was used to close the cracks and potentially enhance the mechanical performance of this alloy variant.
Furthermore, high-temperature tensile tests were carried out to determine the behavior at elevated temperatures above 750℃ and to derive the influence of the alloying elements. Here, the potentially positive influence of hot isostatic pressing on the properties of the impure, sulfur-rich variant was also investigated.

Speaker Country:

Österreich

Powder for MAM / **10**

Cost-Effective Metal Powder Production through Continuous Process with SMS group

Authors: Yannik Wilkens[1]; Peter Weiland[None]

[1] *SMS group GmbH*

Corresponding Author: yannik.wilkens@sms-group.com

The SMS group supplies and develops plant technology for producing high-quality metal powder suitable for Additive Manufacturing (AM) and other applications. The cost-effective and high-quality powders are essential for driving the growth of metal AM as a sustainable industrial technology. The SMS group has achieved this by integrating a gas atomization plant (VIGA - Vacuum Induction Gas Atomization) into their 3D-Test Center, resulting in improved powder production methods that meet the requirements for AM.

Additionally, the SMS group has collaborated with a customer to develop an innovative powder production process that transforms the conventional batch-wise process into a continuous one, enabling cost-effective and large-scale production of up to 4,000 tons per year. This new process significantly increases production capacity, reduces setup times, melting, and cooling times, and lowers production costs for spherical, high-quality metal powders. The process involves two Vacuum Induction Melting (VIM) furnaces that hold the liquid melt, which is atomized successively through the nozzle, which can be exchanged during operation. Melting takes place at lowest oxygen content by using vacuum technology to ensure the highest quality levels comparable to those of the conventional process.

Speaker Country:

Germany

Powder for MAM / **12**

Outokumpu meets powder

Authors: Andoni Sanchez-Valverde[1]; Marten Franz[1]

[1] *Outokumpu*

Corresponding Authors: andoni.sanchez-valverde.erice@outokumpu.com, marten.franz@outokumpu.com

Outokumpu plans to commence production of spherical metal powders using a Vacuum Induced melting inert Gas Atomization (VIGA) plant in Krefeld in the latter half of 2023. Additionally, collaborative efforts with entities such as IEHK - Steel Institute RWTH Aachen University, and Swerim metals research institute have led to advancements in pilot-scale development of special-grade powders, specifically 253MA and 904L, which can offer a wider range of possibilities for Additive Manufacturing (AM) industries. The upcoming presentation will highlight the following achievements:

- Identification of the atomization window required for producing 253MA and 904L powders.
- Evaluation of the characteristics of the produced powders to determine their suitability for AM technologies.
- Conducting printing and post-processing trials for the 253MA grade.
- Development of printing parameters specific to the 904L grade.
- Performance of mechanical testing on AM 904L parts, with a subsequent comparison against cold-rolled material.

These achievements underscore the relevance of these developments within the additive manufacturing industry.

Speaker Country:

Spanish nationality located in Germany

Process- and Quality Control & Sustainability / **13**

Prediction of internal defects by layer-by-layer surface texture measured using in-situ monitoring system in laser powder bed fusion additive manufacturing

Author: Makiko Yonehara[1]

Co-authors: Toshi-Taka Ikeshoji [2]; Kenta Aoyagi [3]; Kenta Yamanaka [3]; Akihiko Chiba [3]; Hideki Kyogoku [2]; Michiaki Hashitani [4]

[1] *Kindai University Hiroshima Branch / TRAFAM*

[2] *Fundamental Technology for Next Generation Research Institute, Kindai University*

[3] *Institute for Materials Research, Tohoku University*

[4] *Technology Research Association for Future Additive Manufacturing (TRAFAM)*

Corresponding Author: yonehara@hiro.kindai.ac.jp

Metal additive manufacturing (AM) is an essential technology in digital manufacturing and has been applied in various fields. Laser beam powder bed fusion (PBF-LB) is the most widely adopted AM technique. However, since the PBF-LB process inevitably generates internal defects in its built material, developing a real-time monitoring and feedback control technology is highly demanded for quality assurance of PBF-LB products and process reproducibility. Therefore, we investigated the correlation between surface texture parameters, built material density, and internal defects to investigate the possibility of using surface texture parameters as feedback input.
An in-situ monitoring method capable of simultaneously measuring the surface textures of the powder bed and the manufactured product was developed. It can measure the surface characteristics layer-by-layer using the fringe pattern projection method and calculate 15 surface texture parameters defined by ISO standards. Samples were prepared by varying the scanning speed and laser power, and the surface properties of each layer were measured. The relative density of the samples was measured. The spatial distribution of internal irregularities was also measured by X-CT imaging.
The results showed a strong correlation between surface texture parameters, density, and internal defects. It suggests that in-situ monitoring of specific areal surface texture parameters can be used as input variables for feedback systems to predict and prevent defect generation during the PBF-LB process.

Speaker Country:

Japan

Process- and Quality Control & Sustainability / **14**

Importance of air humidity in characterizing powders for additive manufacturing

Author: Marco Mitterlehner[1]

Co-authors: Alexander Schicker ; Manuel Tomisser [1]; Michael Schatz [1]

[1] *voestalpine Böhler Edelstahl GmbH & Co KG*

Corresponding Author: marco.mitterlehner@voestalpine.com

Due to the recent boom in additive manufacturing, there has been an increased interest in, and need for, proper characterization of the powders used. One aspect of powder characterization that has often been ignored in the past is air humidity. However, with additive manufacturing, the requirements for the metal powder used have changed significantly compared to classical powder metallurgy. As a result of this change, it is now also necessary to take environmental influences into account that were previously not considered to play a major role, such as air humidity. This was shown by the study carried out, in which different Böhler AMPO powder grades were characterized in atmospheres with varying air humidity levels. In addition, water uptake by adsorption on the powder surface was also investigated by means of Karl Fischer titration.

Speaker Country:

Austria

Post-Processing of AM parts / 15

Joining of L-PBF-printed AlSi10Mg by Refill Friction Stir Spot Welding

Authors: Fabian Bobner[1]; Sebastian Fritsche[1]

Co-authors: Jonathan Draper [2]; Athanasios Toumpis [2]; Alexander Galloway [2]; Philipp Schwemberger [3]; Patrick Herzig [3]; Sergio Amancio [1]

[1] *Graz University of Technology, Institute of Materials Science, Joining and Forming*

[2] *University of Strathclyde, Department of Mechanical & Aerospace Engineering*

[3] *M&H CNC Technik GmbH*

Corresponding Author: bobner@tugraz.at

Laser Powder Bed Fusion (L-PBF) is a widely used additive manufacturing technique for producing lightweight, high-performance components for the automotive and aerospace industries. Its ability to produce complex, geometry-optimised parts is often limited by the size of the printer's build chamber. To overcome those size limitations, LBPF components can be joined using rivets, screws or appropriate welding techniques. Furthermore, the joining of smaller printed parts also allows for greater design flexibility, fewer support structures and therefore, increased printing efficiency. Refill Friction Stir Spot Welding (RFSSW) is a novel solid-state welding technique for joining different wrought aluminium alloys or aluminium to other ferrous and non-ferrous metals. In this study, the feasibility of joining L-PBF-printed AlSi10Mg was investigated. The effect of process parameters on the ultimate lap shear force of single-lap joints was correlated using design of experiments and analysis of variance. Furthermore, the microstructure was examined using light optical microscopy (LOM) and scanning electron microscopy (SEM) to ensure the integrity of the spot welds. A suitable RFSSW process parameter window and resulting quasi-static mechanical performance have been determined to enable the design of future L-PBF AlSi10Mg components joined by RFSSW.

Speaker Country:

Österreich

Laser Melting, Electron Beam Melting & Direct Energy Deposition Processes / 17

Microstructure of deposited AISI M4 high speed steel on AISI D2 tool steel substrate using L-DED process

Authors: Giovanna Colombo[1]; Mário Boccalini Júnior[1]; Marcelo Veiga[2]; Moysés Lima[1]

[1] *Institute for Technological Research*

[2] *SENAI ISI-Laser*

Corresponding Author: mbj@ipt.br

Microstructures of single layer AISI M4 high speed steel deposited on AISI D2 tool steel substrate using L-DED process with two levels of global energy density were characterized and compared.
A five-axes PRECO-SL 8600 CNC machine was used to deposit the M4 powder feedstock with a continuous wave laser source, near-infrared wavelength laser beam, 2.0 mm spot size and coaxial continuous feed nozzle. The M4 powder had particle size between 60 μm and 210 μm and volumetric

mean diameter of 119µm. The quenched and tempered D2 substrate was 15 mm thick with 755 HV hardness. Two laser power/scan speed sets were used: 700 W/800 mm/min and 1100 W/500 mm/min, that is GED = 26.3 J/mm2 and GED = 66 J/mm2, respectively.
The microstructures were characterized through optical micrography, SEM, EDS microanalysis and EBSD.
Four different zones could be distinguished, owing to their microstructure features: deposition, dilution, HAZ and substrate. The effect of GED on the microstructure features was explored.

Speaker Country:

Brazil

Process- and Quality Control & Sustainability / 19

Digitalisation of the Quality Infrastructure - Using the Example of Additive Manufacturing

Author: Martin Epperlein[1]

Co-authors: Kai Hilgenberg [1]; Frank Löffler [2]; Benjamin Helfritz [3]

[1] *Bundesanstalt für Materialforschung und -prüfung*

[2] *Physikalisch-Technische Bundesanstalt*

[3] *Deutsches Institut für Normung e.V.*

Corresponding Author: martin.epperlein@bam.de

Rapidly advancing technologies and progressive digitalisation are posing challenges to the established quality infrastructure (QI), which is the overarching system of institutions and processes to ensure the quality and safety of products and applications. In response, the key stakeholders of the German QI established the initiative QI-Digital aimed at developing new solutions for modern quality assurance. One of the central use cases herein is quality assurance in additive manufacturing, in which we establish a fully interlinked additive process chain to collect and process data from each production step, allowing for a comprehensive digital view of the physical material flow. Within this process chain, we demonstrate, test, and evolve prototypes of digital QI tools like machine readable standards and digital quality certificates. This is complemented by research on the process level, comprising the evaluation and refinement of methods for in-situ and ex-situ quality assurance, as well as algorithms for registration, reduction, and analysis of process data. Machine learning techniques support the identification of quality-relevant process data. A federated dataspace based on Gaia-X will ensure data-integrity along the process chain and enable the automated comparison of process data with requirements from digital standards, as well as the issuing and handling of digital quality reports. This paper presents the current status, goals, and vision for the QI-Digital use case in additive manufacturing, which serves as a laboratory to develop, refine and demonstrate elements of a digital QI and their interaction along the process chain.

Speaker Country:

Deutschland

Laser Melting, Electron Beam Melting & Direct Energy Deposition Processes / 20

Numerical modeling of distortions and residual stresses during wire arc additive manufacturing of an Al-5083 alloy with weaving deposition

Authors: Hugo Drexler[1]; Fabio Haunreiter[2]; Lukas Raberger[3]; Leonhard Reiter[3]

[1] *LKR Leichtmetallkompetenzzentrum Ranshofen GmbH*

[2] *LKR Leichtmetall Kompetenzzentrum Ranshofen GmbH*

[3] *Fronius International GmbH*

Corresponding Author: hugo.drexler@ait.ac.at

Additive manufacturing using wire arc technology, especially Cold Metal Transfer (CMT), has become increasingly popular in the generation of large-scale and complex shaped 3D parts. However, heat input and solidification shrinkage during deposition causes distortions and residual stresses. These can significantly affect the geometric accuracy and mechanical properties of the deposit. Process simulation offers the possibility to predict the evolution of such stresses and distortions numerically. Possible violations of geometric tolerances and high stress concentrations can be identified in advance. Expensive trial-and-error can be reduced or eliminated.
This study deals with the numerical modeling of residual stresses and distortions occurring during additive manufacturing of Al-5083 parts with weaving deposition. The effects of various modeling parameters on the simulation results including clamping forces, heat source geometry and mesh size will be investigated. Furthermore, the impact of an accurate implementation of the heat source weaving pattern will be elaborated. The mechanical material properties for the simulation are evaluated utilizing in-house standardized test equipment. Validation of the thermomechanical simulation is done by monitoring temperatures and distortions during the process. Additionally, 3D scans of the part geometry and residual stress measurements using the hole drilling method are conducted post manufacturing.
This study shows the capability of the numerical prediction of residual stresses and distortions for wire arc additive manufacturing processes. The results provide useful insight on the importance of certain input parameters to calibrate the thermomechanical simulation model.

Speaker Country:

Österreich

Tools, Space and Aircraft, Automotive, Medical and others / 21

Hybrid PBF-LB/M of Pure Copper for Hairpin Winding Heads of Electric Traction Drives

Author: Carsten Putz[None]

Co-author: Johannes Henrich Schleifenbaum [1]

[1] *RWTH Aachen University*

Corresponding Author: carsten.putz@dap.rwth-aachen.de

In the automotive sector, the so-called hairpin technology currently dominates the copper winding of stators in traction drives. In addition to the advantages of higher power density and deterministic production process steps, the winding technology also entails complexities and disadvantages. The production of hairpin stators requires high investments for production machines and their highly complex tools for manufacturing the windings. These production lines are also inflexible with regard to different variants of hairpin stators. In contrast, additive manufacturing technologies enable tool-free production of complex 3D geometries.
In the field of PBF-LB/M, the processability of pure copper for electrical applications has been intensively researched and improved in recent years. Therefore, the approach of printing complex winding heads of a hairpin winding directly on conventional copper conductors using PBF-LB/M process is researched in this study. Challenges regarding alignment in the hybrid process, constant electrical

conductivity in the transition zone as well as redesign are faced and investigated. By integrating additive manufacturing in hairpin stator production and developing an innovative production process chain, process steps, machines and tools can thus be substituted. By exploiting design potentials of additive manufacturing, winding head heights can additionally be reduced, thus reducing losses in the e-machine and saving quantities of copper material. The approach is validated using a hairpin stator from the automotive sector. The same conventionally produced hairpin stator is used as a benchmark to evaluate the results achieved by the hybrid stator in a production engineering context.

Speaker Country:

Germany

Powder for MAM / **22**

Study of the influence of atomization and functionalization treatment conditions on the microstructure of 316L(N) steel powder particles for consolidation by LPBF

Author: William BURGE–CATINOT[1]

Co-authors: Pierre-François GIROUX [1]; Hicham MASKROT [1]; Philippe CASTANY [2]

[1] *Université Paris-Saclay, CEA, Service de recherche en matériaux et procédés avancés, F-91191, Gif-sur-Yvette, France*

[2] *Univ Rennes, INSA Rennes, CNRS, ISCR – UMR 6226, F-35000, Rennes, France*

Corresponding Author: william.burge-catinot@cea.fr

Within the framework of the development of the additive manufacturing processes carried out by the CEA, this work aims at studying the influence of atomization and functionalization treatment conditions of grade 316L(N) steel powder particles, identified as a material of interest for the components of future nuclear reactors, on the microstructure after consolidation by L-PBF. Previous work has demonstrated the impact of using different commercial 316L steel atomized powders on the microstructural characteristics of material obtained after consolidation by L-PBF process [1]. Especially, one of the tested powders led to the production of a material with a refined and quasi-equiaxial grain structure, unlike steels characterized by a columnar grain structure typically obtained by L-PBF with the same process parameters. Even if the mechanisms of this singular behavior are not clearly identified yet, the atomization conditions and the contents of minor elements and impurities in the powders seem to have a significant influence on the observed phenomenon. Indeed, TEM observations performed on the consolidated materials show that the refined microstructure has an enhanced precipitation density, due to fine chromium/iron carbides precipitates of around 20 nm diameter. These precipitates could act as additional nucleation sites, preventing the epitaxial growth of the grains during L-PBF consolidation. This specific precipitation, observed after L-PBF consolidation, is assumed to result from the atomization process conditions, inducing a low nitrogen content in particles of elaborated powders.
This study aims at identifying the influence of the nitrogen content on the 316L steel consolidated by L-PBF microstructure. First, TEM observations have been performed to the specific 316L powder precursor, which show a fine precipitation currently under identification. Secondly, powders with various nitrogen levels are produced and studied. To control the nitrogen content of the powder, two processes are investigated: (i) nitriding treatment of the reference powder, using nitrogen atmosphere, and (ii) ultrasonic atomization in controlled conditions. Afterwards, those powders are consolidated by L-PBF process with optimized and fixed parameters, in order to focus on the influence of the nitrogen content of the powder on the final microstructure (grain size, grain morphology, cell structure and precipitation structure). Finally, tensile tests and hardness tests are performed to compare the mechanical performances and identify the anisotropic behavior associated to each microstructure.

Speaker Country:

France

Process- and Quality Control & Sustainability / **23**

Development of sensing luminescent layers by laser powder bed fusion for corrosion monitoring

Author: Christina Baslari[1]

Co-authors: Hicham Maskrot [1]; Wilfried Pacquentin [2]; Sonia De Sousa Nobre [3]; Daniel Zambon [4]; Rachid Mahiou [4]

[1] *Université Paris-Saclay, CEA, Service de Recherche en Matériaux et procédés Avancés, 91191, Gif-sur-Yvette, France*

[2] *Université Paris-Saclay, CEA, Service de Physico-Chimie, 91191, Gif-sur-Yvette, France*

[3] *Université Grenoble Alpes, CEA, LITEN DTNM, F-38054 Grenoble, France*

[4] *Université Clermont Auvergne, Institut Chimie Clermont Ferrand, CNRS, F-63000 Clermont Ferrand, France*

Corresponding Author: christina.baslari@cea.fr

In high-tech industries such as nuclear and aeronautic fields, metal components are exposed to harsh environments that can cause their early failure. Preventive maintenance is therefore necessary in order to prevent any risks. This kind of intervention is costly, time consuming and can require the shutdown of the facilities. Moreover, replacements induce a need for spare parts and increase waste. In a circular economy approach, it would be relevant to focus on extending the service life of metal components and propose new eco-designed solutions for smart management of maintenance. The proposed solution consists in embedding luminescent particles in strategic locations of metallic parts by additive manufacturing. Thus, photoluminescence could be an effective non-destructive testing method to monitor the degradation of the material. Additive manufacturing is a suitable process for this kind of operation as it allows the development of advanced materials without adding additional process steps. In this study, Laser Powder Bed Fusion (L-PBF) technology was used to incorporate Ce3+ doped yttrium aluminum garnet (YAG:Ce) into a 316L stainless steel matrix. These luminescent pigments were successfully embedded within the metal matrix as assessed and identified by Scanning Electron Microscopy (SEM). Chemical composition and microstructure of both materials were analyzed by energy dispersive spectroscopy (EDS). The microstructural changes of 316L matrix related to the incorporation of luminescent particles have been analyzed by backscatter diffraction (EBSD) and microhardness tests. Influence of process parameters (laser power, scanning speed) on the size, morphology and incorporation rate of phosphors was also studied. Photoluminescence spectra (PL) showed that interactions between the metal matrix and the luminescent particles induce structural, physical and chemical modifications that reveal new optical features. Finally, the first tests in corrosive conditions have been carried out to monitor corrosion rate of 316L

Speaker Country:

France

Plenary Talks / **25**

Advancing 3d printing with EOS Smart Fusion, Beam-Shaping and new materials

Author: Tina Schlingmann[1]

[1] *EOS GmbH*

Corresponding Author: tina.schlingman@eos.info

How can we reduce the cost per parts of metal applications? How do we succeed in the growth of series production?
“Smart Fusion”, the innovative EOS software, is not only the solution to these questions, but also ensures a resource-saving and Responsible Manufacturing.

Speaker Country:

Germany

Process- and Quality Control & Sustainability / 26

Analysis and energy modeling of metal additive manufactured parts based on standard tensile test samples

Author: Joachim Brinkmann[1]

Co-author: Henrik te Heesen [1]

[1] *University of applied science Trier*

Corresponding Author: j.brinkmann@umwelt-campus.de

Additive manufacturing has long since become an essential tool in modern production processes, with an increasing focus on quality assurance and resource-efficient application. Technological advancements aim to increase manufacturing speed, batch size, quality, and ease of handling.
Despite a growing awareness of environmental and climate protection, increased customer interest in climate-friendly resource-saving products, and rising energy prices, resource efficiency in additive manufacturing is often only considered in passing. However, metal additive manufacturing offers immense potential. This study uses standardized tensile test specimens to analyze the energy demand, materials, and manufacturing machines in real processes, examining manufacturing density, orientation, and packing density within the build volume. The results reveal a strong dependency of energy demand on process time and the utilized manufacturing system.
This information can be used to derive specific recommendations for the manufacturing system, production parameters, and energetic optimizations through adapted design, packing density, and orientation within the build space. Additionally, the material flows, and processes surrounding the actual manufacturing offer numerous optimization potentials.
The extended degrees of freedom provided by AM, coupled with a design methodology tailored for MAM, result in a high degree of innovation and vast energy-saving potential. Further savings and recycling potentials exist for the production materials used, such as metal powders, energy, and inert gas, although recycling is currently only envisioned for the material itself. A long-term goal is the optimization and prediction of resource requirements in additive manufacturing concerning the complete product life cycle.

Speaker Country:

Germany

Laser Melting, Electron Beam Melting & Direct Energy Deposition Processes / 27

Experimental investigation of the Interfacial Properties of Hybrid Aluminium Alloys Manufactured using Wire-DED Plasma Arc Process

Author: Ziad Mohamed[1]

Co-authors: Tom-Eric Adams [1]; Peter Mayr [1]

[1] *Chair of Materials Engineering of Additive Manufacturing- Technical University of Munich*

Corresponding Author: ziad.mohamed@tum.de

Wire-DED Plasma Arc (W-DED-PArc) has emerged as a promising Additive Manufacturing technology for fabricating high-performance and large-volume metal parts. However, producing multi-material components remains one of the challenges due to the interfacial properties, intermetallic phases, and compatibility of the different alloys to be joined together. The current study investigated the effect of different substrate alloys (2017, 5038, and 7075) on the interfacial properties during single-layer and multi-layer depositions of AlSi10Mg alloy using W-DED-PArc. The microstructure and mechanical properties of the interface were evaluated through optical microscopy, scanning electron microscopy, and hardness tests. Additionally, porosity analysis was carried out. The results showed that the build-up of AlSi10Mg alloy on all substrate alloys was successful, with a well-defined mixture zone and good interfacial bonding between the build-up and substrate. However, the microstructure and mechanical properties of the deposited layers varied depending on the substrate alloy. Furthermore, the hardness profiles across the build-up were found to be similar for the 2017 and 7075, while the 5083 exhibited a different behaviour due to the weldability and the chemical composition difference. These results suggest that W-DED-PArc can be used to fabricate AlSi10Mg alloy on different substrate alloys with acceptable interfacial properties and mechanical properties. In conclusion, this study provides valuable insights into the effect of substrate alloys on the build-up and interfacial properties of AlSi10Mg alloy using W-DED-PArc. The findings suggest that W-DED-PArc can be a useful technique for the fabrication of multi-material parts and components.

Speaker Country:

Germany

Post-Processing of AM parts / 29

Surface finishing of additively manufactured hydraulic manifold : a case study.

Authors: Jean-François Vanhumbeeck[1]; Nicolas Nutal[1]; Benoît Bonvoisin[2]; Philippe Hendrickx[3]; Alberto Lavatelli[3]; Arnaud Rosenberger[4]; François-Xavier Holvoet[5]; Jan Peirs[6]

[1] *CRM Group*

[2] *European Space Agency*

[3] *SABCA*

[4] *APWorks*

[5] *Chimiderouil*

[6] *BMT Aerospace*

Corresponding Author: jean-francois.vanhumbeeck@crmgroup.be

During this presentation, we will share preliminary results of FITFAME project (ESA GSTP GT1A-314MS), focusing on the finishing of additively manufactured components with complex geometries. The first case study selected for this project is a hydraulic manifold, belonging to the Ariane 6 thrust vector control (TVC) actuator. The manifold was completely redesigned in order to exploit the benefits of additive manufacturing to improve its hydraulic performances while reducing weight. LBPF (Laser Powder Bed Fusion) processing in Scalmalloy was selected for the manufacturing.
The manifold features bent and interconnected internal channels with different diameters, which constitutes a real challenge in terms of surface finishing. Three different technologies were evaluated for the finishing of the inner surface of the channels after the additive manufacturing process, namely abrasive flow machining, chemical and electrochemical polishing. Coupons featuring representative internal channels were printed and surface finished using these 3 technologies. The performances of the surface finishing processes were evaluated based on criteria of geometrical tolerances,

treatment homogeneity, ability to remove solid particle contaminants and final roughness. A mapping of material removal was performed as well. A methodology based on CT-scans is proposed to map material removal and evaluate surface condition inside the post-treated inner channels in a non-destructive manner. In parallel, coupons, representative for the most challenging geometrical features of the outer surface of the manifold were also printed and surface finished. Five finishing technologies were compared, among which chemical polishing, electrochemical polishing, DLyte™, Coolpulse™ and MMP technology™. This presentation will describe the results of this finishing study at coupon level.

Speaker Country:

Belgium

POSTER SESSION & WELCOME RECEPTION / 31

Effect of environmental factors on stainless steel 316L powders used for laser powder-bed fusion additive manufacturing

Author: Ali Alhajeri[1]

Co-author: Ali Usman [1]

[1] *Department of Mechanical Engineering, King Fahd University of Petroleum & Minerals, Dhahran, 31261, Saudi Arabia*

Corresponding Author: g202114030@kfupm.edu.sa

Additive manufacturing (AM) processes, such as laser powder-bed fusion (LPBF), are commonly used to produce various components by using a laser to melt metal powders. Due to its widespread utilization, stainless steel 316L is one of the most commonly used materials in LPBF. It is well known that powders used in LPBF are affected by various factors, such as the manufacturing process, composition, and size. It is widely believed that variations in powder properties, such as powder size, composition, etc, can affect the printed parts'. Results from literature have shown the impact of powder properties on the porosity, mechanical properties and surface characteristics of printed LPBF parts. In this work, the effects of environmental factors, such as humidity, on the properties of powders will be studied. The study will look into the flowability, microstructure, and powder size of as-received powders. Next as-received powders will be subjected to humid environments and tested. Results will be compared to assess the impact of humid and as-received powders. It is believed that increase in powder humidity would decrease the flowability of metal powders used for LPBF and therefore would affect printed parts. This will allow us to gain a deeper understanding of the effect of humid powder on powder properties.

Speaker Country:

Kuwait

Plenary Talks / 32

Tailor-made materials for additive manufacturing based on powder blends

Author: Anke Kaletsch[1]

Co-authors: Christoph Broeckmann [2]; Marie-Luise Scheck [1]; Felix Radtke [1]; Simone Herzog [1]

[1] *RWTH Aachen University*

[2] *Institut für Werkstoffanwendungen im Maschinenbau / RWTH Aachen*

Laser Powder Bed Fusion (PBF-LB) is one of the most important additive manufacturing processes and extremely flexible in terms of geometrical freedom. With regard to the materials to be processed, however, this flexibility is not yet given in PBF-LB. In general, a limited variety of standard alloys is available. Thus, powders for specialized applications are often very expensive. A new approach to expanding the range of materials for additive manufacturing is the powder toolbox principle. Here, different standard powders can be mixed with each other, with elemental powders or other additives, e.g. carbides or nitrides, to produce new alloys and materials. The alloying then takes place in situ during the PBF-LB process.
This presentation will show some examples of how powder blends can be used to adapt and develop materials. In addition, the presentation will show the challenges that still need to be overcome when working with powder blends in the PBF-LB process.

Speaker Country:

Germany

Process- and Quality Control & Sustainability / 33

Automation as a Key Factor in LPBF Process Quality Assurance

Authors: Vikas Veerakumar[1]; Martina Riccio[1]

[1] *Additive Industries*

Corresponding Author: v.veerakumar@additiveindustries.com

Automation as a Key Factor in LPBF Process Quality Assurance
The majority of the current LPBF systems were originally designed for prototyping use, hence they face challenges with reproducibility as well as many manual operations are still needed for their use. Additive Industries has developed the next-generation highly automated industrial additive manufacturing system that not only substantially increases productivity but also overcomes the common reproducibility limits to produce high quality parts
These are the main areas of an LPBF process that can be automated:
• System Automation: Handling (eg. powder handling, buildplate handling, integrated robot, automated bed leveling)
• Optics: Optics validation and calibration (eg. laser-to-laser; laser focus calibration, multibeam tool)
• Application: Multi Laser processing (eg. DLA)
• Data: Print process data with powder bed images using job reporting tool
If the automation on the handling level is one of the keys to achieving the highest productivity (eg. the AI' integrated robot and automated bed leveling allow users to run up to 8 jobs in a row), the automation applied to the optics validation and calibration is the key for process reliability and quality control.
The presentation will showcase the advantages of a high automated LPBF system on the process and product quality.
The results of our experiments will demonstrate how the automated laser-to-laser calibration process, which aligns lasers to a fixed reference (4 lasers act as 1), ensures repeatable results job after job and between different systems. Results demonstrating the consistency of the material properties within the building area thanks to the automated laser focus calibration will be presented as well.

Speaker Country:

Netherlands

Laser Melting, Electron Beam Melting & Direct Energy Deposition Processes / 34

Processing of metallic materials by laser powder bed fusion at elevated temperatures

Authors: Martin Malý[1]; Daniel Koutný[1]; Mojmir Cyril Michálek[2]

[1] *Brno University of Technology*

[2] *SVS FEM s.r.o.*

Corresponding Author: martin.maly2@vut.cz

Laser Powder Bed Fusion (L-PBF) is a 3D printing technology that has gained worldwide acceptance due to its high resolution and accuracy. However, high equipment and material costs, residual stresses in the manufactured parts and internal defects are still major barriers to widespread industrial use. Preheating is a process in which the powder bed is heated during the production run. This leads to a homogenisation of the temperature field, which usually results in lower residual stresses. It also affects the interaction between the laser beam and the powder as well as the solidification process. The effects of high temperature preheating on residual stresses have been studied on Ti6Al4V and Inconel 939. This study evaluates the suitability of preheating to reduce the number of support structures, thereby reducing production costs and environmental impact. The results showed that preheating at high temperatures led to a rapid reduction of residual stresses in Ti6Al4V, but also to a rapid powder degradation. In contrast, preheating led to increased residual stresses in Inconel 939 due to microstructural changes. Therefore, preheating was evaluated as an uneconomical method for removing support structures in Ti6Al4V and Inconel 939.

Speaker Country:

Czech Republic

Laser Melting, Electron Beam Melting & Direct Energy Deposition Processes / 36

Effect of extensive preheating on hot cracking susceptibility of gamma' - strengthened Ni-based superalloy processed by Laser powder bed fusion

Authors: Maurizio Vedani[1]; Marawan Abdelwahed[2]; José Ramón Blasco Puchades[3]; Michele Buttazzoni[4]; Mario Martínez Ceniceros[3]; Luis Portolés Griñán[5]; Rasheed Michael Ishola[6]; Ludovica Rovatti[6]; Constantin Zenz[4]; Andreas Otto[4]

[1] *Politecnico di Milano, Dept. of Mechanical Engineering*

[2] *Ain Shams University, Faculty of Engineering, Design and Production Engineering Department, Cairo (Egypt), Politecnico di Milano, Department of Mechanical Engineering, Milan (Italy)*

[3] *AIDIMME Instituto Technologico, Valencia (Spain)*

[4] *TU Wien, Institute of Production Engineering and Photonic Technologies, Wien (Austria)*

[5] *AIDIMME Instituto Technologico, Valencia (Spain)*

[6] *Politecnico di Milano, Department of Mechanical Engineering, Milan (Italy)*

Corresponding Author: maurizio.vedani@polimi.it

The processing by Laser powder bed fusion of non-weldable gamma'-strengthened Ni-based superalloys is recognized as challenging, especially due to hot cracking and liquation cracking mechanisms that occur during the solidification and the early cooling stages of the alloys.
The current study, which is based on activities carried out within the Horizon 2020 joint research project CUSTODIAN (grant agreement number 825103), offers an insight into the solidification mechanisms of the two CM247LC and IN713LC alloys, identifying the pre-heating temperatures

which can mitigate cracking phenomena during LPBF processing. In particular, investigations on single track remelting showed that hot cracks could still form even after preheating at around 900℃, which shows gamma' precipitation and segregation of carbide-former elements at the cell boundaries according to both microstructure observations and thermodynamic calculations. To acquire a better understanding about the ability of implementing extensive preheating to industrial AM processing, a numerical simulation tool was developed, simulating the effects of a dual beam laser system, capable of dynamic beam shaping. The output of the numerical model was first validated against experimental results of single-track scans. Then, further development was conducted to find optimal combinations for the shape, size, and power distribution of primary and secondary beams, in order to reduce the cooling rates in certain critical temperature ranges of the solidification and cooling process, to mitigate solidification cracking of these critical gamma'-strengthened Ni-based superalloys.

Speaker Country:

Italy

Plenary Talks / **37**

Additive Manufacturing - a journey in time

Author: Stefan Seidel[1]

[1] *Pankl Racing Systems AG*

Corresponding Author: stefan.seidel@pankl.com

-

Speaker Country:

Austria

Plenary Talks / **38**

A combined approach of process and systems engineering for increased productivity in Laser Powder Bed Fusion

Author: Tim Lantzsch[1]

[1] *Fraunhofer, Institute for Laser Technology*

Corresponding Author: tim.lantzsch@ilt.fraunhofer.de

In recent years, Laser Powder Bed Fusion (LPBF) has become a viable manufacturing technique for production due to the possibility to manufacture complex parts without additional tools. Nevertheless, to facilitate a wider industrial adoption of LPBF, current deficits such as lack of productivity and robustness need to be overcome. The enhancement of process boundaries and the development of the next generation of LPBF machines are thus crucial to establish further industrial AM use-cases. Fraunhofer ILT utilizes a combined processes and systems engineering approach in LPBF to address these challenges. Current research topics include the use of multi-beam processing, laser beam shaping and novel machine concepts and components as well as geometry-adaptive processing strategies and in-line process monitoring.

Speaker Country:

Germany

Plenary Talks / **39**

Update on the World Market for Powder Metallurgy & Special Steels”

Author: Benedikt Blitz[1]

[1] *SMR Premium GmbH*

Corresponding Author: b.blitz@smr-premium.com

The speech will also focus on the production of Metal Powders and Powder Metallurgical Steels and especially its associated production technologies like HIP, MIM and AM. As they are and will become key future core technologies for a number of demanding products and thus for the usage in different associated industries. The presentation will also highlight the actual supply and demand situation of metal powders and the manufactured metal powder steels, will introduce leading manufacturers of both powders and steels, and summarizes installed capacity and new capacity that are on the way as well as new players that enter this high value industry. The presentation will also highlight the recent developments in the world of Forged Special Steels and remelted steels (nickel alloys, stainless steel, alloy tool steel and alloy steel) as well as will give an overview about end-user demand and structures of these special steels and also summarize the actual status of installations on a global scale.

Speaker Country:

Germany

UK-Highlight Session / **40**

Overview of current metal AM activities in the UK: a metallurgy standpoint

Author: Marco Simonelli[1]

[1] *University of Notthingham, Centre of Additive Manufacturing*

Corresponding Author: marco.simonelli@nottingham.ac.uk

-

Speaker Country:

UK

UK-Highlight Session / **41**

Addressing hot cracking in PBF-LB of high-strength Al alloys: process and alloy design strategies

Author: Marco Simonelli[1]

[1] *University of Notthingham, Centre of Additive Manufacturing*

Corresponding Author: marco.simonelli@nottingham.ac.uk

-

Speaker Country:

UK

UK-Highlight Session / **42**

The metallurgical challenges associated to multi-material PBF-LP: a case study on 316L and CuCrZr

Author: Alasdair Bulloch[1]

[1] *University of Nottingham, Centre for Additive Manufacturing*

Corresponding Author: alasdair.bulloch@nottingham.ac.uk

-

Speaker Country:

UK

UK-Highlight Session / **43**

A glimpse to the future: metallurgical insights into a novel metal jetting technique for multi-metal additive manufacturing

Author: Negar Gilani[1]

[1] *University of Nottingham, Centre for Additive Manufacturing*

Corresponding Author: negar.gilani@nottingham.ac.uk

-

Speaker Country:

UK

Laser Melting, Electron Beam Melting & Direct Energy Deposition Processes / **44**

Quality improvement of additively manufactured Ti64-samples by addition of Boron.

Author: Jelena Petrusa[1]

Co-authors: Richard Görgl [2]; Benjamin Meier [3]; Fernando Warchomicka

[1] *Joanneum Research*

[2] *JOANNEUM RESEARCH*

[3] *Joanneum Research Forschungsgmbh*

Corresponding Author: richard.goergl@joanneum.at

Ti-6-4 processed by L-PBF (Laser Powder Bed Fusion) is known to have an anisotropic microstructure due to the unidirectional build process, which leads to anisotropic ductility and fatigue behavior. Boron is known to be a nucleation starter within Titanium alloys, leading to a refinement in the microstructure. Within this work, the effects of in-situ alloying of Ti6Al4V and B on the microstructure, mechanical properties, and their anisotropy should be investigated.
Additionally, the same alloy system (Ti-6-4 plus Boron) will be investigated via Laser-Directed Energy Deposition (L-DED), and results from both AM technologies will be compared.
Furthermore, hybrid samples made of Ti-6-4 produced by a combination of L-PBF and L-DED will be built and investigated regarding their mechanical properties, especially in the transition zone.

Speaker Country:

Austria

Laser Melting, Electron Beam Melting & Direct Energy Deposition Processes / 45

Bidirectional Thermo-Capillary-Gravity Modeling for Analyzing the Wire-Based Directed Energy Deposition

Authors: Alireza Mosalman Haghighi[1]; Jialuo Ding[1]; Yongle Sun[None]

[1] *Cranfield University*

Corresponding Author: alireza.mh@cranfield.ac.uk

Wire-based directed energy deposition (w-DED) is a sophisticated technology for producing structural components. Managing bead features and defining process parameters are critical parts of the w-DED process for producing a flawless final product with minimal material waste. Based on thermophysical relations, a thermo-capillary-gravity bidirectional model has been devised in this study for rapid prediction of bead geometries or process parameters of w-DED. Bead geometries can be predicted using process parameters and material properties in the forward algorithm. In the backward algorithm, inputs of bead geometries and material properties yield process parameters as outputs. The bi-directional model has been validated for the deposition of 316L with the laser DED, ER90S-G steel with plasma transferred arc (PTA), and cold wire gas metal arc (CW-GMA) processes.

Speaker Country:

United Kingdom

Laser Melting, Electron Beam Melting & Direct Energy Deposition Processes / 46

L-PBF of the metastable beta Titanium Alloy Ti-5553: Microstructure and mechanical properties

Authors: Benjamin Meier[1]; Jelena Petrusa[2]; Fernando Warchomicka[None]

[1] *Joanneum Research Forschungsgmbh*

[2] *Joanneum Research*

Corresponding Author: benjamin.meier@joanneum.at

Ti-5Al-5V-5Mo-3Cr or Ti-5553 is a metastable β Titanium alloy with excellent mechanical properties. Compared to the most common titanium alloy, the α and β Ti6Al4V, it offers improved tensile and fatigue strength while highly tunable by heat treatment.
In scope of this work, the processability of T-5553 by Laser powder bed fusion (L-PBF) is investigated. The possible advantages of metastable β alloys for L-PBF are evaluated, and the influence of achieved microstructures on mechanical properties is shown.

Speaker Country:

Österreich

Laser Melting, Electron Beam Melting & Direct Energy Deposition Processes / **47**

Aluminium Wire and Arc Additive Manufacturing for the aerospace sector

Author: Eloise Eimer[1]

Co-authors: Jialuo Ding [1]; Stewart Williams [1]

[1] *Cranfield University*

Corresponding Author: e.eimer@cranfield.ac.uk

Wire and Arc Additive Manufacturing (WAAM) is a metal 3d printing process suitable for building large, semi-complex, near-net shape components. The Welding and Additive Manufacturing Centre at Cranfield University has been at the forefront of WAAM development, working on this technology for over 17 years, investigating processes, materials, and the manufacture of components. WAAM can replace conventional subtractive manufacturing to build high-performing parts for the aerospace sector. It can also replace complex assemblies in the automotive industry, reducing lead time, waste and costs. Investigations in collaboration with the Sustainable Manufacturing Systems Centre at Cranfield quantified the sustainability effect of the implementation of WAAM when manufacturing new or repairing exciting parts.

This talk will focus on the aluminium research programme within the Cranfield Centre research and industrial project portfolio. This covers the development of new alloys using in-situ alloying and advanced processes, high productivity WAAM, inter-layer cold work and milling, and component manufacture. Recent results of industrial and publicly funded projects will be presented, highlighting progress regarding deposition rate (up to 4.5 kg) and manufacture of large and complex components. As a case study, the European-funded project “Innovative Aluminium filler Wires for Aircraft Structures” outcomes will be presented, covering the design of a new aluminium lithium alloy for WAAM, process condition development, and the successful deposition of an aircraft wing component demonstrator.

Speaker Country:

UK

POSTER SESSION & WELCOME RECEPTION / 48

Microstructure mechanical property relationship for post heat treated electron beam melted Ti-6Al-4V alloy

Author: Amit Kumar Singh[1]

Co-authors: Sushil Mishra [1]; Anish Ranjan Singh [1]

[1] *Department of Mechanical Engineering Indian Institute of Technology Bombay*

Powder bed Electron Beam Melting of Ti-6Al-4V possesses better ultimate tensile strength than the conventional mill annealed Ti-6Al-4V. The changes in microstructure, tensile and fatigue crack growth rates were observed in the heat-treated samples below and above β transus temperature for one hour residence time followed by water and furnace cooling. Heat treatment below β transus temperature do not erase the signature of epitaxial growth during the re-melting of subsequent layers in EBM process. Whereas, the heat treatment above β transus temperature erases the footprint of additive manufacturing and epitaxial columnar grain growth of prior β grans is converted into coarse α+β phase and the structure is homogenous normal to building and transverse directions and hence the structure is similar to conventional Ti-6Al-4V. Very fine grains decorated with nano-size β phase in as build microstructure possess better mechanical strength, ductility and fatigue crack growth resistance than heat-treated samples.

Speaker Country:

India

Plenary Talks / 51

Metal Additive Manufacturing - A Look at recent Technology Trends and Market Evolution

Author: Bastian Barthel[1]

[1] *Lead Consultant sinter-based Additive Manufacturing*

Corresponding Author: barthel@ampower.eu

Speaker Country:

Germany

Plenary Talks / 52

OPENING

Author: Gerhard Hackl[1]

[1] *ASMET*

Corresponding Author: gerhard.hackl@asmet.org

..

Speaker Country:

Austria

POSTER SESSION & WELCOME RECEPTION / 54

Fatigue behaviour and biocompatibility of CP-TI grade 2 fabricated by LB-PBF: Influence of printing orientation and surface treatments

Author: Jelena Petrusa[1]

[1] *Joanneum Research*

Corresponding Author: jelena.petrusa@joanneum.at

The Selective Laser Melting (SLM) process commonly known as Laser-based Powder Bed Fusion (LB-PBF), enables the production of structures with unprecedented degrees of freedom that represents an excellent condition for development of metallic implants for biomedical applications. In this study, the effects of laser energy density on relative density and microstructure (presence of internal defects) of cp-TiGd2 fabricated by LB-PBF are studied. Additionally, the influence of printing orientation and different surface treatments on surface topography, fatigue behaviour and biocompatibility are investigated. The aim of the research is to develop additive manufacturing (AM) process parameters that can achieve full density of cp-TiGd2 with long fatigue life and satisfactory biocompatibility, as a low-cost alternative to biomedical materials such as Ti-6Al-4V and Ti-6Al-7Nb.

Speaker Country:

Austria

Plenary Talks / 55

Innovative tempering methods for demanding production processes enabled by additive manufacturing

Author: Armin Wiedenegger[1]

[1] *voestalpine Additive Manufacturing Center*

Corresponding Author: armin.wiedenegger@voestalpine.com

Additive manufacturing offers broad potential for cooling and heating molds or components. Well-balanced, near-contour temperature control channels were only the first step. Modern concepts should be highly energy efficient, meaning both reduction of the component's carbon footprint and optimization of the production process. These can include multi-material solutions (e.g. copper/steel), lightweight construction or functionally integrated heat pipes. Other functions such as venting or integrated sensors are elementary components of a next-generation AM component.

Speaker Country:

Germany

Mixed Topics / **57**

Controlled conditions for a reproducible process - upgraded sensor solution

Author: Zuzana Pronayova[1]

[1] *IST AG*

Corresponding Author: zuzana.pronayova@ist-ag.com

Integration of mass flow and pressure sensors in the gas supply system with the goal to control gas distribution and evaluate gas consumption is already common. A newly introduced FGF sensor module combines thermal mass flow, gas density and pressure in a single flow channel. The FGF module can identify gas type and compensate mass flow measurement accordingly. If, for example, inert gas supply switches from Argon to inexpensive Nitrogen for a less sensitive procedure, the module automatically takes notice, tracks the change and mass flow measurement maintains ≤±3%f.s. accuracy. As an additional safety function, gas flow in both directions can be measured. During idle periods, any gas flow in the wrong direction can be evaluated as leakage indication. This multiparametric module is designed and manufactured in close cooperation by Truedyne Sensors AG and IST AG, with both companies being part of Endress+Hauser and dedicated to compact sensor solutions for process control.
Eval-Kits | TrueDyne Sensors AG
Laser optics is sensitive to condensation, while metal powder raw materials are hygroscopic in nature and require dry storage and processing environment. Multiple measuring points, where reliable humidity measurement can enable fast process control and thereby optimal use of resources for high quality products, have been identified. In the processing chamber, a well-positioned humidity sensor can ensure that any residual humidity is purged, and no condensation is present on sensitive optical components. Purging based on the signal from a RH/T sensor can therefore shorten start-up time and directly translate into lower cost of process gases.
As additive manufacturing processes get more complex and processing times longer, maintaining low humidity and stable temperature conditions becomes just as important as instituting them. IST AG newest generation of RH/T sensors integrate a ceramic microheater, which is applied to condition the capacitive humidity sensor. A quick reconditioning procedure, which takes only a couple of minutes, significantly improves long-term accuracy. Since requirements for process connections are as individual as clothes, IST AG can dress RH/T modules in custom shaped housings to fit assembly needs. Even more important is the possibility to fit calibration to monitored thresholds. As an example, a common low humidity calibration allows to evaluate dew point at -40℃ with +/-4℃ Td.
Humidity module for dew point monitoring, assembled | IST AG (ist-ag.com)
Last sensor innovation to be addressed is temperature measurement of the build-in plates holding the manufactured product. Much effort is invested into creating an even temperature distribution with the printing bed temperature being one of the tightly controlled process parameters. Multiple temperature sensors are usually incorporated and need to be evaluated as an array. Such a multipoint measurement can benefit from a build-in reliable master sensor, against which all other temperature sensors can be checked or even reset in a remotely controlled recalibration procedure. For this purpose, IST AG has designed a new temperature module. It combines a resistive Pt1000 element with capacitive Curie point detection to create a unique temperature sensor with an automatic precision check every time the selected Curie point temperature is crossed. The sensor tip fits into all standard probe dimensions between 3 and 6 mm. A small signal evaluation board, which can be positioned remotely at up to 1.5m distance has a digital (I2C) interface and transmits the measured temperature along with information on the last precision check performed.

Speaker Country:

Switzerland

Mixed Topics / **59**

Molten Metal Deposition: the single-step direct aluminium addi-

tive manufacturing technology

Author: Chola Elangeswaran[1]

Co-author: Jonas Galle [2]

[1] *ValCUN*

[2] *ValCUN*

Corresponding Authors: chola.elangeswaran@valcun.be, jonas.galle@valcun.be

Metal additive manufacturing is lacking behind on the adoption by industry for industrial production. Despite the well-known advantages, the total production, handlings and integration efforts are the main barriers, especially for aluminium alloys. Molten Metal Deposition is a new metal AM technology that tackles these barriers. This is realized be use of wire feedstock, absence of lasers, reduced support structures & thermal stresses, allowing automation and processing of high strength aluminium alloys (6xxx & 7xxx).
This presentation will give an overview on how the nature of the technology can realize the step towards economical serial production. Additionally, the material characterization & properties will be presented on how this relates to the performance and cost of applications.

Speaker Country:

Belgium

POSTER SESSION & WELCOME RECEPTION / 60

Classification of Parts for Additive and Traditional Manufacturing Technologies using Machine Learning and Image Processing

Author: Baris Ördek[1]

Co-author: Yuri Borgianni [1]

[1] *Free University of Bozen-Bolzano*

Corresponding Author: boerdek@unibz.it

The introduction of additive manufacturing (AM) has dramatically increased design freedom, and at the same time complicated the identification of the most suitable manufacturing technology for mechanical parts. Manufacturing process selection is typically carried out by experts, but this operation is increasingly challenging and experts are difficult to recruit. Hence, the main aim of this research is to differentiate the parts to be fabricated using additive and traditional manufacturing technologies. The proposed methodology uses images of CAD (Computer-aided design) models that are taken from freely accessible web databases. The dataset contains forty images extracted using SOLIDWORKS 2022 software, where 42.50% are AM-ed products. The proposed hierarchical image clustering algorithm had 87.50% accuracy. Thus, this methodology shows great potential for manufacturing process selection and image processing applications.

Speaker Country:

Italy

Laser Melting, Electron Beam Melting & Direct Energy Deposition Processes / 61

Harnessing Advanced Laser Beam Shaping to Enhance the Laser Powder Bed Fusion Process

Authors: Sepide Hadibeik[1]; Hossein Ghasemi[2]

Co-authors: Andreas Burn [2]; Florian Spieckermann [1]; Jürgen Eckert [1]

[1] *Montanuniversität Leoben, Chair of Materials Physics*

[2] *Swiss Advanced Manufacturing Center (SAMC)*

Corresponding Author: hossein.ghasemi@sipbb.ch

A notable limitation in current commercial laser powder bed fusion (LPBF) systems emanates from the non-uniform thermal conditions caused by conventional laser beams. The utilization of Gaussian intensity patterns in existing setups gives rise to significant issues, including excessive overheating and material evaporation, stemming from the concentration of energy at the central beam point. Conversely, the beam peripheries experience low intensity and inadequate heat conduction, impeding the attainment of the required material melting point. In this study, we have developed a dynamic beam shaping technology based on a Liquid Crystal on Silicon (LCoS)-type spatial light modulator. This advancement addresses the existing limitations and enhances both the efficiency and quality of the LPBF process. The proposed technology exhibits promising potential to yield a significant upsurge in the productivity and part quality of the LPBF process. Here we present a breakthrough in enhancing the printability of Zr-based bulk metallic glass by utilizing proper beam shape to reduce the HAZ and chance for crystallization of BMGs during LPBF process.
Keywords: Laser Powder Bed fusion, Beam Shaping, Bulk Metallic Glasses

Speaker Country:

Switzerland

POSTER SESSION & WELCOME RECEPTION / 62

Rejuvenation behavior impacted by process parameters in Zr-based Bulk metallic glass manufactured by laser powder bed fusion

Author: Sepide Hadibeik[1]

Co-authors: Florian Spieckermann [1]; Jürgen Eckert [2]

[1] *Montanuniversität Leoben*

[2] *Montanuniversität Leoben, Austrian Academy of Sciences*

Corresponding Author: sepide.hadibeik-neishaboori@unileoben.ac.at

In the context of additive manufacturing, bulk metallic glasses (BMGs) are a type of material that has gained attention due to their potential for producing large and intricate parts. However, when using the laser powder bed fusion (LPBF) technique to 3D print BMGs, there are challenges associated with the reheating of previously solidified layers during the process. This reheating can impact the structural relaxation of the solidified layers. The reheating can lead to annihilation of free volume and negatively affect the ductility of the material at room temperature, making it more brittle. To address this issue, the researchers in this investigation explored how different laser and process parameters can modify the thermal history of the BMG during LPBF. By adjusting these parameters, they aimed to mitigate the negative effects of reheating on the relaxation enthalpy. To characterize the changes in the material, differential scanning calorimetry (DSC) was used, which measures the amount of heat absorbed or released by the material as it undergoes thermal changes. This enables to analysis the relaxation behavior and energy state of the 3D-printed Zr-based BMG, providing insights into how the material's properties are affected by the LPBF process.

Speaker Country:

Austria

POSTER SESSION & WELCOME RECEPTION / 63

Advanced digitalization tools for increased value in SLM

Author: Isidro Rivero Pérez[1]

Co-authors: Òscar Alonso Almirall [1]; Sergi Bafaluy Ojea [2]; Iban Gonzàlez [1]; Charbell De Soto [1]; Pilar Castejón Galan [1]

[1] *Leitat Technological Center*

[2] *Leitat*

Corresponding Author: sbafaluy@leitat.org

The actual state of the art in SLM is linked to the utilization of certain parameters according to the metal powder. Nevertheless, the shape and geometrical features of the parts to print as well as unexpected defects during the fusing process may lead to inconsistencies in the final part properties. In addition, there is a lack of monitoring tools that allow to analyze the process in-situ and stop it or apply correction strategies. The main objective of this work is to develop a combination of digital tools, including parts segmentation, process monitoring and defect detection, acting from the build planification to print validation. The proposed methodology includes process data and images capture with InfiniAM© as well as the application of computer vision techniques, machine learning (ML), 3D data representation and artificial intelligence (AI) for the extraction high-level information of process issues and their mitigation. An interactive interface was developed to be able to segment CAD geometries according to relevant geometrical features (down-skin, up-skin, thicknesses, etc.) and thus, to be able to assign the adequate process parameters to them. The acquired data during a build was represented with a high-detail 3D view with tunable resolution (up to 15 μm/voxel) and employed to detect layer defects, gas footprint and the dimensional deviation of printed parts within each layer. Also, 2D regression models were built aiming to simulate and predict the detector measurements. To conclude, the developed tools can successfully be used to validate SLM jobs and ensure the lack of macro-defects.

Speaker Country:

Spain

POSTER SESSION & WELCOME RECEPTION / 64

Metallic Porous Biomaterials for Orthopedic Implants: Design to Mechanical Evaluation

Author: Chetana Madhukar Suryawanshi[1]

Co-authors: Ravi Bhallamudi [1]; Sushil Mishra [1]

[1] *Indian Institute of Technology Bombay, India*

Corresponding Author: suryawanshi.chetana12@gmail.com

Lattice structures (porous scaffolds) with interconnected pores provide better osteointegration compared to solid implants and minimize the stress shielding effect by reducing the effective elastic modulus of implants closer to the natural bones. This research focuses on developing biocompatible

Orthopedic implants with reduced stress-shielding, better load-bearing and osteointegration capabilities. Lattice structures with great bio-mimicry features and mechanical properties were designed by considering optimum pore shape, pore size and porosity percentage. Based on Gibson-Ashby scaling laws for a relation between relative density, effective elastic modulus and yield strength, Gyroid lattice unit cells with porosities ranging from 65% to 85% were designed with a variation of 5% to bring the stiffness of implants close to cortical and cancellous bones. The Ti-6Al-4V alloy, with excellent mechanical properties and biocompatibility, was used for the development of porous implants. The quasi-static performance of Gyroid lattice structures was investigated computationally by performing FEA, including size-effect analysis to obtain size-independent mechanical properties. The size effect analysis indicated that 43 unit cells are sufficient to obtain bulk mechanical properties of the lattice structure.

Lattice structures were manufactured using Direct Metal Laser Sintering, a powder bed fusion technology. The microstructural evaluation of additively manufactured lattice structures was performed using Scanning Electron Microscopy, as the micro-defects generated during the additive manufacturing process affect the mechanical strength of structures. The lattice structures were tested under compressive loading conditions to assess their suitability for load-bearing orthopedic implants. The deformation behavior of lattice structures was analyzed using the DIC technique.

It was observed that the Gyroid lattice structure provides easy control over porosity, thus, scaffolds' effective elastic modulus and strength. The Gyroid lattice structures with 65% to 85% porosities provide an effective elastic modulus of 0.2 to 3 GPa and yield strength of 6 to 45 MPa; thus, they are suitable for implantation near cancellous bones but need improvement in strength for implantation near cortical bones.

Speaker Country:

India

POSTER SESSION & WELCOME RECEPTION / 65

A Post Processing Technique to Achieve Nanofinishing and Biocompatibility Enhancement of Ti-6Al-4V Femoral Head fabricated by Laser Powder Bed

Author: Atul Singh Rajput[1]

Co-authors: Sajan Kapil ; Manas Das

[1] *Indian Institute of Technology*

Corresponding Author: atulsingh@iitg.ac.in

Ti-6Al-4V alloys are extensively used as a substitution for human bones as they are biocompatible, lightweight, corrosive resistant, and have low elastic modulus. Additive Manufacturing (AM) is the best suitable process for realizing complex biomedical implants of Ti-6Al-4V alloys. However, some implants require a mirror-like polished surface typically obtained through a post-processing technique. Therefore, this work proposed a novel post-processing method to improve the surface quality of additively manufactured Ti-6Al-4V alloys. Hybrid Electrochemical Assisted Magnetorheological (H-ECMR) utilizes the synergic action of mechanical abrasion and electrochemical reaction to enhance the surface quality of the parts without affecting their surface topography. However, the H-ECMR finishing process effectively applies to parts with initial surface roughness (Ra) in the sub-micron range. Hence, chemical etching is used as an intermediated process after fabricating the Ti-6Al-4V femoral head by Laser Powder Bed Fusion (LPBF) to reduce the surface roughness in the sub-micron range. Moreover, a Scanning Electron Microscope (SEM), Atomic Force Microscope (AFM), and optical profilometer are used to examine the change in the surface quality before and after post-processing of the LPBF fabricated femoral head.

Speaker Country:

India

POSTER SESSION & WELCOME RECEPTION / 66

A Non-Pneumatic Method of Powder Feedstock Handling in Directed Energy Deposition

Author: AMBRISH SINGH[1]

Co-authors: Sajan Kapil [2]; Manas Das [2]

[1] *Indian Institute of Technology Guwahati India*

[2] *Indian Institue of Technology Guwahati*

Corresponding Author: singh176103107@iitg.ac.in

Most commercial Directed Energy Deposition(DED) machine tools use pneumatic methods of feedstock handling; the current study proposes a gravity-based design. The powder metering in the current design is accomplished via a helical-grooved metering rod rotating inside a powder-filled hopper, continuously dispensing powder mass in a small user-defined quantity. This powder is then shaped into a convergent powder stream through a powder delivery nozzle, followed by its subsequent injection into the melt pool. The proposed powder handling unit exhibits several advantages over conventional ones, such as minimized spatter, improved powder recycling, minimized cost of operation, etc. Furthermore, the setup is modular and simple in nature and can be mounted to any laser welding head, thus imparting additive manufacturing capabilities. Discrete Element Method(DEM) simulations and initial prototypes establish the viability of the proposed design.

Speaker Country:

India

POSTER SESSION & WELCOME RECEPTION / 67

Computer Aided Process Planning for multi-axis deposition during Robotic Wire based Directed Energy Deposition

Authors: Ritam Sarma[1]; Sajan Kapil[2]; Shrikrishna N. Joshi[2]

[1] *Mechanical Engineering Department, Indian Institute of Technology Guwahati*

[2] *Department of Mechanical Engineering, Indian Institute of Technology Guwahati*

Corresponding Author: ritam@iitg.ac.in

Wire-based Directed Energy Deposition (W-DED) is an often preferred method for the fabrication and repair of large metallic mechanical components because of its high deposition rate and cost-effectiveness. Utilizing higher kinematics for deposition in robotic W-DED facilitates the creation of overhanging structures without the need for additional support structures. However, there is currently no universally accepted solution for toolpath planning for robotic setup that exists in the literature. Therefore, this study introduces a novel framework for computer-aided process planning for multi-axis deposition during robotic W-DED, using already established CAD/CAM systems originally designed for the machining process. The framework initiates with the creation of the virtual robotic cell within the CAD/CAM system. Subsequently, the CAD model is imported into the CAD/CAM environment, and slicing planes are generated. The contours derived during slicing are

employed for the generation of multi-axis toolpaths. Moreover, the framework enables the use of nontraditional user-defined toolpath trajectories for deposition. Finally, a generic algorithm for post-processing the generated robotic toolpath is presented. The effectiveness of the proposed framework has been demonstrated through the fabrication of different components using the robotic W-DED process.

Speaker Country:

India

POSTER SESSION & WELCOME RECEPTION / 68

Improving tooling in cooling - Case studies from the wire drawing process exploring the benefits of additive manufacturing

Author: Joakim Larsson[1]

[1] *Örebro University*

Corresponding Author: joakim.larsson@oru.se

Components such as cables, screws, nails and many other things vital for our modern society are made from cold drawn wire. The wire is produced by pulling hot rolled wire through a single or a series of tools called drawing dies. In this process the cross-section of the wire is reduced, and the mechanical properties of the material is enhanced. Even though it is classified as a cold working process, there are rather high temperatures in the dies due to extreme tribological conditions resulting in high frictional forces between the wire and the die.
Studies have shown that the temperature of the drawing tool has an impact on the productivity of the drawing process. High temperatures cause lubrication degradation resulting in damages on the dies and the produced product. It has been shown that with a decreased tool temperature the productivity could be increased, and the tool wear rate decreased.
In this poster, case studies are presented in which the benefits from additive manufacturing have been utilized to improve the cooling capacity of the drawing dies in industrial wire drawing processes.

Speaker Country:

Sweden

Tools, Space and Aircraft, Automotive, Medical and others / 69

AM for New Space: Leverage PBF and DED for hybrid manufacturing of Satellite Tanks

Author: Thomas Weitlaner[1]

[1] *MT Aerospace AG*

Corresponding Author: thomas.weitlaner@mt-aerospace.de

This presentation gives insights into current and upcoming metal applications for Space and Aerospace players based on Laser Powder Bed Fusion (L-PBF). What are the highlights and what are hurdles, that need to be tackled in the next months and years?
What is more, it will provide a status on currently ongoing R&D projects, that show the pro's and

con's of Direct Energy Deposition (DED) for space applications and what it will take to industrialize DED. As a final highlight, it will reveal, how L-PBF and DED could be combined to enable applications that will contribute to the future success of moon-landing missions.

Speaker Country:

Germany