Metal Additive Manufacturing Conference - MAMC 2022

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TU Graz

Book of Abstracts

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AM-Process- and Quality Control & Post Processing of AM Parts / 2

Clean and reliable metal powders – a statistical approach

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Users of metal powder based additive manufacturing systems are often afraid of not receiving the right quality. And looking at the bulk of metal powder which shall be put in the machines it is definitely understandable that uncertainties exists:
There are many factors affecting the powder quality and moreover which of them has an influence on the printing result? For many it feels like finding the needle in the haystack when being confronted with the question of potential contaminations which is of major concern when it comes to critical parts especially for aircraft solutions or medical applications.
Aspects like individual quality sense of a supplier, experiences with prior deliveries or pro-active and extensive testing of each new batch can be found within the AM community. Within this presentation a new approach will be explained to overcome the worries by offering statistical based quality-numbers for metal powders.

Speaker Country:

Germany

Powder for MAMC / 3

Aluminum powders beyond standard applications

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Metal additive manufacturing has developed and opened numerous fields of new components being used in aerospace, motorsports, automotive or light weight construction. The more challanges have been targeted, the more new powder materials were needed. Being among the lightest materials, Aluminum was always in scope for driving those projects. Especially from the moment also mechanical properties and heat resistance could be improved to meet competitive requirements.
m4p developed more than 30 new materials beside the standard powders already used in the market within the last 4 years including also AL-based alloys for high strength, heat resistant or conductive applications.
Strength-AL, Resist-AL, Pure-AL to be introduced.

Speaker Country:

Austria

Powder for MAMC / 4

Steels for Additive Manufacturing - looking at the Oil and Gas industry

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As the oil and gas companies seek to find sources of production in low-risk areas they are moving further offshore and deeper underwater. This has driven the demand for more corrosion-resistant materials, which are stronger and lighter than existing materials. Many of these materials, such as duplex and super duplex steels, martensitic stainless steels etc. are now widely used in conventional manufacturing processes. The additive manufacturing of such materials is, however, limited with most oil and gas additively manufactured components being produced out of the standard 316l and Ni-718.
In this white paper, we show the properties and characteristics achieved by additive manufacturing of three such materials widely used in the Oil & Gas industry, a martensitic stainless steel - m4p™ type13-X, a duplex steel m4p™ type10-SDX, and a super duplex steel - m4p™ type62-DX.

Speaker Country:

India

Tools, Space and Aircraft, Automotive, Medical and others / 5

Investigations into the robustness of additively manufactured, embedded electrical conductors

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Latest development in multi-material design realised by metal additive layer manufacturing technologies include the integration of sensors & conductors.
Specifically electrical conductors out of metal (e.g. copper) have to be insulated from the metal solid to avoid short circuiting and provide the designed functionality over the lifetime.
The presented investigations involve several different specimen types, which were altogether manufactured in the following way: an atmospheric plasma coating process was used to deposit two stack of layers out of Aluminium oxide onto an aluminium alloy substrate. In-between those stacks of appro. 200µm thickness, several layers of Copper are crated in the same way, again using spherical powder of 10-20µm size. This setup of an insulted Cu track is subsequently embedded by wire+arc additive manufacturing, applying aluminium alloy, resulting in an aluminium body with locally integrated electrical conductor.
Those samples were mechanically tested in static and pulsating load conditions, while measuring the Ohmic resistance in parallel.
All different test scenarios show a remarkable robustness of the conductors in the elastic as well as plastic regime. Results from metallographic and X-ray analysis provide an insight into the macroscopic design of these multi-functional test articles.
An outlook into future applications is exhibiting the exploitation potential, specifically in context of H2020 project MULTI-FUN.

Speaker Country:

Österreich

AM-Process- and Quality Control & Post Processing of AM Parts / 6

On Reduced and Detailed Simulations of Additive Manufacturing Processes

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Most of the research on the numerical simulations of Additive Manufacturing (AM) processes have focused on the detailed Finite Element (FE) simulations to optimise these manufacturing processes and to calibrate their process parameters. Although, many details of the dynamic and transient multi-physical processes, like AM processes, are required to be simulated to obtain accurate results, the amount of computing time and efforts are still challenging even for the today's highly parallelized computing schemes. Meanwhile, with the manufacturing digitalisation transformation and its real-time modelling requirements, there are prerequisites for fast and reliable predictive and corrective models to handle real-time optimisations. The hybrid and reduced physical-data driven modelling schemes have already been employed in some digital twining technologies to reduce the simulations' times towards the real-time scale. This research work presents the overview of the hybrid and Reduced Order Modelling (ROM) schemes for AM process modelling where quick and agile models can be created to handle the multi-physical and dynamic nature of these processes. Additionally, the ways to combine the Machine Learning (ML) technologies with ROM scheme to estimate the optimized process parameters and improve the product qualities are elaborated and pilot case studies are presented to show the applicability and accuracy of these hybrid techniques.

Keywords: Reduced order models, machine learning, additive manufacturing, hybrid modeling, digital twin, data driven models

Speaker Country:

Austria

Systems & Equipments for MAM / 7

Lithography-based Metal Manufacturing: Technique, Materials & Applications

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Lithography-based metal additive manufacturing (LMM) is a novel additive manufacturing technology, which enables the production of functional metal components with smooth surface aesthetics, high feature resolutions and complex shapes, unmatched by other metal additive manufacturing technologies. The LMM printer fabricates so-called green parts applying the principle of photopolymerization with DLP-based stereolithography. The printed green parts comprise of the metal powder held in shape by the photopolymer-based binder system. During the layer-wise printing process,

metal powder is homogeneously dispersed in a light-sensitive resin which solidifies by a polymerization reaction. As the fabrication process does not require supporting structures, unlike typical stereolithography processes, the parts can be cleaned without difficulty with solvent solution without damaging the surface. To gain the final metallic properties, the green parts require a debinding and sintering step, similarly to other sinter-based methods, such as Metal Injection Molding (MIM). After the post-processing, the relative density, microstructure and mechanical properties of the parts produced by the LMM technique are equivalent to the properties of MIM fabricated components. Sintered 316L stainless steel parts can reach > 98% of the relative density with > 500 MPa tensile strength. Typical Ra surface roughness values for as-sintered parts (without any surface treatment) are <5 µm independent of printing direction.
LMM is developed as a complementary technology for a MIM mass production to support quick prototyping and fast design iteration steps, while also enabling the small-scale production of complex shapes which would be too difficult for MIM. Thus, LMM can help the MIM producers to facilitate efficient customer support and product development and can also be used as a standalone production technique for wide range of functional metal components.

Speaker Country:

Austria

AM-Process- and Quality Control & Post Processing of AM Parts / 8

Advanced microstructure investigations of metallic 3D-printed parts

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The micro- and nanostructure of additively manufactured alloys designed for certain applications are influenced by atomic-level effects arising from either added or randomly inserted impurities.
While the addition of elements in very low concentrations is required for the tuning towards a specific microstructure, different production routes of the feedstock and the printed parts as well as process parameters or post-processing are responsible for the undesired elements. Oxygen, for example, is responsible for nano- or micrometer sized pores formation, amorphous phases or delamination from a given support material but can also shifts the allover microstructure inducing formation of metastable new phases, thus dramatically influencing the expected process-property-relationship.
This paper presents advanced microscopy studies supplemented by analytical characterization methods performed on 3D-printed metallic parts [1,2,3]. The focus lies on the detection of light elements and their influence on microstructural evolution during printing and post-processing, with emphasis on heat treatment.

This work received financial support by the Austrian Science Fund (FFG): SP-2021-04 (INSIGHT) and from the European Union's Horizon 2020 research and innovation program under grant agreement No 823717 – ESTEEM3.

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Speaker Country:

Austria

Laser Melting, Electron Beam Melting & Direct Energy Deposition Processes / 9

Wire-based electron beam additive manufacturing of Ni-rich NiTi Shape Memory Alloy

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NiTi based shape memory alloys (SMA) gained importance in the aerospace industry due to their unique shape recovery properties. Regardless of the great demand, the fabrication of SMAs is rather complex. For instance, forging and machining are limited due to the high strength and reactivity of NiTi alloys. Recently, additive manufacturing (AM) was disrupted as a feasible solution to mitigate these problems related to conventional fabrication methods. Most of the reported AM techniques for NiTi based alloys involve laser in powder-bed fusion. These techniques have achieved considerable success regarding shape complexity and elimination or reduction of secondary post-fabrication operations. However, these technologies have some limitations, such as built shape size and issues regarding interstitial contamination. In this context, wire-based electron beam additive manufacturing (w-EBAM) has shown capable of overcoming or mitigating such drawbacks. W-EBAM uses wire as feedstock and electron beam as an energy source, fabricating medium-to-large near net shape parts in a vacuum chamber. If compared to the current powder-bed fusion, the use of wire allows for more efficient use of feedstock, the electron beam leads to low energy losses, and the vacuum atmosphere hinders built contamination. Therefore, w-EBAM has gained momentum increasingly achieving more acceptance for industrial applications. We have newly demonstrated the w-EBAM feasibility on NiTi SMA. This work aims to evaluate how w-EBAM manufacturing parameters affect the functional properties of a Ni-rich NiTi alloy. Design of experiments and statistical analysis were used to support the understanding of the relationships between process parameters and structural stability, microstructure and transformation temperatures. Finally, post-manufacturing heat treatment was applied. A further enhancement of w-EBAM specimen functional properties was demonstrated through mechanical testing.

Speaker Country:

Austria

Laser Melting, Electron Beam Melting & Direct Energy Deposition Processes / 10

Laser powder bed fusion of Ni-rich NiTi by in situ alloying: an exploratory study on the printing of defect-free parts

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Recently NiTi based shape memory alloys (SMA) have been widely explored for the fabrication of complex parts through additive manufacturing (AM). Among the AM techniques, laser powder bed fusion (LPBF) is on the top and gaining momentum in reason of recent and remarkable advances. Using pre-alloyed NiTi powder as a feedstock, it was possible to correlate the processing parameters to the formation of defects such as porosity and/or lack of fusion, map transformation temperatures – of uttermost importance for the functional shape memory and superelastic effects –, and print functionally graded structures. Nonetheless, when alloying NiTi, Ti is quite sensitive to impurity pick-up (especially oxygen), which compromises the functional properties. Moreover, Ni and Ti have a different vapour pressure meaning that during the melting the former element is prone to evaporate. The aforementioned drawbacks change the chemical composition of the alloy, leading to undesirable effects that must be mitigated during the atomization process. Once this atomization becomes critical, these facts increase remarkably the powder price thus hindering research on the topic. One alternative relies on the so-called in-situ alloying, where elemental Ni and Ti are pre-mixed and alloyed during the LPBF process. Two main advantages of this method are i) compositional flexibility and ii) lower costs. In the last decade investigations on the in-situ alloying of SMA were conducted, demonstrating the feasibility of this method for printing functional and dense samples, mostly printed in a similar substrate with prior heating. The present work explored a different scenario, printing Ni-rich NiTi in a dissimilar (Ti) and non-heated substrate obtaining dense parts. For attaining adequate results, a literature-based printing parameters range was determined. Defect-less printed parts were submitted to thermophysical tests aiming to determine their transformation temperatures. Subsequently, mechanical assessment demonstrated a superelastic behaviour, attaining outstanding strain recovery after cyclic tests.

Speaker Country:

Austria

Additive Design & Engineering / 12

3DWelding - Additive Fabrication of Structural Steel Elements

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The Collective Research Project 3DWELDING // Additive Fabrication of Structural Steel Elements investigates the possibilities of 3D printing with steel (WAAM - Wire and Arc Additive Manufacturing) in the construction industry. The goal of the project team, which consists of university partners and industrial partners along the value chain, is to develop a fast, economical and stable fabrication process of welded steel parts with material properties commonly used in structural steel construction.
Two fundamental questions are discussed in the paper. The first focus lies on the general geometric

possibilities offered by this process. The influence of various parameters such as wire feed speed, travel speed and torch inclination on the seam shape and build-up rate will be presented. The microstructure of the manufactured components is checked and evaluated. Print strategies are developed for different requirements. Necessary cooling times are used effectively due to an alternating strategy. Temperature management in the components mostly describes the critical path.
Therefore, suitable process parameter sets are defined. These obtained parameters were then used to fabricate different samples.
The second focus is on testing and determining the material strength to be achieved. In the course of the project, different filler metals up to a nominal steel grade of S460 equivalent are tested with regard to their strength, with a particular focus on the joint area between substrate and welded structure. For this purpose, test methods for testing additively fabricated components are being newly developed. In particular, shear tests parallel and transverse to the welding direction require new approaches.
Knowing the geometric and mechanical properties, in order to be able to guarantee safe application of the different materials, a parameter window for each material is defined. It is thus ensured that within this parameter window, while maintaining the specified interlayer temperature, the printed structure always meets the necessary requirements for strength and stiffness.

Speaker Country:

Austria

Additive Design & Engineering / 13

Concepts for bridging voids in Metal Additive Manufacturing for repair of gas turbine blades using Laser Powder Bed Fusion

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One of the main advantages of Additive Manufacturing (AM) processes such as Laser Powder Bed Fusion (L-PBF) is the possibility to manufacture complex near-net-shape components. Therefore, the L-PBF process is becoming increasingly important for the manufacturing and repair of gas turbine blades. Despite the great freedom in design, there are also limitations to the process. Manufacturing overhangs or bridging voids are some of the main challenges, as it is not possible to print into loose powder. In the conventional L-PBF process, overhangs with angles $\alpha_{crit} > 45°$ are supported by support structures, which are subsequently removed. Gas turbine blades feature voids for cooling, which have to be bridged in L-PBF. However, such cooling voids are closed in the upper area by the bottom of the squealer tip. Therefore, no support structures can be used, as subsequent removal is not possible. In this work, different concepts for bridging voids are developed for future application in gas turbine blade repair. For this purpose, a test geometry is derived from the tip area of a gas turbine blade as a reference. By changing the initial geometry of the reference body, different designs for bridging cavities are developed. For the design, the requirements of the L-PBF process are analyzed and considered. Subsequently, these different designs are manufactured by L-PBF. The different approaches are compared with respect to the increase in mass relative to the reference body. In addition, the specimens are visually inspected for warpage, shrinkage and imperfections by overheating. From the seven developed bridging concepts, one concept is selected based on low weight increment, warpage and shrinkage and allows for a 20 mm void to be bridged.

Speaker Country:

Germany

Laser Melting, Electron Beam Melting & Direct Energy Deposition Processes / 14

Microstructural design of self-lubricating metals for forming processes and aerospace applications using laser metal deposition (invited)

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Laser deposition processes such as laser metal deposition or direct energy deposition are additive manufacturing techniques that offer a great flexibility and efficiency compared to traditional subtractive manufacturing processes. However, the extreme thermal conditions during deposition and the rapid cooling times pose great challenges in the alloy design. This work illustrates how to overcome these challenges in order to design nickel, iron and titanium-base self-lubricating alloys. The selected alloys are blended with lubricious compounds for achieving a microstructure containing soft metals inclusions or metal sulfides. The goal is the development of metallic alloys able to provide low friction in metal-to-metal contacts operating in extreme environments such as high temperature or vacuum, without the aid of external lubricants.

The microstructure and phase composition of the deposited self-lubricating alloys are characterized using X-ray diffraction, scanning and transmission electron microscopy, showing the importance of having the soft metal as single phase without forming intermetallic compounds or being in solid solution. Additionally, the role of the metal sulfide composition and stoichiometry formed during the laser deposition process on friction is discussed. Afterwards, the friction and wear performance of the developed alloys are evaluated using high temperature tribological tests in air and vacuum. The results show that the self-lubricating laser deposited alloys are able to control friction from room temperature to 600 ℃ in ambient air and at least until 300 ℃ in vacuum. This overall tribological performance makes the presented self-lubricating alloys potential candidates for high temperature forming and aerospace applications.

Speaker Country:

Austria

Tools, Space and Aircraft, Automotive, Medical and others / 15

Hybrid cast and wire arc additive manufacturing of an aluminium component for the automotive industry

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This work is a feasibility study for the usage of hybrid cast and WAAM manufactured components from a material science perspective. An A356 aluminium alloy in T6 condition was taken as cast

substrate and a, regarding the chemical composition, identical AlSi7Mg wire was used to add structures. The welding was accomplished using a Fronius TPSi400 operating in CMT mode. Fundamental trends for the formation of the microstructure at changing welding parameters for the WAAM deposited material could be found. Two WAAM building strategies with different welding parameter sets were compared regarding their mechanical and microstructural properties. Additionally to microsection examination, tensile and fatigue strength testing was conducted. The better suitable set was used for the production of a hybrid cast and WAAM structure. The joint was found to show no lack of fusion or binding errors, but showed clustered pores. The mechanical properties of the hybrid structure was inferior to the solely additive and cast materials. Fracture analysis including SEM microscopy revealed the heat affected zone in the cast as the weakest part of the hybrid structure, with a significant drop in tensile and fatigue strength. Usage for commercial purposes is believed to be not possible at this stage, however utilisation in the components development process may already have advantages.

Speaker Country:

Austria

Tools, Space and Aircraft, Automotive, Medical and others / 16

Additive Manufacturing challenges in Fine Blanking at Faurecia Seating

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Abstract: Additive Manufacturing challenges in Fine Blanking in Faurecia Seating

Lead time and cost reductions are key objectives in the Automotive Industry ,and it is particularly important for tooling spare parts .Reducing inventories gives a balance between stocks versus avoid mis-deliveries to final customers; reduce volume of stored spares can occur a positive financial ratio towards product cost break-down to keep competitiveness. For the last decades, the trend was to increase technical feasibility with additive manufacturing in various fields of mechanical industry (i.e. plastic molding devices, aerospace machined components, measurement jigs, ends devices for robotic, ….) thanks to low carbon or specific alloys. A new trend initiated in the last 3 years for development of alloyed powder and specific new development of machines allows to manufacture parts with high carbon and heavy alloy contents, in order to achieve higher mechanical properties as 62HRc. This opened the field of stamping tool application. Faurecia Automotive Seat Structure and Systems start to develop solution for Fine blanking applications, jointly with Tooling steel manufacturers, to stay at least competitive in tooling cost-wise, and, also develop new way of concept for tool spare design. From science to reality, deep experimental and fundamental investigations are led in Faurecia Advance Manufacturing team. Recent industrial demonstrators reach the industrial target score in term of lifetime. Scientific and industrial results are reviewed in this presentation, which is illustrated by metallurgical lab reports, manufacturing analysis, effective application is mass production and innovative realization in fine blanking field.

Speaker Country:

France

Powder for MAMC / 17

Comparison of Novel Powder Spredability Test and Established Flowability Metrics

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In recent years, there has been much activity to develop a test to measure the quality of thin layers produced from metal powders, otherwise known as the property of spreadability. Several strategies have been published but no single test has yet been adopted by the powder metallurgy community. This study presents the development and testing of one such measurement technique that is simple, fast and inexpensive. It incorporates both a mass-based measurement and image analysis for density of the layer and to identify defects within the layer. Furthermore, the measurement technique has been benchmarked for over twenty powders and compared to several tests for flowability, namely Hall and Carney flowmeter tests, static angle of repose, Hausner ratio and powder rheometry. The new measurement technique was shown to be repeatable and reproducible. It is able to identify defects using image analysis and automatically measure layer area. Multilinear regression analyses with all experimental techniques indicate that layer density measured using the new technique is correlated to a combination of flow rate index, specific flowability energy and Hausner ratio. However, these metrics must be used in combination and it is not possible to use any one of them to predict layer density. Other flowability metrics showed no correlation to spreadability. These results can be used to inform experimental design of powder testing to ensure adequate spreading behaviour in additive manufacturing and can also be used to aid development of a spreadability test.

Speaker Country:

Sweden

Additive Design & Engineering / 18

AM of the Fe-Cr-Co alloy system: Using the in- situ alloying process to manufacture magnetic parts with a defined chemical gradient

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In recent years, additive manufacturing has become increasingly relevant for producing magnetic materials due to higher demands for miniaturisation and complex-shaped magnet parts. With laser powder bed fusion (LPBF), magnet parts of the Fe-Cr-Co system can be produced with notable shape accuracy. The chemical composition can be modified directly in the printing chamber with the in-situ alloying technique. With this novel method, complex alloys can be produced with a chemical composition accustomed to each specific case of application. The next logical step in this direction is the development of a functionally graded structure with in- situ alloying which is the aim of this study.

The approach for the development of this novel process has been specifically designed for the ORLAS Creator, the 3D printer used. Three alloys of the Fe-Cr-Co system have been chosen as base materials which have been provided as stocks of elemental powder mixtures. To each of these stock materials, four different alloying elements (Ti, Al, Nd and Mo) have been added with the aim to create a defined

chemical gradient in discrete steps. To validate the accuracy of the process, the resolution of chemical segregation between and at the interfaces of regions of different concentrations of alloying elements has been determined by SEM- EDS investigations. Additionally, different printing parameters known to produce sound parts of the material have been chosen to be printed simultaneously to investigate their influence on the accuracy at the interfaces between the regions.

Speaker Country:

Austria

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

Study on processing of large scale magnesium alloy AZ91 component manufactured by Plasma Metal Deposition (PMD®) for space applications

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In space applications, low density materials are required to reduce the vehicle weight and therefore increase the payload. For this reason, magnesium alloys are of interest, their low density would be beneficial to substitute aluminium in many aerospace structure applications, depending on the exact stiffness and load-bearing requirements. However, magnesium alloys are more challenging to process than aluminium.
Plasma Metal Deposition (PMD) is an advanced emerging additive manufacturing technique that belongs to the Direct Energy Deposition group, using a plasma as energy source for melting materials in powder or wire shape with high deposition rates. The application of PMD manufactured Mg-alloys components in space hardware is beneficial as allows implementing integral designs, complex and large structures.
In this study, the processing of experimental AZ91 wires into a near net shape component using the additive manufactured technique PMD is developed with the aim of producing a large scale complex technological demonstrator. This demonstrator will then be tested to assess its compliance with the requirements of the intended application.
Thin-wall structures are fabricated, tensile test samples and test coupons are extracted to evaluate mechanical properties, microstructure and phase formation of the as deposited and heat-treated material. Furthermore, to be qualified for space applications the corrosion behaviour of the processed AZ91 material is studied.

Speaker Country:

Spain

Laser Melting, Electron Beam Melting & Direct Energy Deposition Processes / 21

Effects of layer thickness and laser energy input on the solution annealing behavior of a laser powder bed fusion processed 316L stainless steel

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316L austenitic stainless steel is a commonly used alloy in a wide range of applications, including energy, petroleum, automotive, and medical industry. 316L has been a choice for combustion section components in steam and gas turbine engines. Owing to its low carbon content and extremely ductile austenitic matrix, 316L is one of the most commercially exploited steels for the laser powder bed fusion (L-PBF) process. Recently, the use of higher layer thicknesses aimed at increasing the productivity of the L-PBF process has been suggested and evaluated on an industrial scale. The as-built microstructure in 316L comprises a cellular/dendritic solidification structure with micro-segregation of alloying elements to the cell boundaries as a result of far from equilibrium, fast solidification. Therefore, in some applications a full homogenization of the microstructure by high temperature solution annealing treatments might be necessary. In the current work, the solution annealing response of L-PBF 316L, in particular, the effect of the layer thickness and energy input on the recovery, recrystallization and grain growth is studied. Scanning Electron Microscope (SEM) and Electron Back Scattered Diffraction (EBSD) results showed that higher normalized energy input during the L-PBF process increases the kinetics of the recrystallization during solution annealing. This is due to the increased number density of energetically preferential nucleation sites for the recrystallization process (i.e., high dislocation density, and low angle grain boundaries). As a result, at high energy inputs a lower annealing temperature was needed for the microstructural homogenization and formation of an equiaxed grain morphology

Speaker Country:

Sweden

Laser Melting, Electron Beam Melting & Direct Energy Deposition Processes / 22

Surface refinement of additively manufactured components: microstructure and mechanical properties

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Abstract
Selective Laser Melting (SLM) has already been used to manufacture of complex parts with high precision. However, the high cost for surface preparation is still a limiting factor for widespread of SLM parts in different industry branches. The high surface roughness and their resulting residual porosity influence the mechanical properties, especially dynamic ones. In this presentation, pack cementation process will be introduced as a novel method to refine the surface roughness and the microstructure in surface zone as well as to improve the mechanical behaviour of SLM parts.
The effect of pack cementation process of the resulted microstructure in the surface zone of SLM specimens was investigated. The as-built and as-modified SLM specimens were compared and the

surface roughness and surface porosity were measured. For this purpose, two different alloys: Ni- and Fe-Basis alloys were examined. Finally, the creep strength at different temperatures as well as the fatigue behaviour for both as-built and as-modified specimens will be presented.

Speaker Country:

Germany

Laser Melting, Electron Beam Melting & Direct Energy Deposition Processes / **23**

Investigations of Plasma Metal Deposition (PMD) of 6061 and 7075 aluminum alloys for aerospace and automotive applications

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Plasma Metal Deposition is an advanced manufacturing technique suitable for printing medium-to-large sized complex parts at high deposition rates while reducing material wastage and lead time. Aluminium alloys are one of the most commonly used metallic materials in manufacturing parts for aerospace and automotive applications due to their lightweight, excellent strength, and corrosion resistance properties. Aluminium alloys have been employed in the WAAM process to produce parts for the aerospace and automotive industries. Challenges during the manufacturing process of aluminum alloys, such as porosity or poor mechanical properties, can be overcome by using arc technologies with adaptable energy input. In this paper, the recent progress on additive manufacturing of 6061 and 7075 aluminum alloys by Plasma Metal Deposition (PMD) is investigated. Standard and modified feedstock compositions of the 6061 and 7075 alloys are being examined to assess the suitability of the Plasma metal Deposition process. The objectives are the evaluation of the weldability, metallurgical characteristics, mechanical properties, and hardness of the manufactured parts. Based on the presented results, the outlook aims at future industrial applications.

Speaker Country:

Austria

Powder for MAMC / **24**

Production routes for spezialized powders

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Advances in Additive Manufacturing by powder bed fusion technologies based on EBM (Electron Beam Melting) or SLM (Selective Laser Melting) as well as other powder based additive routes such as

LMD (Laser Metal Deposition) have led to an increase of demand on spherical powders [1]. However, most applications are realized through a handful of commercially available powders. Customized alloys and new materials are needed to enlarge the field of possible applications and enhance the performance of additive manufactured parts. This presentation introduces production routes for customized Titanium-alloy powders, high-temperature alloy powders as well as refractory metal based High Entropy Powders, which represent a new class of materials for additive manufacturing, commercially unavailable until now.
For titanium alloys, the alloying elements are compacted into consumable electrodes, which are molten into an ingot via Vacuum Arc Melting (VAR) or Electron Beam Melting (EBM), depending on the alloying elements. To obtain homogeneous feedstock for the Electrode Induction Melting Inert Gas Atomization (EIGA), the ingot is remolten in an Induction Skull Melter (ISM) and gravity cast into a steel mould. This high purity feedstock is then atomized and classified under Argon atmosphere.
Through the adjustment of process parameters, the particle size distribution (PSD) can be shifted from very fine to coarse, resulting in tailored PSD for different additive manufacturing processes. [2]
A novel processing route invented by GfE allows the production of feedstock for the EIGA of alloys with very high melting points. This includes brittle, high temperature intermetallics, such as MoSiB and VSiB as well as refractory based High Entropy Alloys which cannot be processed by conventional meltmetallurgical technologies to stable EIGA electrodes. The availability of such powders represents a breakthrough, allowing results from fundamental research to be transferred into products and widening the application field of additive manufacturing.
The extension of additive manufacturing into the refractory based HEA opens the possibility to build high strength parts. The high intrinsic strength of refractory based HEA compensates the impossibility to forge additively manufactured parts to enhance the microstructure. [3]

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Speaker Country:

Austria/Germany

Laser Melting, Electron Beam Melting & Direct Energy Deposition Processes / 25

Novel process approach for additive manufacturing using inductive wire melting by forced droplet detachment

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Additive manufacturing (AM) has developed very dynamically in recent years and is becoming increasingly popular. For AM in metal, laser powder bed fusion (LPBF) is the most commonly used process and has been successfully applied in many industrial applications. It allows the fabrication of complex structures, but is time consuming, expensive and limited in build volume. To date, no AM technology for large-volume metallic components has been established on an industrial scale like

LPBF. This paper presents a new process approach to fabricate larger metallic structures from steel by inductive melting of a continuously fed wire. The presented method is characterized by the comparatively low energy input in contrast to comparable processes for AM, such as arc, laser or electron beam. Previously published work is based on the principle of a melt reservoir of low-melting alloys and droplet delivery using gas pressure or vibration. In contrast, the approach described here is to transfer the material directly from the end of the wire to the substrate by continuous drop deposition. However, to avoid a stochastic material transition, a suitable process strategy has to be chosen. This challenge is met by a pulsed coil current and the resulting periodically varying Lorentz forces in order to achieve regular and forced droplet detachment. Using the FEA software COMSOL Multiphysics, different coil geometries were investigated in order to determine the Lorentz forces and the temperature distribution in the moving wire. For the experiments, a suitable coil was manufactured and connected to a high frequency induction power supply. The generator power was controlled with a sinusoidal oscillation of 4 Hz. Tests confirm the principle of controlled droplet detachment and reveal the great potential of this technological approach.

Speaker Country:

Germany

Tools, Space and Aircraft, Automotive, Medical and others / 26

Innovative solutions for High Pressure Die Casting Tooling Applications via Laser Powder Bed Fusion processing and performance evaluation of X35CrMoV5-2 Tool Steel

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One of the main challenges for metal Laser Powder Bed Fusion process to achieve widespread industrialization is the lacking of confidence and maturity level in terms of process robustness, standard procedures and expected performance. All the aforementioned conditions coupled with low productivity rates and limited amount of alloys that can live up to those expectation, limit the growth in many occasions.

For tooling applications such as High Pressure Die Casting, traditional solutions based on martensitic carbon based tool steels have been reported to be most challenging when implemented via L-PBF. Therefore, users tend to rely on alternatives such as maraging steel concepts with an overall moderate success. In the current study a novel tool steel, X35CrMoV5-2, was developed and evaluated. High productivity rates up to 20 cm3/hr are reported, scaled up to actual designs for HPDC applications. Moreover, critical performance indicators for these applications such as toughness, high temperature strength and soldering resistance we evaluated. The results indicate a performance superior even to current conventionally manufactured solutions.

Speaker Country:

Sweden

Plenary Talk / 27

’What’s ahead for remelted Tool steels and update on PM & AM Tool steels’

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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

Powder for MAMC / 28

Mechanical behavior of additive manufactured Nb-Ti and Ti-Nb-Zr alloys using plasma atomized and HDH powders

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Mechanical behavior of additive manufactured Nb-Ti and Ti-Nb-Zr alloys using plasma atomized and HDH powders
Mário Boccalini Jr., Railson B. Falcão, Marcelo F. Moreira, Fernando J. G. Landgraf, Moysés L. de Lima

Monotonic mechanical properties of beta Nb-48%Ti and martensitic Ti-13%Nb-13%Zr alloys processed through Laser Powder Bed Fusion (LPBF) with two different types of powder, spherical plasma atomized powder (PA) and irregular shaped powder produced by Hydrogenation-milling-dehydrogenation process (HDH), are compared.
Twenty cylinders with 12 mm diameter and 92 mm length were produced through LPBF in a SLM-Cusing M2 machine (5 for each alloy/powder set), under argon atmosphere with oxygen content controlled to be less than 0.1%. Laser power and scanning speed were selected based on achievement of porosity below 0.5%: both powders of Nb-48%Ti alloy were cast using 300W and 1100mm/s, while powders of Ti-13%Nb-13%Zr alloy were cast using 200W and 1000mm/s for PA powder and 200W and 1000mm/s for HDH powder. All samples were produced with the same scanning strategy, that is, 4 mm islands in a chess pattern with 90 degrees rotation of the tracks in each layer with Z direction perpendicular to the longitudinal axis of the cylinders. The four operation platforms were heat treated for stress relief at 650^{0}C for two hours before removing the cylinders through wire electro discharge machining.
All cylinders were post-processed with turning to obtain specimens for tensile tests performed with universal machine.
For both alloys, specimens cast with HDH powder presented higher strength and lower ductility than the specimens cast with PA powder. This is attributed to the solid solution hardening promoted by the higher oxygen content of the HDH powder.
Fracture analysis was performed in order to correlate mechanical properties with fractographic and microstructure features of the alloy/powder sets.

Speaker Country:

Brazil

Powder for MAMC / 29

Copper Alloys for Additive Manufacturing Processes

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Nowadays, Copper alloys are widely used in additive manufacturing applications. Generally spoken, a higher thermal and electrical conductivity goes hand in and with a lower yield strength. Hence, a lot of efforts are being undertaken to improve mechanical properties of copper alloys, e.g. by improving dispersion strengthening or aging mechanisms, by chosing the right heat treatment and of course also by adding more and more expensive alloying elements such as silver, chromium and niobium. In this presentation, an overview is given over experiences and trends in laser powder bed fusion of copper alloys targetting high electrical and thermal conductivity as well as high strength alloys e.g. for mould inserts.

Speaker Country:

Austria

Laser Melting, Electron Beam Melting & Direct Energy Deposition Processes / 30

Rapid material multi-parameter optimization for small scale series productions in PBF-LB/M

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In this talk, two case examples of multi-parameter optimization is described, where parameter sets for multiple features such as surface roughness, downface integrity, mechanical performance or bulk density are optimized simultaneously using compact design of experiment. In the first case, a component with specific requirements on weldability, corrosion resistance and mechanical resistance led to a need for rapid powder manufacturing and printing parameter optimization in stainless steel 310, not typically available on the PBF-LB-market. In another example, the industry needs for simultaneously cheaper components and a more environmentally friendly component resulted in an EUREKA research project, VARETIT, on recycling TiAl6V4 components using grinding as opposed to classical gas atomization. The morphology of this powder is terrible, but it is shown how such a powder feedstock can, using compact design of experiment studies, lead to cost effective components fulfilling component requirements while minimizing the CO2 footprint.

Speaker Country:

Danmark

Additive Design & Engineering / 31

Optimization of a Casted Part in 3D Sand Printing in Comparison to other AM Technologies

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Additive Manufacturing (AM) has an increasing impact on modern fabrication processes. Especially in terms of tools, gauges and other consumables like grippers and fixtures, AM proofs to decrease costs and speeds up development processes. In addition to metal AM processes 3D-sand-printing (3DSP) may fill the gap towards larger parts with several tons of weight for example tooling frames for presses. With the need of a reduction of the CO2 footprint of products and processes 3DSP allows to design more complex castings by using bionic principles. With this in mind lightweight designs for tools and big parts for mobility applications are accessible. For example it is a cost effective way to build big parts for trains and other heavy vehicles.
The benefit of new design opportunities can be shown in two case studies. A cargo hinge for railroad applications optimized with respect to bionic principles was manufactured with a reduction of 20% in weight in comparison to the conventional part. Furthermore a hybrid press frame manufactured by using WAAM and 3SPD technologies shows the potential of lightweight design to reduce energy consumption during press operations.
voestalpine Foundry Group, the Metal Forming Division and voestalpine Böhler Welding Group are joining forces to think new ways of developing tools and big parts. Especially 3DSP combined with wire+arc Additive Manufacturing (WAAM) is one of the options to reach such goals.

Speaker Country:

Austria

Laser Melting, Electron Beam Melting & Direct Energy Deposition Processes / 32

Adaptive Process Control for Laser Powder Bed Fusion

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Additive manufacturing by means of LPBF offers a wide range of possibilities across industries, especially with regard to the variety of geometric shapes of the components that can be produced. In conventional LPBF, however, the process parameters are still largely determined independently of the component geometry. This leads to deficiencies due to local overheating and a corresponding change in the process conditions, especially in filigree component areas, which ultimately lead to limitations in process robustness and component quality. At Fraunhofer ILT, an adaptive LPBF

process control is being developed in which the process parameters, in particular the laser power, are dynamically adapted to the component geometry to be manufactured. By analyzing the energy input given by the vector paths, potentially critical component regions are identified during data preparation and a local adaptation of the process parameters is carried out there. On a technical level, the laser power can be adjusted precisely in the sub-milimeter range.

In this presentation, the shortcomings of conventional process control are first presented and, based on this, the theoretical model for identifying critical component regions is derived. On this basis, measures for adjusting the laser power in the critical component regions are then investigated. The focus is on ensuring melt pool dimensions that are as constant as possible. In particular, high-speed videography of the melt pool will be used in the presentation to illustrate melt pool dynamics, both with conventional and adaptive process control. In addition, the challenges with regard to the adaptation of the machine control technology for the implementation of adaptive process control and the necessary steps for the transfer of the approaches to commercial LPBF systems will be discussed.

Speaker Country:

Germany

Additive Design & Engineering / 33

Mechanical behavior and anisotropy of material properties of additively manufactured lattice structures

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Additive Manufacturing (AM) provides new constructive possibilities for design engineers. Many structures with features like cavities or thin beams are difficult to manufacture using conventional methods such as casting or machining while AM can ease this difficulty. However, the design of the mechanical properties of individual lattice structures is still an obstacle for their commercial application. The challenge here is that no adequate and comprehensively validated models exist for predicting the anisotropic mechanical properties of lattice structures. Current approaches, in which an estimation of the mechanical properties is made via the relative density of the lattice structure (e.g., Gibbson-Ashby model) have limited accuracy and cannot reproduce the anisotropic and asymmetric behavior of lattice structures
The present study addresses the identified deficiency by providing experimental data on the compressive and tensile behavior of LPBF manufactured lattice structures with various parameters. Analysis of the data provided allows the derivation of a strategy for describing the asymmetric mechanical properties of lattice structures. This provides designers with a new resource to inform future design applications of LPBF lattice structures and facilitates their further commercial adoption.

Speaker Country:

Germany

AM-Process- and Quality Control & Post Processing of AM Parts / 34

Influence of post-processing on corrosion resistance of additively manufactured stainless steel

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Many industries desire to replace conventionally manufactured stainless steel (SS) with additively manufactured (AM) SS due to multiple advantages connected to AM. However, questions about the influence of the unique AM microstructures on corrosion resistance and the applicability of standard corrosion tests remain largely unanswered. Furthermore, the influence of post-processing steps on local corrosion resistance and Stress Corrosion Cracking (SCC) of AM SS is only partially explored. In order to safely implement AM SS in corrosive environments, more research is necessary.

This work investigates corrosion properties of two SS alloy systems, austenitic 316L and super-duplex stainless steel (SDSS) 2507, additively manufactured via Powder Bed Fusion – Laser Beam (PBF-LB). The corrosion properties of these alloy systems are correlated to the effect of microstructure, sampling methodology and post-processing operations by either conventional heat treatment or hot isostatic pressing (HIP). Additionally, the effect of post-processing by HIP and shot peening on the SCC properties of PBF-LB 316L SS is explored.

For both materials, microstructure, crystallographic texture, and porosity were characterized by light optical microscopy and scanning electron microscopy with electron backscatter diffraction. Corrosion resistance was assessed by standard tests ASTM G150, ASTM G48 and ASTM G61. Additionally, immersion tests in relevant service media were conducted and microstructure evaluation by Scanning Kelvin Probe force microscopy was performed. For PBF-LB 316L SS, SCC-testing was performed by 4-point bend and slow strain rate tests and correlated with residual stress measurements using X-ray and neutron diffraction.

The results show that the corrosion properties of PBF-LB SS austenitic 316L and SDSS 2507 meet or even exceed that of conventionally manufactured materials. However, a correctly performed heat treatment is crucial to obtain adequate corrosion resistance. Moreover, SCC test results and residual stress data are linked to microstructure and SCC resistance of PBF-LB 316L SS in relation to conventional 316L SS material.

Speaker Country:

Sweden

Laser Melting, Electron Beam Melting & Direct Energy Deposition Processes / 35

Influence of laser power and scanning speed on the formation of hot cracks during the processing of high-speed steel HS2.2.2 by laser powder bed fusion

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The manufacturing of high-speed steel (HSS) components using the laser powder bed fusion (LPBF) process could create an unprecedented combination of the materials' mechanical properties and the design freedom enabled by the process to unlock new applications, such as milling heads with functionally optimized cooling channels. However, the processing of HSS with the LPBF process shows high susceptibility to cracking. This study aims to reduce hot cracking for the processing of HS2.2.2 by investigating the influences of preheating temperature, laser power, and scanning speed on the formation of hot cracks. The density, hardness, and melt pool geometry of the produced parts are measured to further examine the relationship between the processing conditions and the resulting properties. The influence of various process parameters on the formation of hot cracks can be demonstrated. Further investigation shows a relation between hot cracking and the melt pool geometry. With a narrow and shallow melt pool, influenced by laser power and scanning speed, the number of hot cracks can be reduced.

Speaker Country:

Germany

Systems & Equipments for MAM / 36

Functional prototype for the validation of the innovative metal additive manufacturing SLEDM process

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Metal additive manufacturing is becoming increasingly important for industrial manufacturing. This is ensured by both the further development of existing processes and the development of new manufacturing technologies. This paper covers the practical implementation of a prototype for the validation of the SLEDM process patented by TU Graz. The setup includes a concept for non-contact powder application for the melting process as well as the concept of energy input via a LED-based light source. The prototype enables simple and fast melting tests with different low-melting powder materials such as tin, zinc and aluminum in an inert gas atmosphere. In addition, the experimental setup forms the basis for the development and adaptation of a suitable light source for the SLEDM process. The evaluation of the recorded measurement data and the analysis of the test results provide important insights into the feasibility of the SLEDM process for industrial manufacturing.

Speaker Country:

Austria

Laser Melting, Electron Beam Melting & Direct Energy Deposition Processes / 37

Electron Beam Based Additive Manufacturing of Highly Alloyed Tool Steels and Tungsten Carbide Metal Matrix Composites: - From Research to Industrialization -

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Electron Beam Melting (EBM) is nowadays well established as an additive manufacturing (AM) technology within Aerospace and Medical industry to produce components out of high-performance materials such as Titanium, Titanium Aluminides, Ni-based Superalloys and even pure Copper.

In comparison to other AM technologies, the hot EBM process leads in general to a low level of remaining residual stresses and prevent parts from warpage.
The ability to use the electron beam for heating and melting is at the same time the enabler for processing non-weldable alloys. Furthermore, fast beam deflection and a controlled vacuum environment offers perfect conditions for an efficient AM processing of high-performance materials for application in extreme environments such as for tooling of metals.

GE Additive is continuously working on expanding the EBM material portfolio to serve o meet customer needs now, and in the future. In this context, material development is often performed in close collaboration together with material suppliers and research centers at universities.

Two recent examples for such material developments for EBM are:

• Highly alloyed cold work and HSS tool steel grades showing a carbon content C >1,0 wt.% for cutting and forming application.

• WC-Ni MMC for ultra-high wear resistance application within Oil and Gas industries.

AM processing of these materials are challenging, as high process temperatures and tight process control due to the crack-susceptibility are required. It is difficult to process using other powder bed AM technologies like L-PBF.

In this contribution we show how EBM enables a successful crack- and defect-free processing of these materials. The inherent high cooling rates during EBM processing led to very fine and homogenous microstructures which are comparable or even better to conventional processed ones.
Thus, corresponding mechanical and microstructural properties in different conditions will be presented and discussed to show EBM material capabilities.

Speaker Country:

Sweden

Tools, Space and Aircraft, Automotive, Medical and others / 38

Variant flexible Hairpin Stator (E-Motor) Production through Parametric Modeling and Additive Tooling

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In Additive Manufacturing (AM), the method of Parametric Modeling (PM) is often used for the design development and creation of products. However, this approach is not yet widely used for the

development of tools for production machines and processes. In the production of hairpin stators (an innovative technology for the copper winding of the static component of an electric motor for electric vehicles) in the field of e-mobility, the demands for variant-flexible production lines are increasing more and more in order to react to the short development cycles of electric motors in a more cost-efficient way.
Therefore, the goal is to achieve this variant flexibility in the production of hairpin stators through Parametric Modeling and Additive Tooling of production tools depending on product characteristics. For this purpose, parametric models of developed tools are generated by implementing design algorithms in parametric design software. By varying the input parameters, which are the properties of the product to be produced (stator of an e-motor), the required variant flexibility is validated. The work is exemplified for one production step of hairpin stator production on a clamping tool for welding hairpins (copper conductors).
The results are discussed and the potential of achieving variant flexible production lines by Parametric Modeling and Additive Tooling is evaluated.

Speaker Country:

Germany

Tools, Space and Aircraft, Automotive, Medical and others / 39

Enhanced cooling by conformal cooling of additively manufactured wire drawing tools made of cemented carbides

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Components made from wire can be found in almost all complex products. In the wire drawing process, hot rolled wire is drawn through a single or a series of tools, which reduces the cross-section of the wire and enhances the mechanical properties of the material. The tribological conditions in the process are extreme and the high frictional forces between the wire and the die results in high tool temperatures. Previous studies have shown that by reducing the temperature of the drawing tool it is possible to decrease the tool wear rate. Hence, cooling of the tool is of high importance in the wire drawing process.
In this study, the possibilities to decrease the tool temperature by introducing conformal cooling in the drawing tool was investigated. Drawing tools made of cemented carbide were designed to utilize conformal cooling and manufactured by additive manufacturing. Results on cooling efficiency and performance in an industrial-like wire drawing process are presented and discussed.

Speaker Country:

Spain

Systems & Equipments for MAM / 40

New calculation software for analytic support structure optimization in metal additive manufacturing

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Powder based additive manufacturing systems often require support structures for overhanging geometries and thermal dissipation. On the one hand the support material should be reduced to a minimum, on the other hand the stiffness of the structures can be used as a fixture for direct machining. The contribution presents a unique analytic model to determine the stresses occurring in the support structures during post-processing. FEM simulations with different support types are carried out to validate the new calculation model. The results of this analysis subsequently serve as basis for dimensioning the support elements of complex and large parts. By specifying a machining process, it is possible to determine the required dimensions of the support structure (e.g. block, rod, cross). The aim of this optimization process is to reduce machining time, material consumption and post-processing costs. The results of the paper and the new software help to implement direct machining into industrial 3D printing processes.

Speaker Country:

Austria

Laser Melting, Electron Beam Melting & Direct Energy Deposition Processes / 41

Effect of minor alloying additions on the stress-rupture properties of a modified Hastelloy X fabricated by additive manufacturing

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In this work, the influence of the as-built microstructure of a Hastelloy X with modified chemistry, processed by power bed fusion-laser beam (PBF-LB), on the stress-rupture properties (816℃, 103 MPa) is studied. Further, the significant effect and underlying mechanisms of the minor and ppm alloying additions on the improvement of the high temperature creep strength of the material is discussed. HX with tailored chemistry, shows significantly low solidification cracking susceptibility during the PBF-LB, while minor alloying additions improve the time to rupture significantly (i.e., by up to 2.5 times).

Speaker Country:

Sweden

AM-Process- and Quality Control & Post Processing of AM Parts / 42

Application of Machine Learning for Process Control in AM - A case study for L-PBF

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The market for laser-powderbed fusion(L-PBF) machines is growing fast and will change the future of manufacturing. Industries such as aerospace, automotive and life sciences are early adopters. However, the widespread uptake falls short of forecasted expectations, due to the lack of stability hindering the printing process, which, to date, is an unsolved key challenge.

Produced metal parts exhibit undesired levels of residual stress and porosities leading to poor mechanical properties and, in extreme cases, premature failure of the part itself. Mitigating these effects requires manual tuning of the process parameters which is error-prone, time consuming and requires a high level of expertise. Currently, there are no solutions on the market allowing such a level of automation.

Machine learning (ML) has led to great success, despite the many setbacks and AI winters in the past, in the control of complex dynamical system. DeepMind recently demonstrated a ML-based process control for nuclear fusion, researchers of the ETH Zurich implemented a learning based controller for quadrupedal robot navigation and highly flexible maneuvering has been achieved for drones. To date, the successful application of ML in other fields hasn't yet translated into advancements in process control for additive manufacturing, however there are promising initial attempts into this direction.

Hence, the main objective of this work is to discuss the application of ML for in-situ, real-time process control to identify optimal process parameters enabling a stable print process which produces parts at a lower cost and with a minimal lead time while safeguarding environmental concerns. More specifically, we are going to discuss:

i.) a learning-based hierarchical control architecture for optimizing scan time, residual stress and porosities based on reinforcement learning.

ii.) a simulation-based training procedure for the various parameters of the control architecture based on a fluidic, thermo-mechanical print process simulation. Furthermore, we'll discuss how to overcome the discrepancies between simulated and real-world data through robust policies.

iii.) a hardware stack to integrate the controller into the L-PBF machine.

Methods proposed in objectives (i) – (iii) are inspired by state-of-the-art research in the fields of robotics, autonomous driving, and life sciences, where they have been thoroughly validated. Moreover, corporate research on process control is experiencing considerable growth suggesting strong demand from customers for relevant solutions.

Speaker Country:

Germany

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

Printing and repair of AA7xxx components with a novel Al composition using Laser Metal Deposition

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By volume, most of the aluminum alloys used in additive manufacturing are either Al-Si based compositions or Airbus's Scalmalloy. However, Al-Si alloys perform poorly and Scalmalloy is expensive due to the use of Sc. Other high strength aluminum alloys families, such as those of the 7xxx series, have been barely used due to their tendency to hot crack while printing. In this framework, a high strength composition belonging to the 7xxx has been developed to be compatible with the additive manufacturing process.

Dense coupons with this novel composition have been printed using Laser Metal Deposition (LMD). The coupons have been used to tune the heat treatment and evaluate the tensile properties, subsequently. A chemical characterization has been also performed to assess the composition evolution during printing and link the strength with the composition. The results are compared to the cast counterparts.

In addition, repair experiments have been performed on 7xxx substrates simulating the presence of defects or manufacturing errors. To do so, the surface is first prepared before printing and later refurbished with the new composition using LMD. The interactions between the component and the repair, such as the deformation, mechanical properties, microstructures, and sizes of the heat affected zones, are measured depending on the energy density of the tested parameters. The impact of the heat treatment to obtain a trade-off between the properties of the repair and the component is also discussed.

Speaker Country:

Belgium

Powder for MAMC / 45

Mechanical Properties of a Zirconium and Tungsten Carbide modified Al-Mg-Sc-Zr alloy (AA5024) processed by Laser Powder Bed Fusion (L-PBF)

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Keywords: Additive Manufacturing, Laser Powder Bed Fusion, AA5024, Zirconium, Tungsten Carbide, Alloy Modification, Aviation

Aluminium alloys have a wide range of applications, specifically in the areas of aviation and aerospace. However, conventional manufacturing processes often limit the complexity of the fabricated parts. With the use of additive manufacturing techniques, near net-shape parts with a great structural complexity can be produced. When it comes to manufacturing aluminium alloys with laser powder bed fusion (L-PBF), many issues can appear. These are mainly due to the intrinsic material properties of aluminium – e.g. a high laser reflectance, a low laser absorption and a high thermal conductivity – which make these alloys difficult to process. Moreover, some aluminium alloys, such as from the 2XXX series, are prone to hot cracking due to their wide solidification interval, leading to formation of different eutectic phases. Therefore, the addition of nanoparticles to pre-alloyed powders is currently of great interest in the research on AM of aluminium based alloys in order to enhance both material's printability and mechanical properties. This study focusses on the modification of an Al-Mg-Sc-Zr alloy (AA5024). The effects of using in-situ alloying to add different particles, i.e. Zirconium Hydride (ZrH_2) and Tungsten Carbide (TC) in different amounts, as well as the effects of different heat treatments on the mechanical properties are discussed. For this purpose, density, hardness and tensile strength were measured on samples in both conditions: as printed and heat treated. Microstructural analysis was performed with light microscopy and SEM-EBSD in order to analyse the effects of the addition of different amounts of nanopowders by in-situ alloying.

Speaker Country:

Austria

Powder for MAMC / 46

Application of the 3D-EHLA process for agile alloy development

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The development of new high-performance alloys is a key factor for innovation and technological advances. However, the conventional development route by means of casting is not designed to facilitate a high-throughput alloy development, since in general only one alloy composition can be made per cast and process inherent challenges like macrosegregations occur when dealing with highly alloyed materials. The newly developed 3D Extreme High Speed Laser Material Deposition (EHLA) process shows promising features for an accelerated alloy development for metal powder-based AM processes. In this work, the applicability of the 3D-EHLA process in the context of rapid alloy development is investigated. In the first step, the parameters (e.g. scanning speed, laser power, powder mass flow) and tools (powder-gas jet, laser radiation) of the 3D-EHLA process and their effect on alloy development processes are evaluated. Subsequently, an integrated methodology is introduced, through which an efficient workflow along the whole process chain of alloy manufacturing and sample evaluation is obtained. Finally, the influence of laser power, scanning speed and powder mass flow on the evolution of the microstructure is be investigated (alloy: 316L). The most pronounced influence of these parameters is found for the scanning speed which displays a negative correlation to the cell size. A positive correlation is found between laser powder/powder mass flow and the cell size.

Speaker Country:

Germany

Plenary Talk / 47

Powder for Metal Additive Manufacturing: Properties and degradation

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Metal powder is the most common feedstock for metal additive manufacturing (AM), including powder bed fusion (laser beam PBF-LB, and electron beam - PBF-EB), binder jetting (BJT) and powder blown directed energy deposition (DED). However, even if the same alloys systems are used for these technologies, they have different requirements to the powder feedstock when it comes to its physical properties and chemistry and utilize different size fractions of the metal powder. On the other hand, metal powder properties are determined by the powder manufacturing methods, where variety of properties can be obtained for the same alloy system, determining their behavior and suitability for AM processing by different AM technologies. During AM process, metal powder is further exposed

to the processing conditions that also differ significantly between different AM technologies. This will result in changes in powder properties during manufacturing cycle, its further handling and hence its impact on the final component properties differ significantly.
Powder behavior is strongly affected by its surface chemistry due to the high large surface area of the powder, that is about 10 000 times larger than the surface area of the bulk material of the same mass. This leads to high surface reactivity, that in combination with the alloy composition will determine powder sensitivity to the powder manufacturing method, handling and AM processing. Initial chemical composition of the powder is determined by the powder manufacturing method. This state, however, is not stable, and progressively changes with time in dependance on powder handling and processing by metal additive manufacturing. Such changes in powder surface chemistry during powder reuse have a strong impact on powder quality and processability by specific AM technologies and hence final component properties. This talk summarizes recent experimental observations and thermodynamic simulations of the changes in powder surface chemistry during the whole life-cycle of metal powder: from its manufacturing, following powder handling and AM processing by variety of powder-based metal AM technologies. Generic model of the powder degradation in dependance on initial powder properties and type of AM process is elaborated. Effect of the reused powder on the defect formation during AM processing and its impact on material properties is discussed.

Speaker Country:

Sverige

Plenary Talk / 48

Additive Manufacturing for Advanced Automotive Measurement Systems - Opportunities & Challenges

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AVL List GmbH (AVL) is the world's largest independent company for development, simulation and testing in the automotive industry, and in other sectors. As a global technology leader, AVL provides concepts, solutions and methodologies in the fields of e-mobility, ADAS and autonomous driving, vehicle integration, digitalization, virtualization, Big Data, and much more.
Since the foundation of the AVL Additive Manufacturing (AM) Initiative in 2017 several activities have been conducted successfully to integrate AM as a strategic technology. In this contribution an overview of AVL's AM achievements in the area of automotive instrumentation and test systems will be presented. After a general introduction, several metal-based AM-enabled use cases with advanced measurement/testing components in various fields (e.g. fuel cell and emission testing) will be discussed. Aside from novel AM-enabled research concepts, innovative (pre-)development components and the implementation of the in-house production of serial AM parts will be described. This will showcase the opportunities and challenges associated with AM to fully exploit its potential for automotive high-precision measurement and test solutions.

Speaker Country:

Austria

AM-Process- and Quality Control & Post Processing of AM Parts / 49

Thermophysical property measurement to support additive manufacturing

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Thermophysical property data such as surface tension, density and viscosity of liquid metals and alloys are key input-parameters for various simulations in fundamental as well as in industry related research. The field of additive manufacturing (AM) became a technological trendsetter in the last years and consequently, the interest in thermophysical property data gained more and more momentum as researchers and developers build and run simulations to better understand and optimize the processes involved in various AM techniques. In case of surface tension and viscosity, however, ab-initio models to calculate said properties for steels and alloys hardly exist and simulations have to rely on experimental data instead. Moreover, surface tension for instance is influenced by surface-active elements like sulfur or oxygen, which is why precise experimental data of the material actually used is to favor.

But measuring thermophysical properties of liquid steels and alloys is a challenging task due to the high temperature and high chemical reactivity of the melt. Hence, a measurement method that allows a contact- and container-less processing of the melt is favorable. The oscillating drop (OD) method in combination with an electromagnetic levitation (EML) device allows to elegantly satisfy these requirements. The sample is levitated freely in an inert gas atmosphere and surface tension and density are obtained from the analysis of high-speed videos while the sample's temperature is measured simultaneously using pyrometry.

In this talk, we will present results from such EML experiments that were performed at the Institute of Experimental Physics (IEP) at Graz University of Technology (TU Graz), among them measurements on products by voestalpine BÖHLER Edelstahl GmBH & Co KG (for instance on BÖHLER W360, L625). These data are used at BÖHLER in simulations targeting to better understand and improve the behavior of those materials in powder production (gas atomization) for AM applications. Furthermore, we will give an outlook on thermophysical property measurement activities planned in the future at BÖHLER that will include not only EML but also measurements with a high temperature rheometer (FRS 1800, Anton Paar GmbH) that was recently acquired.

Speaker Country:

Austria

Tools, Space and Aircraft, Automotive, Medical and others / 50

Best Practices to Implement a Part Family Certification Approach for Aviation

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Current Qualification and Certification methods of Additive Manufactured aviation products are based on Point Design (or Qualification) approaches. Multiple destructive testing routines are performed per part number to qualify the manufacturing process.

Considering the large sources of variability affecting part quality in Additive Manufacturing (AM) processes, and the rapid innovations of dedicated equipment and materials released on the market each year, part and process qualification is generally heavier in time and costs compared to traditionally manufactured products.
A recognized evolution of Qualification and Certification (Q&C) methods, is based on the approach of Part Family as an intermediate step toward the Process based Qualification.
The basis of this approach consists in sharing engineering data across multiple part numbers to reduce repeated and extensive qualification operations when parts design, application requirements and their production processes present commonalities.
As result, this logic could lead to substantial costs and lead time benefits for both internal parts production and external procurement, allowing qualification to cover a range of similar parts instead of qualifying one part number at a time.
The paper, presents a consensus based guideline to implement a Part Family approach to qualify and certify additive manufactured products for the aviation industry, providing best practices to define parts and process similarities in terms of material data, geometry, manufacturing and inspection requirements.
The outcome of this work sets the basis for standardization of the Part Family Q&C approach within the ASTM F42.05 committee.

Speaker Country:

Italy

Laser Melting, Electron Beam Melting & Direct Energy Deposition Processes / 51

High Temperature Tensile Strength of Ti6Al4V Processed by L-PBF – Influence of Heat Treatment, Microstrucutre and Powder Reuse

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Ti6Al4V the most widely used Alpha-Beta Ti-alloy for application in medicine, automotive and aerospace, known for its high strength and corrosion resistance, but also its high maximal operating temperature of around 420℃. Combined with its decent weldability under shield atmosphere it became a standard alloy for additive manufacturing processes, especially laser and electron beam based powder bed fusion. While being well studied at room temperature, influence of L-PBF process on its properties at elevated temperatures are little. Therefore, in scope of this work, tensile properties of Ti6Al4V for temperatures from RT up to 450℃ for different heat treatments and microstructures as well as powder conditions are investigated and compared to aerospace standards.

Speaker Country:

Österreich

Powder for MAMC / 52

Ultrasonic atomization of Fe-based soft magnetic alloys

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The most widely used soft magnetic alloys are still legacy silicon steels, even in demanding applications such as modern electric car motors. The widespread use of amorphous and nanocrystalline alloys with far superior soft magnetic properties is hindered by size restrictions enforced by their standard manufacturing methods. The laser powder bed fusion method can produce amorphous or nanocrystalline parts without the size restriction of classical methods. However, careful selection of processing parameters and chemical composition of multicomponent soft magnetic alloys is needed to print such materials successfully. There is currently a very limited offer of commercially available soft magnetic alloys in the form of a spherical powder needed for powder bed fusion techniques. Ultrasonic atomization is a novel powder production technology ideally suited for research and development needs for metal additive manufacturing. The technique allowed for the processing of two iron-based soft magnetic alloys with different glass forming abilities. The influence of atomizing frequency on atomized powders was studied. Particle size distribution was measured with laser diffraction methods and image analysis from scanning electron microscopy. The phase composition was determined with the X-Ray diffraction technique. Thermal properties of the powders were assed with the differential scanning calorimetry, and magnetic properties were measured using a vibrating sample magnetometer. Both studied iron-based soft magnetic alloys were suitable for processing by laser powder bed fusion.

Speaker Country:

Poland

Powder for MAMC / 53

Development of Cobalt Free Maraging Steels for Additive Manufacturing

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Maraging steels are a well-established material system for Additive Manufacturing (AM), especially for laser powder bed fusion (L-PBF), due to the high hardness & toughness produced by a martensitic aging heat treatment, which does not require carbon. Maraging steels have been successfully applied to L-PBF for conformal cooled tooling and tyre mould production. However, standard maraging steels, such as 18NI300, include significant cobalt and nickel content, where new legislation has been created, due to the health & environmental hazards, to limited their use and promote alternatives. Therefore, the development of cobalt free maraging steels have attracted the attention of AM powder producers to create alternatives to the standard composition of maraging steel, including 18NI300. Preliminary results for an new cobalt free maraging steel is presented and compared with the latest information on 18NI300.

Speaker Country:

United Kingdom

Tools, Space and Aircraft, Automotive, Medical and others / 54

A cost-effective hybrid approach for the manufacturing of a high-performance injection mould inserts using the laser-powder-bed-fusion process

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Laser powder bed fusion (LPBF) is a manufacturing process capable of additively fabricating injection mould inserts with conformal cooling channels (CCC) in various steels. This article reports the results of a case study in which an injection mould insert is produced using a newly developed hybrid-build hybrid-metal LPBF technique combined with conventional manufacturing methods. A broken insert from an existing high-volume injection mould, made of wrought beryllium copper, is replaced by a hybrid-built hybrid-alloy steel alternative. The new insert, designed with CCC, made of hybrid maraging 300 steel powder and wrought pre-hardened tool steel, is fabricated using the LPBF process and finished with conventional mould-making methods. Compared with standard AM-build practices, a 55% saving in time is attained. Results from the moulding trial reveal a 62% reduction in cooling time and 27% reduction in overall cycle time, respectively. When considering the running cost of the moulding machine, the additional costs in using AM technology and the cost-saving per part moulding achieved, the cost break-even quantity is 20,000 moulded parts, an equivalent of 67 hours running time. The overall result demonstrates how metal AM technology, with the right approach, can be adopted in the plastic moulding industry to increase profitability.

Speaker Country:

New Zealand

Plenary Talk / 55

A toolbox towards first-time-right production in powder bed fusion

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A significant factor slowing down the establishment of metal-based additive manufacturing techniques as production processes is insufficient reproducibility and productivity. Among all additive manufacturing processes, the highest maturity level is shown by laser-based powder bed fusion of metals (PBF-LB/M). Nevertheless, the process is characterized by several phase changes and a highly dynamic melt pool, which may lead to the formation of process defects. Currently, continuous wave, vector-based exposure using Gaussian spots with spot diameters in the range of 40 to 120 µm represents the standard approach to laser-based powder bed fusion of metals. Within the keynote, the potential of tailoring the energy input in time and space on melt pool dynamic, process behavior, and resulting component properties are shown. The talk is guided by two technical innovations in PBF-LB/M (i) the potential of beam shaping technology for smoothening the process dynamic

and increasing productivity and (ii) the capability of pulsed exposure for a support-free building process and thus reduction of post-processing. We have shown in selected examples a significant increase in the production speed with the change of the spatial energy input (beam shaping). This combined with the reduction of support structures via tailored temporal energy input leads to an essential reduction of the overall process chain in PBF-LB/M. In the future, a toolbox with different process strategies will empower the first-time-right manufacturing and the voxel-based tailoring of components in PBF-LB/M.

Speaker Country:

Germany

Plenary Talk / 56

Acceleration of the LPBF process

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To increase the relevance of LPBF in industrial manufacturing, it is necessary to increase the productivity of the process. This can be achieved on existing machine systems without changing the hardware by locally adapting the energy input in the LPBF process by using qualitative (and slow) parameters only in areas where the geometry or the application also requires it - while manufacturing with more productive parameter sets otherwise. The energy input can be adaptively adjusted locally by prior simulation and flexible machine control. Another approach can be to modify the laser-optical system in LPBF machines to shape the laser beam and thus couple the energy into the powder material. This allows the use of greater laser power and therefore more productive process parameters. This can enable the use of higher laser power and hence greater scanning speeds. Simulation at Fraunhofer ILT is used for a better understanding of the interactions between laser radiation and powder in the process zone and to determine suitable parameters.

Speaker Country:

Germany

Plenary Talk / 57

Additive Manufacturing – a game-changer in Automotive engineering

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coming soon…

Speaker Country:

Austria

Plenary Talk / 58

AM in tooling – Much more than conformal cooling

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Conformal cooling in mold inserts was one of the first applications of metal 3D printing. The potential of optimized temperature control to reduce scrap or cycle time was recognized early on. In the meantime, however, not only the technology and the available tool steels have evolved, but also the possibilities in the field of tool design. Both the way near-contour cooling channels are designed and other benefits that 3D printing can bring have been developed. 3D printing makes it possible, for example, to monitor and control the injection molding/die casting process much better through position-optimized sensors. Similarly, for example, targeted porosity can ensure good venting throughout the mold, even for challenging injection molded parts. 3D printing can do much more than cooling close to the contour.

Speaker Country:

Germany