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Metal Additive Manufacturing Conference

Industrial Perspectives in Additive Technologies

PROGRAMME

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Örebro Castle
Sweden

ASMET
THE AUSTRIAN SOCIETY FOR METALLURGY AND MATERIALS

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Monday 25 November 2019

Plant Visit: AMEXCI and Lasertech LSH AB - (25 November 08:30-11:30)

Registration - (11:30-12:45)

Opening - 1: Rikssalen (25 November 12:45-13:00)

Govenor Maria Larsson

Keynote - 1: Rikssalen (25 November 13:00-15:00)

time	[id] title
13:00	**[3] AUTOMOTIVE STAMPING TOOLS & DIES AND INJECTION MOULD MADE BY ADDITIVE MANUFACTURING THROUGH LASER-BASED POWDER BED FUSION** *Presenter: ASNAFI, Nader (Örebro University)* Design and production of tools, dies and moulds are two important steps in the development of new components/products. These steps determine both the lead time (Time-To-Production/-Market) and the size of the investments required to start the production. This paper deals with design and production of stamping tools & dies for sheet metal components and injection moulds for plastic components. Laser-based Powder Bed Fusion (LPBF) is the additive manufacturing (henceforth even called 3D printing) method used in this investigation. The stamping tools & dies should withstand the requirements set in stamping of hot-dip galvanized DP600. Solid and topology optimized forming and cutting/blanking/trimming tools made in maraging steel (DIN 1.2709) by LPBF are approved/certified for stamping of 2 mm thick DP600. A working station in a progressive die used for stamping of 1 mm thick DP600 is 3D-printed in DIN 1.2709, both with a honeycomb inner structure and after topology optimization, with successful results. 3D printing results in a significant lead time reduction and improved tool material efficiency. The cost for 3D-printed stamping tools and dies is somewhat higher than the cost of those made conventionally. DIN 1.2709 is certified in this study as tool material for stamping of hot-dip galvanized DP600. The core (inserts) of an injection mould is 3D-printed in DIN 1.2709, conformal cooling optimized and 3D-printed in Uddeholm AM Corrax, and compared with the same core made conventionally. Additive manufacturing results in localized tool production and lower total costs. The cooling and cycle time can be improved significantly, if the injection moulding core (inserts) is optimized and 3D-printed in Uddeholm AM Corrax. The best results are obtained, if the 3D-printed core is NOT only an optimized copy of the conventionally designed and manufactured version. The best results are obtained, if the core is redesigned to utilize the full potential of 3D printing. This paper accounts for the results obtained in the above-mentioned investigations.

13:30	**[56] 3D-PRINTABLE MATERIALS: DESIGN PRINCIPLES FOR STRONG AND TOUGH POLYMERS, CERAMICS AND METALS** *Presenter: STAMPFL, Jurgen (Inst. of Materials Science and Technology Christian Doppler Laboratory Photopolymers in Digital and Restorative Dentistry)* Additive manufacturing (AM) has developed into a promising technology for various engineering applications and provides advantages over conventional manufacturing methods like casting or milling. Nevertheless, 3D-printable materials are still fighting to meet the demanding requirements of many applications in engineering and biomedicine. The presented work will give an overview about general toughening concepts for polymeric, ceramic as well as metallic 3D-printable materials and give insight into the interconnections between the most relevant thermomechanical properties (strength stiffness, toughness, heat deflection temperature) for these materials. Most AM materials have their origin in traditional manufacturing (metals for casting and CNC-machining, polymers for injection molding, …) and only partially fulfill the requirements of dedicated AM materials: Processing based on selective laser melting/sintering or photopolymerization, respectively, put specific demands on the utilized materials if the mechanical properties of the final part should be optimized. With the significantly increased consumption of 3D-printable materials, the necessity to use raw materials which are specifically optimized towards being used in AM is steadily growing and a detailed scientific investigation of such materials is required. Since AM allows not only to define the shape of a part, but also enables the variation of material properties within the part (gradient materials, digital materials, …), new routes for a sound scientific investigation of 3D-printable materials are available. Several examples of recently developed 3D-printable materials (metallic high-performance alloys, strong and tough photopolymers, high-strength ceramics) will be presented and will illustrate this approach.
14:00	**[4] DIGITALIZATION OF AM: THE STAIRCASE** *Presenter: GRAICHEN, Andreas (Siemens Industrial Turbomachinery)* Siemens in Finspong has worked with additive manufacturing since 2009. During the following 10 years, the organization has gone through a whole hype cycle, also the disappointing parts. In 2015/16, decisions were made to cope with the perceived challenges by an increased use of digitalization tools. A bold mission statement was issued and strategies for its implementation devised, called “The Staircase”. In a stepwise approach the digital fitness is increased, aiming at a fully autonomous 3D-printing process. The historic development as well as an outlook into the future will be given.
14:30	**[62] POWDER BED FUSION AND JETTING PROCESSES - COMPLEMENTARY TECHNOLOGIES FOR METAL ADDITIVE MANUFACTURING OF INDUSTRIAL PARTS** *Presenter: ALLITSCH, Edmar (EOS Holding AG)* LPBF (laser based power bed fusion) has seen tremendous growth over the past years, powered by the transition from prototyping without design limits to industrial production of high performance parts and the current trend to digital manufacturing. Jetting technologies are joining the growing market of additive manufacturing with the target of higher productivity and MIM-like part properties. The paper is highlighting the specifics, strengths and limitations of these 2 technology families as well as suitable applications. Consideration is given to part properties for specific alloys, material and design sweet spots as well as the respective manufacturing eco systems. The author is summarizing why these technologies will rarely compete for the same application but rather complement each other and will further accelerate the industrial use of additive manufacturing.

<u>Coffee Break</u> - (15:00-15:30)

Systems and Equipment Engineering - 2: Länssalen (25 November 15:30-16:30)

time	[id] title
15:30	**[54] NEW ARCHITECTURES AND ENERGY SOURCES FOR METAL ADDITIVE MANUFACTURING (SLEDM)** *Presenter: HAAS, Franz (IFT - Graz University of Technology)* The proposal deals with a completely new technique and energy source for melting of metal powder. The paper is focused on the machine itself, its topology optimized design and the energy transfer to the material. The printer consists of lightweight material und uses a cooling system for the projection part that reuses the removed energy to preheat the platform and the already printed part. Major characteristics of the new system are the need of a small volume of metal powder, the maximum possible avoidance of support structures and the opportunity of post-processing during the printing process. Results of test experiments will be presented and the outlook shows possible applications in the future for mass production. This realistic scenario is based on the possible reduction of printing time by the factor of 10 to 20.
15:50	**[21] ADAPTION OF COST CALCULATION METHODS FOR MODULAR LASER-POWDER BED FUSION (L-PBF) MACHINE CONCEPTS** *Presenter: DIRKS, Sebastian (Chair for Digital Additive Production (DAP) of RWTH Aachen University)* Methods for cost calculation of Laser-based Additive Manufacturing (LAM) have evolved over the last two decades. Starting from a rapid prototyping manufacturing method, cost calculation over time included more than single part production for small series or mixed batches. New machine developments nowadays include large scale production and introduce modular machine designs that give LAM factory operators more decision freedom on machine configurations and expansibility. To leverage this freedoms potential, LAM costing methods must be adapted to calculate and visualize the economic consequences of different module configurations. In this work a modelling architecture of L-PBF machines using virtual modules is presented. Using principles of the industry 4.0 communication standard OPC UA, a virtual machine is set up, parametrized and connected to the AM digital process chain. Two different views on the cost information are used, optimized for different use cases. First, the product view allows detailed analysis of cost allocation to parts in mixed batches and the layered geometry of the part. The costs are allocated to overlapping process area categories , e.g. up-, down- or inskin, hull or core, supports. Second, the machine view tracks utilization of all machine modules, divided into the states idle, active, off and maintenance. The theoretical Overall Equipment Effectiveness (OEE) is calculated on a module basis, enabling economic analysis and optimization of module composition as well as module improvements and new modular machine constellations. This allows focusing research and development on most valuable improvements. By calculating different scenarios like spare part production, mass production or rapid prototyping, the part portfolio to be manufactured can be considered.
16:10	**[38] NEW ELECTRON BEAM POWDER BED FUSION SYSTEM WITH OPEN SOURCE SOFTWARE, TAILORED FOR MATERIALS RESEARCH AND DEVELOPMENT** *Presenters: ACKELID, Ulf (Freemelt AB), OHLDIN, Patrik (Freemelt AB), LJUNGBLAD, Ulric (Freemelt AB)* Additive manufacturing provides opportunities for improving properties of existing alloys and developing new material compositions. Materials produced with powder bed fusion (PBF) often exhibit unique microstructures, due to the small melt pool and rapid solidification associated with PBF. Unfortunately, most commercial PBF systems are intended for production only. They are too big for small scale experiments, have limitations in terms of beam control and cannot be modified to the needs of an R&D user. This paper describes Freemelt ONE, a new electron beam PBF system for R&D, providing benefits such as: - open source software offering unsurpassed freedom to explore innovative melting strategies - small build volume and low powder consumption - short turnaround time - high tolerance to powder quality - outstanding vacuum for highly reactive materials - very hot powder bed, >2000 °F (1100 °C), beneficial for crack-sensitive materials - easy attachment of R&D equipment, e.g. RGAs or X-ray spectrometers, giving endless possibilities for in-situ process monitoring.

Business Models & Engineering: Business Models & Engineering - (25 November 15:30-15:50)

time	[id] title
15:30	**[32] INTEGRATION OF BENEFIT CONSIDERATIONS IN COST ANALYSIS FOR ADDITIVE MANUFACTURING** *Presenter: SCHRÖER, Tobias (FIR at RWTH Aachen)* In this paper, we propose an integrated cost-benefit model to evaluate the economic utility of Additive Manufacturing (AM) for specific business cases. The high flexibility of AM enables novel product design possibilities and new production systems paradigms. The resulting creation of additional benefits for customers and companies is a subject undergoing intense study. In recent years, the application of AM has shifted its focus from prototyping to series manufacturing. However, in most cases AM-technologies still cannot compete with conventional mass production technologies in terms of production costs. A fundamental reason is that the benefits of AM are not considered by simple evaluation of production costs. Since production technologies are usually evaluated based on costs, many potential business cases remain undetected. Making use of the additional benefits of AM increases its competitiveness as a production technology. As cost comparisons will remain an inevitable part of business decisions, cost models have to incorporate additional value creation by AM . Hence, practitioners need a holistic approach to consider costs and benefits of AM simultaneously in order to determine AM business cases. Our objective is to develop an easy to use model that supports the user in identifying the relevant benefits for a specific use case and consider the added value in a cost model. A fundamental requirement to achieve this is a structured analysis and evaluation of actual advantages of AM. We conduct a literature research on AM potentials and their interdependencies. Based on expert interviews we categorize the results and build a hierarchical structure of AM benefits. The result is an interactive graph that helps users to explore new benefits and unlock their potential. The benefits are integrated into a cost model to allow a holistic quantitative evaluation of the business case. Our interactive approach based on the cytoscape graph framework helps identifying the key impact factors of the business case and makes it easy to run scenario-based analyses.

Material & Process Design & Engineering - 1: Rikssalen (25 November 15:50-18:10)

time	[id] title
15:50	**[17] APPLICATIONS OF CALPHAD BASED TOOLS TO ADDITIVE MANUFACTURING MODELS** *Presenter: MARKSTRÖM, Andreas (Thermo-Calc Software AB)* Finite element modelling of Additive processes requires material property data which are not always readily available, especially when using non-standard alloys. CALPHAD tools can calculate properties such as specific heat, density, enthalpy, and mobilities, which can be used as inputs to other codes. These properties are expressed as functions of composition and temperature, which is useful since the additive process can impart large thermal and compositional gradients during a build. More advanced CALPHAD simulations that predict diffusional phase transformation and precipitation behavior can also be used to determine the effect of not only solidification, but also repeated thermal cycling on the final microstructure. As thermal histories will be location specific in a build, these types of simulations can give insight into the local mechanical behavior, when coupled with more advanced structure/property relationships. A few case studies have been highlighted to demonstrate the importance of CALPHAD tools in additive modeling.
16:10	**[0] ICME BASED GEOMETRY AND PBF PROCESS PARAMETER OPTIMIZATION FOR Ti64 GIMBAL** *Presenters: ZIELINSKI, Jonas (Digital Additive Production – RWTH Aachen), MEGAHED, Mustafa (ESI Group)* An aerospace gimbal made of Ti64 is topologically optimized to achieve the same performance with a substantial weight reduction. The Ti64 powder is characterized and numerically studied to ensure spreadability and recyclability. Process parameters are optimized both experimentally and numerically to achieve material density of 99.5%. The distortion of the original geometry was studied numerically and compared with a trial print to validate the material properties used as well as the solution procedure. Finally, the topologically optimized geometry is studied with the chosen process parameters to assess manufacturability. The results are compared with 3D scans of the final part confirming the accuracy of the ICME platform and the combined numerical and experimental work flow.

16:30 **[10] ADDITIVE MANUFACTURING FOR EXTRUSION TOOLING**

Presenter: SCHARLAKEN, Tom (VIVES University College)

Practical research on the implementation of metal additive manufacturing in extrusion tooling applications has been deducted by VIVES University College and the ProPolis research group from KULeuven in Belgium. In polymer extrusion lines, molten plastic is forced through a die to define the rough shape of plastic profiles. Calibration units are positioned right behind the mould; their function is to cool the plastic profiles in order to give them their final and exact shape. This cooling process needs to occur as uniform as possible to prevent geometrical distortion, and as fast as possible to maintain higher production speeds. To achieve this, calibration units feature highly complex cooling channels and vacuum slots. These often intricate channels and slots are very challenging to create using conventional tooling such as CNC-milling and EDM technology, resulting in sub-optimal cooling processes and more complex cooling block assemblies.

Where the above subtractive technologies run into their limits, additive manufacturing opens up new possibilities for designers and engineers because of the technology’s geometrical freedom: improved cooling, shorter lead times, faster production speeds and therefore a shorter time to market. These possibilities are explored in the aforementioned research through a number of practical case studies for Belgian extrusion companies. Through thermal simulations, calibration units modelled for conventional CNC machining/EDM are compared to new designs made specifically for additive manufacturing. These simulations provide insight in pressure drops and heat transfer from extrusion profile to cooling water, and therefore aid in the optimisation of cooling channel layout. Once optimised, the new design is printed with selective laser melting technology and tested in production. Measurements on heat transfer are executed and compared to the conventional cooling units, showing great promise for additive manufacturing as an alternative production method for calibration units in polymer extrusion.

16:50 **[36] DESIGN OF EASILY REMOVABLE LATTICE-BASED SUPPORT STRUCTURES FOR L-PBF**

Presenter: ZAREI, Omid (Digital Additive Production (DAP), RWTH Aachen University)

Laser Powder Bed Fusion (L-PBF) is a manufacturing technology based on layer-by-layer material additions of fused metal powder. One important characteristic of this technology is its capability to produce components with highly complex geometries. The L-PBF process requires support structures that connect the components to a substrate plate in the machine. These support structures have two main functions: The first is to dissipate the generated heat when melting the material; the second is to constrain the solidified material to ensure geometrical accuracy of the component. The latter is especially relevant for the downward facing surfaces with lower overhang angles which might collapse without support structures. Overhang angle is defined as the angle between a tangent plane to a downward facing surface in a component and the substrate plate; usually critical angle, describing the manufacturability of a feature without support structures, is defined for a specific L-PBF process and material. Depending on the component geometry, a considerable amount of support structures is necessary to ensure manufacturability. After the L-PBF process, all the supports need to be removed - which can amount to a time-consuming task that increases overall product cost. This serves as a motivation to design easily removable support structures.

The approach presented in this study aims at designing L-PBF supports as lattice structures. Lattice structures are often used to reduce component mass in lightweight applications, sometimes with complex heat transfer functionalities. These properties can be used for improved designs of support structures and they can be further optimized for better removability. In this study, different types of lattice-based support structures are used for a Siemens gas turbine component - a resonator box - and their production time and removability are compared. The results can be used to design optimal support structures for other similar components.

17:10 **[14] FROM MELT POOL TO MICROSTRUCTURE: A SIMULATIVE APPROACH OF MATERIAL BEHAVIOUR IN THE L-PBF PROCESS**

Presenter: ZIELINSKI, Jonas (Digital Additive Production RWTH Aachen University)

An important goal for the additive manufacturing community is to predict the material-dependent effective mechanical properties of a build-up specimen.

In this work, we use three coupled simulations to calculate the mechanical properties of L-PBF processed IN718. In the future this approach could be used for newly designed materials to estimate the expected mechanical properties and the resulting microstructure (As extra step, the thermo physical properties of the new alloy have to be calculated in advance).

The simulation chain to solve this challenge involves the simulation of the melt pool behaviour during the L-PBF process to obtain the solidification conditions. Those are required to then calculate the microstructural growth behaviour with the phase-field method. The resulting microstructure is homogenized to obtain the final effective mechanical properties of the L-PBF processed material.

The simulation results are compared with according results from experiments at each step to verify the approach and each simulation result.

17:30 **[39] GRAINY IMAGES: IN-SITU OPTICAL MICROSCOPY OF AM MICROSTRUCTURES DURING MECHANICAL LOADING**

Presenter: RONNEBERG, Tobias (Imperial College London)

316L stainless steel produced by laser powder bed fusion (LPBF) is strong, ductile and anisotropic, yet it remains unclear how its unique microstructural features contribute to these properties. This talk presents work seeking insight into the deformation mechanics in LPBF materials. Samples were built to near net shape of flat dog bones in a consumer LPBF machine (Renishaw AM250) before being prepared and etched to reveal the bulk microstructure on the gauge surface. Using a custom made optical imaging system and a tensile testing jig, this surface was imaged during loading. The mechanical response around features such as melt pools, grains and porosity was analysed using digital image correlation (DIC). This procedure was repeated for a variety of samples to examine the effects of build orientation, scanning strategy and heat treatment. Samples were analysed using SEM and EBSD before and after tests to validate and inform the microscopy data. Results from stainless steel samples indicate grain orientation strongly affects yield behaviour. Grains whose [001] direction was parallel to the direction of loading were found to deform before other grains. Areas of early local plastic deformation were found to align with boundaries of large grains, while layer and melt pool boundaries provide little resistance to deformation. Porosity seems to play only a minor role at low applied stresses, but becomes increasingly influential at higher stresses until failure. The talk will conclude with a discussion of how these findings may help inform design for additive manufacturing (DfAM) and process optimisation.

17:50 **[65] PRODUCTION OF AM PARTS IN DUPLEX STAINLESS STEELS USING DED AND HIP**

Presenter: SHIPLEY, James (Quintus Technologies AB)

Duplex materials are commonly used on wrought form due to their high strength and excellent corrosion resistance. Attempts have been made to additively manufacture these over a number of years, often producing very ferritic microstructures.

Penn State University have conducted a number of trials as part of a PhD program, using Directed Energy Deposition (DED) with a laser energy source, with subsequent post processing using Hot Isostatic Pressing (HIP). Materials include UNS S32101, UNS S32205, UNS S32507 and UNS S32760.

This presentation will focus on the microstructures achieved in the as-built condition and following HIP. Mechanical testing, corrosion testing etc. are ongoing and will hopefully be available before the conference.

Power Production and Characterization - 2: Länssalen (25 November 16:30-17:50)

time [id] title

16:30 **[16] MICROSTRUCTURAL AND MECHANICAL PROPERTIES OF ADDITIVE MANUFACTURED MATERIALS**

Presenter: OLSSON, Elin (Erasteel Kloster AB)

The rapidly growing implementation of AM technologies has led to a growing range of new applications. With new applications comes the demand for new alloys and properties.

The final properties of AM materials are influenced by many different powder related properties, such as particle size distribution, chemical composition and flowability. Different machines use different manufacturing techniques and process parameters, which also influence the properties of the AM printed material. Finally, the choice of manufacturing direction and post processing also has a major impact on the final properties.

In this study, the microstructural and mechanical properties such as hardness, toughness and strength have been investigated for a number of AM printed materials using different AM techniques, process parameters and post processing.

16:50 **[1] INFLUENCE OF PREHEATING TEMPERATURE ON HARDNESS AND MICROSTRUCTURE OF HIGH-SPEED STEEL HS 6-5-3-8 MANUFACTURED BY LASER POWDER BED FUSION**

Presenter: SAEWE, Jasmin (Fraunhofer Institute for Laser Technology ILT)

Laser powder bed fusion (LPBF) is an additive manufacturing process employed in many industries, for example for aerospace, automotive and medical applications. In these sectors, nickel-, aluminum- and titanium-based alloys are mainly used. In contrast, the mechanical engineering industry is interested in tool steels for many of their applications. Current research is often limited to hot work tool steel with up to 0.5 % carbon content using LPBF. However, many applications need more wear-resistant steel alloys with higher hardness, both of which can be achieved with a higher carbon content, like in high-speed steels. Since these steels are susceptible to cracking, preheating temperature needs to be applied during LPBF processing.
In a previous study, we applied a preheating temperature of 500 °C for HS 6-5-3-8 (also called ASP2030) with 1.3 % carbon content. We were able to manufacture dense (ρ > 99.9 %) and crack-free parts from HS 6-5-3-8 with a hardness > 62 HRC (as built) by LPBF. In this study, we investigate the influence of preheating temperatures up to 600 °C on hardness and microstructure as a function of part height for HS 6-5-3-8. The analysis of different part height is necessary because state-of-the-art preheating systems induce heat only into the base plate. Consequently, parts are subject to temperature gradients and different heat treatment effects apply depending on part height during the LPBF process. The microstructure was studied by light optical microscopy (LOM), scanning electron microscopy (SEM) and electron backscatter diffraction (EBSD).

17:10 **[9] INFLUENCE OF MATERIAL PROPERTIES ON SPHEROIDISATION PROCESS IN GAS ATOMIZATION**

Presenter: DOPLER, Martin (hightech metal Prozessentwicklungsgesellschaft mbH)

For many contemporary powdermetallurgical applications, spherical powders are preferred. Spherical particles have a lower oxygen content, a better flowability and their behaviour is – compared to irregular particles – better predictable.

The powder production process via melt atomization can be divided into the following steps:

a. primary breakup into ligaments

b. ligament breakup

c. secondary breakup and/or spheroidisation, while simultaneously cooling and freezing take place.

Apart from thermodynamic conditions during the process, melt properties such as viscosity, density, surface tension, heat capacity and thermal conductivity will influence the processes around spheroidisation.

As a first step, a 4-force model (viscosity, surface tension, external dynamic and inertia forces) is applied on the melt droplet to predict the influence of the melt properties on spheroidisation separately. Secondly, the spheroidisation process is calculated for different materials such as Copper, Iron or Titanium for existing atomisation systems.
Finally, suggestions are presented which may help to produce more spherical particles.

17:30 **[12] RAPID ALLOY DEVELOPMENT OF NEW PROMISING HIGH ENTROPY ALLOYS VIA LASER POWDER BED FUSION**

Presenter: EWALD, Simon (Digital Additive Production, RWTH Aachen University)

In this contribution, a method for screening and developing new materials by using L-PBF will be introduced. Up to now, the process of designing and developing new alloys is tedious and expensive. That can be significantly accelerated by the Rapid Alloy Development (RAD) approach. This approach describes a new and faster way of creating tailored alloys. New alloys can be fabricated and processed directly by dry-mixing of elementary powders. Thus, a large range of alloy compositions can be quickly produced, analyzed and evaluated. The Al-C-Co-Fe-Mn-Ni system is considered as the investigated material. First, promising alloy compositions are determined by using simulation tools and thermodynamic data bases. Second, different dry-mixed alloy compositions of AL-C-Co-Fe-Mn-Ni are qualified for the L-PBF process in order to screen the alloy. Finally, the various fabricated alloys are evaluated by AM processibility, microstructure (OM, SEM, EBSD, EDX) and mechanical properties.

Process Optimization & Control and Quality Assurance: Process Optimization & Control and Quality Assurance - 2: Länssalen (25 November 17:50-18:10)

time	[id] title
17:50	**[64] OUT-OF-PLANE SURFACE MEASUREMENT AND POROSITY QUANTIFICATION USING FRINGE PROJECTION STRUCTURED LIGHT SYSTEM FOR USE IN POWDER BED FUSION MANUFACTURING** *Presenter: O'DOWD, Niall (University of California San Diego)* Metal parts created by additive manufacturing are often difficult to dimensionally characterize due to the complex surface structures created by welding phenomena present in state-of the art printing machines. The most holistic techniques involve measuring the surface of each sintered layer of powder, however, this is complicated to perform in a non-contact, non-destructive, and in-situ manner. Techniques such as Spectral Domain Optical Coherence Tomography can be used to perform this task, but are limited to large pointwise measurement, limiting the speed and resolution of measuring the surface topography of each layer. In this work, we propose a method of layer-by-layer instantaneous area interrogation using a structured light system. We are presenting the design and measurement results of a low-cost fringe projection system to perform high resolution out-of-plane measurements on each build layer, and the quantification of small pores of sizes 0.050 mm and smaller. The measurement system proposed is purposefully selected to be small enough to allow for in-situ implementation inside a variety of different AM machines. Measurement results of the system are shown on test specimens dimensionally verified with lab-ordered profilometer measurements, presenting the validity of the structured light measurement system.

Welcome Reception - (18:10-20:00)

Tuesday 26 November 2019

Keynote: Keynote - (26 November 08:30-09:00)

time	[id] title
08:30	**[50] STATE OF THE INDUSTRY - 3D-PRINTING DEVELOPMENTS & APPLICATION BREAKTHROUGHS** *Presenter: PIRKLBAUER, Peter (Airbus Operations GmbH)* The world of additive manufacturing has reached - literally - outer space, within this keynote, an overview of advanced applications as well as developments from around the globe will be presented.

Process Optimization & Control and Quality Assurance: Process Optimization & Control and Quality Assurance - 1: Rikssalen (26 November 09:00-10:00)

time	[id] title
09:00	**[15] LASER ADDITIVE MANUFACTURING OF INTERMETALLIC ALLOYS FOR HIGH-TEMPERATURE APPLICATIONS** *Presenter: RITTINGHAUS, Silja-Katharina (Fraunhofer ILT)* Intermetallic alloys like e.g. Iron-Aluminides, Titanium-Aluminides or Molybdenum-Silizides are prospective materials for high-temperature applications. For additive manufacturing (AM) intermetallic structural materials are particularly challenging due to their high melting points, oxygen susceptibility and low temperature brittleness. The feasibility of manufacturing intermetallics with laser additive manufacturing (LAM) is demonstrated and recent results in characterizing rapidly solidified material with respect to correlations between process, composition and microstructures are presented. Results on mechanical properties of AM intermetallic materials are comparatively discussed with regard to applications and conventional production methods. Current challenges, e.g. homogenous distribution of alloying elements and applicability are addressed.
09:20	**[22] FEASIBILITY STUDY OF ADDITIVE MANUFACTURING OF INCONEL 625 USING EBM PROCESS** *Presenter: ZHAO, Xiaoyu (Department of Production Engineering, KTH Royal Institute of Technology)* Electron Beam Melting (EBM) is one of the important metal AM processes especially feasible for manufacturing with high-performance or superalloy like Inconel. This research is carried out to evaluate feasibility of manufacturing Inconel 625 by the EBM process. Focusing on process parameters such as speed function for hatching process and the line offset for both contouring and hatching process, nearly full dense samples- over 99.7% of the wrought material - were produced. As expected, the surface roughness variation between the samples printed with and without contour, as peak to valley distance (Rt), indicated greater need for the post-process machining. The measured Vickers Hardness (30HV30) of density cubes reached a level equivalent to as-rolled and annealed materials. The samples machined from bulk specimens exhibited good tensile properties, as well as the near-net shaped specimens with only 2 mm in radius machining for final specimen dimensions. However, the significant differences can be observed between the samples fabricated with and without contour. The test results showed the potential of EBM process to manufacture with the Inconel 625 materials; however, the process parameters should be further optimized. In addition, an in-depth analysis of the differences between the samples fabricated with and without contour should be carried out in detail. Key Words: Additive Manufacturing, Electron Beam Melting, Inconel 625, Near-net Shape Manufacturing

09:40 **[61] MICROSTRUCTURE AND MECHANICAL PROPERTIES OF ELECTRON BEAM MELTED TiAl6V4 ALLOY MANUFACTURED USING DIFFERENT SCANNING STRATEGIES**

Presenter: BIFFI, Carlo (CNR)

Powder bed additive manufacturing offer the possibility of tailoring the beam scanning strategy for improving the homogeneity of the material response, productivity, inner and outer integrity. Moreover, the selection of the scanning strategy is associated to the part size and shape to be realized.
Therefore, this work studies the effect of different building strategies on the microstructure and mechanical properties of TiAl6V4 parts, produced by Electron Beam Melting. In details, four different combinations of hatch/contour scans were taken into account in the manufacturing of xy and z orientated samples. Surface morphology, relative density, microstructure and mechanical properties were evaluated and associated to each process condition. The effect of the sample size on the mechanical response and microstructure was also considered in some specific process conditions.
Specimens were produced with Electron Beam Melting (EBM) and tested to study the effect of scanning strategies, performed with optimal process parameters, on surface morphology, microstructure and mechanical properties. As the standard condition consists in the use of different parameters for scanning the hatch and the contour, the other conditions were investigated using separately the hatch strategy and the contour one, orientated from the centre to the border, and vice versa. Due to the material anisotropy, samples were fabricated both in vertical and planar directions.
The achieved results indicate that the contours and hatch parameters affect both microstructure and mechanical properties, due to the relative electron beam scanning heat transfers.
This work demonstrates that the scanning strategies affect both microstructure and mechanical properties. Pure contour and hatch scanning modify the surface morphology and density, due to different melting induced by the electron beam path. Moreover, both the building direction and the scanning strategy can promote the formation of different microstructures, able to offer modified mechanical properties.

Keywords: Electron Beam Melting, Additive Manufacturing, TiAl6V4, Microstructure, Surface, Mechanical Properties.

Power Production and Characterization: Power Production and Characterization - 2: Länssalen (26 November 09:00-10:00)

time [id] title

09:00 **[13] INFLUENCE OF POWDER APPLICATION PARAMETERS ON POWDER BED PROPERTIES AND ON PRODUCTIVITY OF LASER-POWDER BED FUSION (L-PBF)**

Presenter: SCHRAGE, Johannes (Chair for Digital Additive Production at RWTH Aachen University)

Despite the advantages in terms of geometrical freedom or lightweight design, the use of L-PBF is often limited by economic constraints or currently achievable part costs, respectively. With an expected increase of L-PBF machine productivity during the next years, an increase of the share of material costs and the share of non-productive time for powder layer application process is to be expeted. This results in a demand for less expensive powder materials and advanced processing strategies for the short-and medium-term advancement of L-PBF. As one possible approach, the processing of gas- and water atomized stainless steel (316L) powders with different morphology and particle size distribution as well as their impact on L-PBF productivity is investigated. The actual powder applicability in L-PBF systems and the L-PBF processability determines the minimum necessary powder quality. The main focus of the presented work is put on the interaction between powder quality, part quality and cost-effectiveness of the L-PBF process. To this end, the influence of the gas and water-atomized powder properties (particle size and morphology) during the powder layer application process at highest possible powder recoating speeds and the resulting powder bed properties (powder layer density, powder bed density, powder segregation) and part properties (part density, surface roughness and tensile strength) is investigated.

09:20 **[18] COMPARATIVE STUDY OF METALLIC POWDER FLOWABILITY'S TESTING METHODS**

Presenter: MARCHETTI, Lorenzo (KTH - Kungliga Tekniska högskolan)

The flowability of a powder is an important characteristic dependent on both the particle ensemble’s physical properties as well as the testing equipment and conditions. In additive manufacturing processes, flowability can be an indicator of the quality of the deposited powder layer. However, flowability significance is not always clear. In this study, we carried out a comparison between different steel powders, as well as different testing methods. Each sample had a unique combination of composition and particle size range. Furthermore, the flowability testing equipment and methods were selected according to standards (angle of repose, Hausner Ratio, Hall flow) or to the published literature (FT4 Powder Rheometer). Firstly, we measured the flowability of different samples for each testing method, in order to investigate the influence of the powder physical characteristics. Secondly, we evaluated the correlation between different flowability testing methods.

09:40 **[8] EVALUATION OF AGING BEHAVIOUR AND RECYCLING POSSIBILITY OF METAL POWDERS**

Presenter: VICARIO, Valentina (MIMETE Srl)

One of the most frequently asked question by users is how long metal powders can be used. MIMETE, the new Italian metal
powders producer, defined an internal Design of Experiment to map the effect of atmosphere (from air to 100% argon), temperature and time on different powders, considering both various alloys and granulometric distribution. The properties analyzed after exposure were initially measured in fully equipped MIMETE laboratory, focusing mainly on chemical modification
superficial characterization and technological properties as flowability and packing tendency. The further step of the experimental work shifted to industrial scale, taking into consideration metal powders only stored for some time or already used
in LPB/SLM process just once or in multiple jobs, applying different approaches to mixing with new powder to fill printers. Properties of final components obtained from new and re-used powders will be compared.

Coffee Break - (10:00-10:30)

Process Optimization & Control and Quality Assurance: Process Optimization & Control and Quality Assurance - 1: Rikssalen (26 November 10:30-11:50)

time [id] title

10:30 **[26] LOW-DEFECT ADDITIVE MANUFACTURING OF HIGH STRENGTH ALUMINIUM ALLOY BY LASER METAL DEPOSITION**

Presenter: LANGEBECK, Anika (BIAS - Bremer Institut für angewandte Strahltechnik GmbH)

A manifold variety of additive manufacturing techniques has a significant positive impact on many industry sectors from small scaled medical applications to overhaul applications on large-scaled machine components. Large components are often manufactured via laser metal deposition (LMD) instead of using powder bed based processes. The advantages of LMD process are a high build-up rate with values up to 300 cm^3/h and a nearly limitless build-up volume.

In combination with the lightweight material aluminium it is possible to manufacture large lightweight components with geometries adapted to customer requirements in small batches. This contributes the pursuit of higher efficiency of machines through lightweight materials as well as lightweight design.

A low-defect additive manufacturing of high strength aluminium EN AW-7075 powder via LMD is an important challenge to concern. During the process a considerable proportion of pores up to over 10% can build and weakens the mechanical properties. Additionally, the heat input affects the hardness of the manufactured part.

A higher hardness could be reached through artificial aging in two steps after the LMD-process. The rapid solidification of the melt pool produces a supersaturated solid solution, which undergoes precipitation hardening during artificial aging.

A significant reduction of pore volume can be achieved by a higher energy input per unit length and an improved shielding gas flow. Therefore, a shielding gas shroud was developed to keep hydrogen from the air away from the process zone. The combination of the improved shielding gas flow with a high energy input per unit length led to a decrease of pore volume from over 7% to lower than 1.5%.

10:50 **[30] ASPECTS OF UNCERTAINTY IN METAL ADDITIVE MANUFACTURING**

Presenter: BOOS, Eugen (Technische Universität Dresden)

With the introduction and further development of Additive Manufacturing (AM) processes, the possibilities of free and force-adapted structural designs are virtually limitless. Tools such as shape and topology optimization allow the creation of components with idealized mechanical properties while remaining lightweight. These components are designed to meet high performance objectives, objectives that can be only met with an adequate manufacturing process. AM, as one of few procedures, offers the production of such free form designs. However, the quality standards required for the high-performance market are not entirely given yet. Known but hard to deterministically quantifiable influences, such as laser energy density, positioning, thermal history and grain structure have a considerable effect on the mechanical properties of the printed components. Although under constant research, these uncertainties are preventing AM from establishing in high-performance industries. To meet the high quality criteria not only an improved understanding of uncertain influences is crucial, but correspondingly the correct mapping of the manufacturing process itself.
This paper presents the concept of a possibility model, based on the fuzzy set theory, to monitor, evaluate and optimize the quality management in Laser Beam Melting (LBM). The proposed model aims to estimate the quality of a component by determining the appearance possibility of pores and their sizes within the solid structure. Image analysis with photodiode signals of micro-sections are used to create a purely machine data driven possibility model.

11:10 **[37] EXPLOITING INTRINSIC HEAT TREATMENT TO TRIGGER PRECIPITATION REACTIONS IN MARAGING STEELS DURING LASER ADDITIVE MANUFACTURING**

Presenter: KÜRNSTEINER, Philipp (Max-Planck-Institute for Iron Research)

Maraging steels show outstanding mechanical properties especially regarding strength and toughness. They exhibit a big advantage over e.g. conventional C-containing tool steels regarding their precessability in Laser Additive Manufacturing (LAM).

Parts produced by Laser Metal Deposition (LMD; DED) possess a unique thermal history: after a rapid quenching from the liquid state, the material experiences a cyclic reheating - the so-called intrinsic heat treatment (IHT). Our aim is to design new steels that are tailor-made for LAM processes exploiting the IHT. We want to produce Maraging steel parts that are already in-situ precipitation hardened during the manufacturing process, avoiding an ageing heat treatment after the LAM process. For this purpose, we apply rapid alloy prototyping to find alloy compositions that respond well to the IHT. We use LMD, a nozzle-based, blown-powder AM-process as well as the powder bed process Selective Laser Metling (SLM).

We could show shown that the IHT can be used to in-situ harden Fe-Ni-Al [1] as well as Fe-Ni-Ti Maraging steel parts printed by LMD. Mechanical properties such as hardness and tensile strength were evaluated and related to the precipitate density, size and chemistry determined by Atom Probe Tomography (APT) and High Energy X-ray Diffraction (HEXRD). Exceptionally high number densities of up to 10^25 NiAl nano-precipitates per m^3 were found in the as-produced Fe-Ni-Al samples. The hardness of the material showed a steep increase of over 200 HV associated with the high number density of those NiAl precipitates.
In the Fe-Ni-Ti system, a dense network of rod shaped ηphase (Ni3Ti) precipitates together with fine, nanometer-sized spherical precipitates are formed upon IHT. An increase in hardness of 300 HV could be achived by precipitation of the ηphase.

Precipitation of NiAl and η-phase can occur only in a martensite matrix. In the Fe-Ni-Ti system we study in detail how martensite start (Ms) temperature, cooling rate as well as IHT strength influence in-situ precipitation. We were able to show how only specific thermal histories lead to precipitation of ηphase and thus how the microstructure can be controlled locally, without changing the alloy composition.

In SLM, the base plate heating is another factor influencing the thermal history. Only if the sample temperature, which is determined by both the base plate heating and the laser heat input, drops below Ms temperature the IHT can trigger precipitation. On Fe-Ni-Al samples we used HEXRD and APT together with hardness measurments to study the in-situ precipitation hardening at different base plate heating temperatures as well as different energy densities (i.e. different strenghts of the IHT).

We demonstrated that the IHT during LAM can be used to trigger phase transformations already during the AM process. This effect should be taken into account for future alloy design for AM.

[1] P. Kürnsteiner, M. B. Wilms, A. Weisheit, P. Barriobero-Vila, E. A. Jägle, D. Raabe: Massive nanoprecipitation in an Fe-19Ni-xAl maraging steel triggered by the intrinsic heat treatment during laser metal deposition. Acta Materialia 129, 52 (2017)

11:30 **[63] STUDY ON THE INFLUENCE OF THE BLADE ON POWDER LAYERS BUILT IN POWDER BED FUSION PROCESSES FOR ADDITIVE MANUFACTURING**

Presenter: MITTERLEHNER, Marco (Technical University Vienna)

For AM performed by DLM route, important aspects are powder characteristics such as flowability but also the morphology of the top layer itself. In the present study, the quality of the applied top layer was studied using a self-made tester for the layer building process and a digital microscope with a large depth-of-field to observe the surface of the top layer. These three-dimensional images have then been analyzed by a self-written program, which calculates specific parameters as well as the size of the particles in the top layer to rate the quality of the surface. Using this technique, the influence using different blades and varying the blade speed during the layer building process on the quality of the surface has been investigated.

Power Production and Characterization: Power Production and Characterization - 2: Länssalen (26 November 10:30-11:50)

time	[id] title
10:30	**[23] MICROSTRUCTURE AND MECHANICAL PROPERTIES OF A COLD-WORK TOOL STEEL PRODUCED VIA ELECTRON BEAM MELTING (EBM)** *Presenters: SELTE, AYDIN (Uddeholms AB), OIKONOMOU, Christos (Uddeholms AB), KARAMCHEDU, Seshendra (Uddeholms AB)* Electron Beam Melting (EBM) is one of the most promising techniques within Metal Additive Manufacturing (AM) techniques, which currently is for the fabrication of high performance components for the aerospace and medical industries, mostly. Among the industrial applications envisioned for the future of EBM, the fabrication of high carbon steels for the tooling industry is of great interest. In this study, martensitic highly alloyed (Cr-Mo-V) cold-work tool steel was processed by EBM. A suitable heat treatment was proposed in order to obtain an optimal microstructure, which was studied by means of optical and scanning-electron microscopy. The mechanical behaviour of the material was characterized by means of compression testing and the tribological performance was assessed by means of abrasive wear tests. The influence of build-direction was further studied with regard to these characteristics. The results obtained were compared with those obtained from the conventionally processed material through the powder metallurgy route.
10:50	**[46] RHEOLOGY OF METAL MELTS - HOW TO IMPROVE GAS ATOMIZATION PROCESSES IN METAL POWDER PRODUCTION BY USING A HIGH TEMPERATURE RHEOMETER** *Presenter: EHGARTNER, Daniela (Anton Paar)* Nowadays rheology is quite commonly known and established in industries such as food and beverages, body care, or petroleum; rheology for metal melts is still at the beginning but gets more and more established in both, research and industry. Rheology helps to determine the viscosity of a certain material at different conditions like temperatures or shear rates. Viscosity is one of the most important material characteristics, besides surface tension, in the gas atomization process during production of metal powder. Only if viscosity of the metal melt lies within certain boundaries a good quality metal powder can be produced. This contribution aims at introducing rheology in general and the advantages for metal powder production in specific. On the basis of several measurements on typical metal alloys for additive manufacturing the results of such measurements are shown and their impact for gas atomization processes is discussed.
11:10	**[51] EX- AND IN-SITU MICROSTRUCTURE INVESTIGATIONS OF POWDERS AND ADDITIVE MANUFACTURED PARTS** *Presenter: ALBU, Mihaela (ZFE Graz)* This paper presents an advanced microstructural analysis of the powder as well as of the as-built and heat treated additive manufactured parts of Al-alloy and N700 steel. Evolution of the microstructure during the heat-treatment was studied in detail in order to better understand the mechanical properties of the printed parts. For crystallographic and chemical characterization down to atomic resolution, ex- and in-situ scanning and scanning transmission electron microscopy (SEM and HR STEM) were involved. STEM acquisition of high angular annular dark field images (HAADF) and differential phase contrast images, as well as both X-ray (EDX) and electron energy loss spectrometry (EELS) spectrum images, were used to localize and identify the elements and their stable and metastable phases. In-situ STEM observations provided information regarding the crystallization of amorphous phases and coarsening/shrinking of grains, diffusion of alloying elements and nucleation of secondary phases at different temperatures.
11:30	**[24] PREDICTED IMPACT OF VAPOUR CHANNEL ON POWDER BED ON PROCESSING IN SELECTIVE LASER MELTING IN REDUCED GRAVITY** *Presenter: FROSTEVARG, Jan (Luleå University of Technology)* Additive Manufacturing provides many opportunities to design and manufacture parts that are difficult or not possible to produce with conventional methods, but in some cases even more important, to be able to produce these or any metal replacement parts in remote places like the moon or Mars. In laser powder bed fusion (LPBF), melt pool dynamics and stability is dependent on a large number of factors, e.g. laser power output, power density, travel speed, reflectivity of powder bed, rapid heating and vaporization. Since travel speeds are often very fast and the laser interaction zone is small, the physical events become difficult to predict but also to observe. This work aims to describe the formation and geometrical characteristics of the vaporization zone and its consequences on the powder bed during processing. Using a combination of theoretical descriptions, resulting material structures and a comprehensive analysis of high-speed images of the processing zone, explanations for the dynamic melt pool behavior are derived. These findings will be used to predict LPBF processability in different gravitational fields, resulting in estimation of feasibility of its use on interstellar bodies with varying gravity.

Lunch - (11:50-13:20)

Keynote: Keynote - 1: Rikssalen (26 November 13:20-14:15)

time	[id] title
13:20	**[68] AMEXCI - ADDITIVE MANUFACTURING EXCELLENCE FOR INDUSTRY** *Presenter: RESEBO, Edvin (AMEXCI)* AMEXCI and its operations.
13:45	**[43] 3D COMPETENCE CENTER FOR ADDITIVE MANUFACTURING AT SMS GROUP - PROVIDING MOST ADVANCED POWDER ATOMIZATION PLANTS FOR THE PRODUCTION OF HIGH-GRADE METAL POWDERS** *Presenter: BRUNE, Tobias (SMS group GmbH)* The SMS group is a group of global players in plant construction and mechanical engineering for the steel and nonferrous metals processing industry with over 14,000 employees in more than 50 global locations. The objective is to provide integrated high-end turn-key solutions for our customers also in the field of Additive Manufacturing (AM). Therefore, SMS is targeting to become a full liner by taking all major processing steps of 3D printing into account, including powder atomization, design and 3D printing. A full scale powder atomization plant for the production of high-grade metal powders has been built to gain detailed operator know-how and production expertise to develop and produce different AM powders. Therefore the SMS group has set up a 3D Competence Center at their location in Moenchengladbach, Germany to continuously investigate all major steps of metal Additive Manufacturing. The main goal is to analyze and develop the different influencing factors during atomization and further powder processing and the correlating properties during processing steps. By this full liner approach for the entire value chain of additive manufacturing, SMS can bring the best value to customers. To realize highest cleanness of the powder the melting and refining of metals and alloys is taking place under vacuum or inert gas atmosphere. The atomizing process with argon or nitrogen, using the close-coupled principal, guarantees defined grain sizes and distribution of metal powders. A self-developed and unique anti-satellite system is used for the needed spherical particle shapes which guarantee good flow properties during the 3D printing process. Detailed know-how of the atomizing process is necessary to ensure highest quality standards of the powder. Therefore SMS currently develops a CFD model that is able to calculate the particle size distribution for varying process parameters such as steel grade, superheating temperature of melt, primary and secondary nozzle size, nozzle protrusion length, gas flow pressure, gas-to-liquid ratio (GLR) and others. Phenomena like the lick-back will be predicted by the CFD model. In addition a laboratory experimental setup for water atomization has been built-up to investigate the interaction between shock/expansion wave structure and water flow (Schlieren measurement, PDA, high speed observations). The full liner approach of SMS group ensures in-depth know-how of all major processing steps of additive manufacturing. All the gained technological understanding is transferred into the Powder Atomization Plant. So that customers are enabled to become the leading supplier of the AM industry by offering metal powder at the highest quality level.

Panel Discussion - (26 November 14:15-15:30)

time [id] title

14:15 **[25] RESEARCH POLICY ON MANUFACTURING IN AUSTRIA**

Presenter: POGANY, Alexander (Policy Expert)

The manufacturing industry, with approximatly 640,000 employees in 29,000 companies and a gross value added of approximatly 50 billion euros per year is the backbone of Austrian economy. Almost every fifth euro in Austria is earned by the domestic manufacturing industry, almost two thirds of the workforce depend directly on it. All the more reason why producing internationally competitive products is an essential factor for prosperity.

Therefore the goal is to keep the manufacturing industry in Austria and to make it fit for the future. Many outstanding production companies are located in Austria, not few of these are global and technological leaders. Still, the pressure from international competition is enormous and domestic industry can only survive if it can develop innovative technologies and improve in productivity.

The requirements are exacting: on the one hand, new high-tech materials, lower production costs and shorter development cycles; on the other hand, greater product diversity, resource and environmentally friendly manufacturing processes, logistics and recycling issues and many more aspects. All this and more demand innovative solutions.

The RTI programme "Production of the Future" by the Austrian Federal Ministry of Transport, Innovation ans Technology (BMVIT) has the following goals since the year 2012:

- Efficient resources and resource management, efficient production technologies to increase international competitiveness and to strengthen Austria's position as an industrial location
- Flexibilizing production to enhance Austria's production expertise
- Manufacturing high-tech products to underscore Austria's position as an innovation center

Funded Projects are placed in the following categories:
Efficiency and quality in manufacturing ad addtive Manufacturing, Advanced materials, surfaces and coatings and nanotechnology, Critical raw materials, Bio-based industry
robotics and photonics

The BMVIT has recently financed an Austrian Roadmap on additive Manufacturing. Goal of this Roadmap was to analyse srentgts and weaknesses of Austrian science and industry and to develop a strategy for future research policy in this field. The Pattform "addtive manufcturing Austria" will cordinate all activities of addtive Manufacturing in Austria and will be the Interface to the public Administration.

14:30 **[57] ADDITIVE MANUFACTURING - TECHNOLOGY ADVANTAGES, MATERIAL PROPERTIES AND QUALITY CONSIDERATIONS IN TOOLING APPLICATIONS**

Presenter: MEDVEDEVA, Anna (Uddeholms AB)

Additive manufacturing is becoming more common as a manufacturing technique, especially in tooling, but the technology is still rather new. It allows shorter lead time and design freedom such as conformal cooling and in-printed porosity resulting in shorter process cycle times, longer tool life and higher quality of components produced. Sensors and actuators can also be printed in the critical areas for monitoring the working condition and online adjust the tooling process. The development of powder is still at an early stage and interaction between printing parameters, powder chemistry and morphology as well as hybrid-tool building and post processing consideration have to be taken into the account to achieve similar and better performance of a printed part compared to the conventionally produced. The presentation provides the examples on the above mention aspects indicating that additive is the tomorrows manufacturing technology.

Panel Discussion - (15:30-16:00)

Coffee Break - (15:30-16:00)

Process Optimization & Control and Quality Assurance: Process Optimization & Control and Quality Assurance - 1: Rikssalen (26 November 16:00-17:40)

time [id] title

16:00 **[5] THE SIEMENS AM-MONITOR: A NECESSARY PUZZLE PIECE FOR INDUSTRIAL 3D-PRINTING**

Presenter: ERIKSSON, Jonas (Siemens Industrial Turbomachinery)

When Siemens in Finspong introduced selective laser melting (SLM) on a broader scale, it became soon clear that the machine performance did not reach the high expectations concerning process stability, repeatability and transferability between several machines of the same type. That is why Siemens with the involvement of machine learning and big data specialists developed the “Siemens AM Monitor”. The present status is described and an overview over the future development is given. Typical imperfections are discussed.

16:20 **[33] DESIGN, MANUFACTURING AND CHARACTERIZATION OF HIGH-STRENGTH Al ALLOYS WITH IMPROVED SLM PROCESSABILITY**

Presenter: CASATI, Riccardo (Politecnico di Milano)

Beam-based additive manufacturing processes are widely used for producing components serving in several industrial applications, but only a few materials have been designed and optimized to bear the specific processing conditions offered by these technologies. Nowadays, a limited number of Al alloys are available on the market and employed for 3D printing of structural parts. Al-Si-Mg casting grades are the most common alloys for additive manufacturing, but they feature moderate mechanical properties. Through this research work, we studied the effect of different alloying elements on the processability by Selective Laser Melting (SLM) of Al-Mg-Cu high-strength alloys. A screening activity has been carried out by blending and processing Al alloy powders with different compositions. The ability of the modified alloys to respond to aging starting from as built and solution annealed conditions has been evaluated as well. The microstructure and phase transformations of the new alloy has been investigated by differential scanning calorimetry (DSC) and scanning electron microscope (SEM) analysis. The novel alloys processed by SLM featured a relative density higher than 99.8 % and were not susceptible to hot cracking phenomena. They also showed a good response to artificial aging, featuring yield strength and an ultimate tensile strength similar or even higher than those of high strength Al alloys produced by conventional casting processes.

16:40 **[11] STUDY OF LASER METAL DEPOSITION OF IN718 ON INCLINED PLANES: INFLUENCE OF INCLINATION ON HEIGHT AND WIDTH OF DEPOSITED MATERIAL**

Presenter: BOLD, Marie-Noemi (Chair for Digital Additive Production, RWTH Aachen University)

Laser Metal Deposition (LMD) as a repair technology has been established in recent times. A commonly used material for repairs of turbines are nickel-base alloys, such as Inconel 718 (IN718), which presents good mechanical properties at temperatures up to 650 °C and good corrosive resistance.

Inclined or curves surfaces pose a challenge in repairing parts with LMD due to the dependence of height and width of deposited tracks on the local inclination angle. An extensive preparation on path planning is needed to ensure high densities and good properties of the deposited material. This paper is a systematic study of LMD of IN718 on inclined planes for a better understanding of changes in the geometry of deposited material tracks. In a first step, height and width of single tracks at various inclinations are evaluated by optical profilometry and metallographic cross sections. The deposition process is recorded with high speed videography and particle trajectories are evaluated. Then, heights of layers built with three different scanning strategies are analysed: a) horizontal single tracks starting from the top going down, b) horizontal single tracks starting from the bottom going up, c) single tracks going up and down. Furthermore, the influence of inclination on dilution of the base material and on defects such as pores and bonding defects is investigated.

By studying the basis of LMD on inclined surfaces, this paper helps to improve and accelerate path planning for repairs by LMD on complex surfaces and to shorten preparation time for repairs of new geometries of parts to be repaired.

17:00 **[45] INTRINSIC HEAT TREATMENT DURING LASER METAL DEPOSITION - DRIVING FACTORS, KINETICS AND EFFECT OF ALLOYING ELEMENTS**

Presenter: BAJAJ, Priyanshu (Max Planck Institute for Iron Research)

In additive manufacturing (AM), parts are built from layer by layer fusion of raw material (eg. wire, powder etc.). Such layer by layer application of heat results in a time-temperature profile which is fundamentally different from any of the contemporary heat treatments. Previous works have established that this unique thermal profile can be exploited for microstructural modifications (eg. clustering, precipitation) during manufacturing [1,2]. The aim of this work is to develop a fundamental understanding of such a strongly non-linear, peak-like thermal history on the precipitation kinetics. To study the precipitation kinetics during the said intrinsic heat treatment experiments were performed using a model Al-Sc-Si alloy. A thin-walled sample was produced by depositing single tracks of material one over the other. This way, in one sample different cooling conditions were achieved in different layers. The induced precipitation in the sample was studied using Atom Probe Tomography (APT) and compared with CALPHAD based simulations. The time-temperature profiles were simulated using an analytical model which was fed into ThermoCalc (a CALPHAD based modelling software) to simulate precipitate evolution. The simulations are calibrated with experimental measurements of precipitate volume fraction and mean radius using atom probe and small angle X-ray spectroscopy. The study shows a complex peak-like behaviour of the driving forces for precipitation and the critical radius for stable precipitates. This results in a complex sequence of nucleation, growth and dissolution of particles with each thermal cycle. The final result is a uniform distribution of nano-sized precipitate particles with a very high number density (~1024 m-3). Further, role of Si, a common impurity in Al alloys, on the precipitation kinetics and thermodynamics of (Al,Si)3Sc precipitates is studied using experiments and first principle simulations.

17:20 **[60] CORROSION EVALUATION OF ADDITIVE MANUFACTURED 316L AND INCONEL 718 USING AFM BASED TECHNIQUES AND STANDARD ELECTROCHEMICAL TESTING METHODS**

Presenter: FUERTES, Nuria (Swerim AB)

The market and research for additive manufactured (AM) materials are currently in fast development. However, there are few studies on the influence of the different AM processes on corrosion properties of the final materials. Moreover, due to the heating history during manufacturing process AM metals have a more complex microstructure compared to conventionally manufactured metals. Since the microstructure has a major influence on the corrosion behaviour there is a need for using advanced characterisation techniques that allow a correlation between microstructure features and corrosion properties.

In this work the materials investigated were a nickel-based alloy, Inconel 718, and an austenitic stainless steel, 316L. The manufacturing methods were two powder-bed fusion techniques and a direct energy deposition technique. The corrosion properties of the printed materials were evaluated by standard electrochemical testing, including pitting potential, repassivation behaviour and critical pitting temperature. In addition to the standard corrosion tests the Atomic Force Microscopy (AFM) based techniques, Scanning Kelvin Probe Force microscopy (SKPFM) and In-situ AFM, were used to study the electrochemical response and corrosion susceptibility at microstructural level. Areas on the specimen with a positive or negative work function were mapped with SKPFM and correlated to anodic and cathodic zones of the microstructure. In the in-situ AFM the specimens were immersed in a corrosive electrolyte and the topography variations due to corrosion were investigated. A correlative investigation was performed between the AFM results and the microstructure and composition using Electron backscatter diffraction (EBSD).

This work showed that the investigated AM processes lead to different corrosion properties of the studied materials compared to the reference alloys. With the AFM based techniques specific microstructures in the alloys were correlated to corrosion initiation.

The combined tests provided new insights into the corrosion properties of AM manufactured metals, however, further work is necessary to develop general standards.

Post-Processing: Post-Processing - 2: Länssalen (26 November 16:00-17:40)

time [id] title

16:00 **[6] "PROPERTIES OF SURFACE ENGINEERED METALLIC PARTS PREPARED BY ADDITIVE MANUFACTURING"**

Presenter: STELZER, Nils (Aerospace Advanced Composites GmbH)

Additive manufacturing technologies allow manufacture of shapes that are not possible with conventional machining. This design freedom is very attractive for space hardware, as equipment performance could be significantly improved with increased shape complexity. Furthermore, conventional machining results in a high buy-to-fly ratio; i.e. more than 70% of the material is transformed to swarf, that must be recycled. Using additive manufacturing, the amount of material to be recycled is substantially decreased, limited to the light structure that may be needed to support the part while it is built. The potential of the Additive Manufacturing technologies is however impeded by the surface finish obtained on the as-manufactured material. Therefore, the influence of various surface treatments, commonly applied to space hardware, on the mechanical properties of three selected metallic alloys prepared by using Selective Laser Melting (SLM) and Electron Beam Melting (EBM) additive manufacturing processes have been investigated.

Within this study, SLM using EOS M400 and EOS M280 equipment and in addition EBM using an ARCAM Q20 machine have been applied for sample manufacturing of three selected metallic alloys (SS316L, AlSi10Mg, Ti6Al4V). The influence of various surface treatments, e.g. anodization, Ni-coating, shot peening, chemical and electrochemical polishing, Hirtisation, and their applicability as well as to obtain low surface roughness has been investigated on these additive manufactured alloys. A trade-off considering various parameter relevant to space applications led to the selection of the best surface treatments for each alloy.

The influence of the selected best surface treatments on the mechanical properties of these additive manufactured alloys have been investigated and compared to as-received samples. Special emphasize has been taken on their tensile, fatigue, and fracture toughness properties. In addition, their corrosion and stress corrosion cracking (SCC) behaviour including microstructural analysis using HR-SEM have been investigated. Furthermore, space relevant coatings and paints have been applied in order to investigate their adhesion under space environments.

16:20 **[40] DIRECT TEMPERING OF A HOT WORK TOOL STEEL FABRICATED BY SELECTIVE LASER MELTING: TEMPERING BEHAVIOUR AND MECHANICAL PROPERTIES**

Presenter: DEIRMINA, Faraz (Sandvik Additive Manufacturing)

In this study, tempering behaviour of AISI H13 fabricated by Selective Laser Melting (SLM) in as-built and “austenitized and quenched” conditions are evaluated. Compared to the austenitized and quenched counterpart, secondary hardening peak is more pronounced and is shifted to a higher temperature in directly tempered H13. It is shown that the decomposition of retained austenite (RA), up to 19vol% in as-built H13, during tempering is responsible for the different tempering behaviour. In spite of significantly higher hardness of the directly tempered parts, comparable fracture toughness is achieved for both samples. In view of the improved hardness, mechanical properties and thermal stability, it is suggested that direct tempering can be sucsessfuly applied to the additively manufactured tool steel parts.

16:40 **[2] AUTOMATED SURFACE FINISHING FOR 3D-PRINTED METAL PARTS AS ENABLER FOR SERIAL PRODUCTION**

Presenter: HANSAL, Wolfgang (Hirtenberger Engineered Surfaces)

With the evolution of 3D printing of metals from the prototyping scale towards a serial production the different steps in the production chain have not only to be fully understood but also adjusted to each other and to the requirements of the final product. Among the different process steps, the post-processing of AM metal parts is a crucial element but nevertheless still an open issue at the industrial scale and up to now often neglected. The 3D-printed metal parts leave the printer, independently from the way of printing in terms of LBM or EBM, with a significant amount of support structures fixed to the part, adhering metal powder (partly sintered powdercake in the case of EBM) and a surface roughness that is about an order of magnitude too high for the technical application.While mechanical post treatment methods are mostly work, time and cost intensive they also cannot provide a proper finishing on sterically hindered parts and inner surfaces. Here electro-chemically based methods, such as the Hirtisation® process, provide a Technique that enables an integrated production process and additionally give an valid option for complete process automatisation.
This presentation gives a report of the results of different electrochemically based surface treatments of 3D-printed metal parts and the corresponding results of mechanical testing. Beside the post-finishing process for support structure removal and surface roughness decrease, the possibilities and importance of protective coatings and corrosion protection will be discussed.

17:00 **[20] PROPERTIES OF SELECTIVE LASER MELTED AlSi10Mg ALLOY PROCESSED USING DIFFERENT HEAT TREATMENTS**

Presenter: PELLIZZARI, Massimo (University of Trento, Dpt. Industrial Engineering)

The AlSi10Mg alloy was fabricated by Selective Laser Melting (SLM) using different post processing conditions. Tensile and dilatometric specimens were obtained with longitudinal axis parallel to the building direction. A first set of samples has been directly aged in the as-built state (AB) while a second batch underwent solubilization annealing (SA) at 540°C for 60min just before artificial ageing (AA) at 160°C for 8h. Solubilization caused the precipitation of Si particles, suppressed by the rapid solidification during SLM. Moreover, it caused partial recrystallization leading to a coarser microstructure. The ageing response resulted very different in the two cases, involving a higher starting hardness for the as-built material, showing a markedly higher hardness during the whole process. In the as built (AB) material, isochronal ageing experiments carried out by differential scanning calorimetry showed the precipitation of Mg2Si particles beneath Si, while the same transformations were much less intense in the solubilized sample, due to the lower Si supersaturation. The ageing process raised the yield strength of about 20% compared to the AB material, slightly reducing the fracture elongation. The same alloy after SA+AA showed a strength 25% lower than the AB+AA material, while ductility significantly increased.

17:20 **[31] TAILORED HEAT TREATMENT OF SELECTIVE LASER MELTED METALS**

Presenter: FUNCH, Cecilie Vase (Technical University of Denmark (DTU))

The selective laser melting process involves very high cooling rates and consequently results in non-equilibrium microstructures of the printed metal. Examples of this are the cellular sub-grain structure observed in austenitic stainless steels and the very fine hierachical martensite formed in Ti6Al4V titanium. Both stainless steels and titanium alloys are commonly heat treated in order to tailor the microstructure, so the desired final properties can be obtained. However, the successful application of these heat treatments usually relies on the microstructure after conventional processing, which often includes deformation and which is radically different from the non-equilibrium microstructure obtained with additive manufacturing. Since one of the main benefits of additive manufacturing is to realize the final design without material waste or specialized post-machining, deformation is often not a desired post-process. Therefore, the conventional heat treatments need to be tailored to the initial microstructure of selective laser melted materials. This research focuses on the effect of heat treatments on the characteristic features of the microstructures (e.g. cells or martensite formation) and tailoring the heat treatments in order to achieve a specific microstructure by either preserving parts of or completely altering the initial state. The investigated heat treatments are inspired by conventional heat treatments for these materials, however adapted to fit the unique qualities of selective laser melting. Both high and low temperature treatments are considered to provide different microstructures. The effect of the treatments is characterized using microscopy, x-ray diffraction and Vickers microindentation.

<u>Conference Dinner</u> - (19:00-22:00)

Wednesday 27 November 2019

Keynote: Keynote - 1: Rikssalen (27 November 09:00-09:30)

time	[id] title
09:00	**[55] OPPORTUNITIES AND CHANCES OF ADDITIVE MANUFACTURING FOR COMPONENTS AND TOOLS** *Presenter: KLEMP, Eric (voestalpine Additive Manufacturing Center)* Additive Manufacturing offers lot of opportunities , especially for tool and components. Besides all positive aspects, there are risk as well, as AM is only successful, if the right design with the right material is combined. There are many USPs being able to be achieved if the complete value chain is consider and the potential is recognised. In this presentation, this approach will be proved by different examples.

Applications - 1: Rikssalen (27 November 09:30-10:30)

time	[id] title
09:30	**[27] PROCESSING AND PERFORMANCE OF X35CrMoV5-2 TOOL STEEL FOR HIGH PRESSURE DIE CASTING MANUFACTURED VIA LASER POWDER BED FUSION** *Presenter: BRORSON, Sofia (Uddeholms AB)* There is an increasing trend in terms of utilization of Aluminium parts produced through high pressure die casting (HPDC) for parts with increased complexity in design and size, especially for the automotive industry, driven by the weight saving philosophy. This places increased demands on the performance of the tool steels utilized for HPDC. Besides the development of new tool steels to fulfil these demands, innovative solutions such as utilization of inserts/ sections produced through Additive Manufacturing (AM) to obtain improved thermal management, aluminium part quality and die-life are being explored. In this regard, the possibility of utilization of the well-established X40CrMoV5-1 type materials conventionally used in such application is being explored. In the current study, the development of process parameters and the subsequent post treatment of a X35CrMoV5-2 powder are discussed. The heat treatment response and the mechanical properties consequently obtained are presented. Furthermore, the performance of the alloy in terms of application specific properties such as thermal fatigue and soldering resistance is evaluated. These properties of the AM tool steel are compared to those of the traditional tool steels used for HPDC. The robustness of the alloy in terms of stability during the printing process is also discussed. The results obtained suggest that the X35CrMoV5-2 tool steel exhibits excellent potential for being utilized in HPDC applications.
09:50	**[19] INFLUENCE OF HEAT TREATMENT ON SOLDERING AND THERMAL FATIGUE PERFORMANCE OF NOVEL AM TOOL STEEL** *Presenter: ÅSBERG, Mikael (Karlstad University)* With additive manufacturing the internal cooling channels can be manufactured to an optimized geometry in order to have conformal cooling. In die casting soldering and heat checking are the main problems. Soldering is a result of the interaction between the steel and the molten aluminium. Heat checking is related to thermal fatigue. The development of AM powder is still at an early stage and the most AM grades on the market are easy to process with laser powder bed fusion, but not designed for the application. Therefore, thermal fatigue resistance has to be tested for existing and new materials. In the present investigation the influence of heat treatment and microstructure on soldering and thermal fatigue resistance was evaluated. Soldering testing was done where tool steel rods were submerged into molten die casting aluminium at 680 °C. The composition and thickness of the intermetallic layer of the samples were evaluated. To simulate thermal fatigue heating with induction was performed between 200 °C and 700 °C for 20000 cycles. Heating time was approximately 0.5 s, and total cycle 2.1 s. The materials were evaluated by measuring the crack depth in the heat affected zone in microscope. Maximum crack depth, mean value of the 10 deepest cracks, and crack density were calculated. Microstructure characterisation was done in SEM.The result showed that the heat treatment influenced microstructure, mechanical properties, crack depth and crack density. Soldering resistance was more sensitive to chemical composition of the steel. Based on these observations the materials were ranked in order to predict the performance of the tested steels in die casting application. Influence of heat treatment on microstructure and properties was discussed to develop new heat treatment regimes.

10:10 **[47] EXPERIMENTAL INVESTIGATION AND PREDICTION OF FATIGUE LIFE OF ADDITIVELY MANUFACTURED KNOCKOUT BAR**

Presenter: SALUNKHE, Sachin (Department of Mechanical Engineering, Institute of Science and Technology, Chennai)

Metal Additive manufacturing (AM) offers new possibilities for the production of complex structures of mechanical parts. Recent investigations on the metal AM show a significant spread and unpredicted failures cannot be excluded. In this paper, we efforts on experimental investigation and prediction of fatigue life of metal additively manufactured sheet metal dies knockout bar. Tensile and fatigue tests of knockout bar are conducted in the MTS Acumen 03 machine. The tests were conducted as per ASTM E8 standards with a diameter of 12mm and length of 100mm rod. The fatigue test was conducted till failure of the samples. The tensile test results were used to analyze the fatigue property of the materials. The samples underwent the zero based analysis of testing (R=0). Finite element (FEM) simulations were performed to validate the experimental test results. The Scanning Electron Microscope (SEM) image of the tensile tested samples reveals the failure of the surface area of knockout bar. The fractured surface of the fatigue tested samples is also studied.

Process Optimization & Control and Quality Assurance: Process Optimization & Control and Quality Assurance - 2: Länssalen (27 November 09:30-10:30)

time [id] title

09:30 **[52] OPTIMIZATION OF 316L PRINTING PARAMETERS FOR HIGHER PRODUCTIVITY OF THE SLM-PROCESS**

Presenter: HÖLLER, Christian (Graz University of Technology)

Selective Laser Melting (SLM), as a leading metal-based Additive Manufacturing technology, has constantly evolved in the past years, but it is still a cost-intense manufacturing technology. One of the major reasons for this is the slow build rate for parts produced by SLM machines. To address this problem, this study presents advanced parameters for the processing of 316L stainless steel which increase the build rate.

At first, the cost structure of SLM process was analyzed and the build time as a main cost driver soon could be identified. Different scenarios where selected to simulate the influence of relevant scanning parameters on the build time. Promising sets of scanning parameters were found and test samples were fabricated. To evaluate their properties, the relative density, surface roughness and microstructure were investigated. The results indicate that the scanning parameter influence the build time significantly. The build time was reduced up to 45 % depending on the chosen scenario whereas the relative density stayed at high ranges of above 98 %. In addition, the inclination angle as a further characteristic value in SLM processing could be enhanced by 15°, which reduces the amount of necessary support structures and its work-intensive removal as a consequence. The results showed that the use of optimized scanning parameters is an effective method to improve the cost efficiency of the SLM process.

09:50 **[49] THERMAL ANALYSIS OF 316L STAINLESS STEEL BULK PARTS USING NUMERICAL SIMULATION OF THE ADDITIVE MANUFACTURING**

Presenter: HODEK, Josef (COMTES FHT)

This study deals with investigation of bulk parts created by Additive Manufacturing (AM) processes. The numerical simulation of AM was used for description of thermal behaviour of bulk parts during the production process. Industrial metal 3D printer InssTek MX-600 was chosen for experimental device because it is classified as a Directed Energy Deposition (DED) technology by ASTM. Further, an austenitic stainless steel 316 was selected because phase transformations do not occur during heating in this steel.
The objectives of this study are twofold: firstly the numerical model of the DED was created to calibrate, to reach high accuracy. Secondly, to determinate the residual stress by contour method. The numerical model was created in Simufact welding software to describe the thermal behaviour of each layer during the process and thanks to numerical simulation was analysed the sensitivity of the process parameters to thermal behaviour of printed part and to compare with the experimental result. The contour method was applied to evaluate the residual stress in part printed by DED. The printed part was cut and measured and then the residual stress was evaluted using the inverse analysis by FEM. The result of this study can be used to build complex structures for components such as turbine blades, energy facilities or medical implants.

10:10 **[7] OPTIMIZATION OF LPB/SLM PROCESS AND MARAGING STEEL POWDERS FOR PLASTIC INJECTION MOULDS**

Presenter: VICARIO, Valentina (MIMETE Srl)

Performances of plastic injection moulds heavily affect productivity and yields of high volume industries as packaging, cosmetics, …. RB is historically specialized in mould design and production and the introduction of a laser bed printer enlarged
its possibilities especially in terms of optimization of cooling channels, more numerous and closer to the functional surface. RB
started working with commercial maraging and other steel powders: they observed some differences among producers and grades and started questioning about the relationship between powders and printing parameters. The necessary metallurgical
competences and laboratory equipment have been found in MIMETE, the new Italian metal powders producer. The two companies are working together on a long-term European project aiming at the development of new optimized powders and
LPB/SLM process parameters to:
1) maximize productivity
2) control roundness and roughness of cooling channels
3) maximize powder life
4) reduce tendency to cracking
5) increase thermal fatigue properties.

Coffee Break - (10:30-11:00)

New Materials - 1: Rikssalen (27 November 11:00-11:40)

time [id] title

11:00 **[58] ADDITIVE MANUFACTURING OF A LOW-ALLOYED ENGINEERING STEEL** *Presenter: AUMAYR, Christin (voestalpine Böhler Edelstahl GmbH Co KG)*

Additive manufacturing of steel powders gained in recent years a lot of attention. In the early stages of Laser Powder Bed Fusion (L-PBF) of steel powders the well-known materials 1.2709, 316L and 17-4 PH have been used due to their very low carbon content. However, since these materials are on the one hand quite soft (316L) and on the other hand in some cases too highly alloyed for specific engineering applications (1.2709), also carbon steels are increasingly considered for use in L-PBF processes. In general it is well known, that carbon limits the weldability of the steel materials. As a rule of thumb, steels with a carbon content below 0.22 wt.-% are suitable for L-PBF processes without powder bed preheating. Therefore, this work will present a new carbon-steel alloy concept which can be processed by L-PBF without powder bed preheating. Due to the special alloy design, it will be shown, that the printed parts are ready-to-use in the as-built state with a well-balanced property relationship of strength, ductility and impact toughness. Beside the usability in the as-printed condition, it will be presented, that an additional heat treatment or even a surface hardening process can be used to gain even better material and part properties compared to the as-built condition.

11:20 **[29] UDDEHOLM AM HEATVAR®: A NEW AM MATERIAL WITH EXCELLENT HIGH-TEMPERATURE PROPERTIES FOR DEMANDING HOT WORK APPLICATIONS**

Presenter: KVARNED, Anders (Uddeholms AB)

It has been hypothesized that the design flexibility offered by additive manufacturing (AM) can be beneficially employed to improve tool life and part quality in high pressure die casting (HPDC) applications, particularly, to address challenges originating from inadequate temperature management. The principle challenge in terms of adapting the AM technology in these applications though is the lack of availability of tool steel materials with properties suitable for the demanding HPDC conditions together with the necessary “printability”.

In this work, the characteristics of a newly developed AM tool steel- Uddeholm AM Heatvar optimized for utilization in HPDC applications are discussed. The processing of the alloy with regard to both printing and subsequent post treatment suitable for the application demands is presented. It is shown that the aforementioned tool steel along with good processability in Laser Powder Bed Fusion (LPBF), exhibits excellent hot-strength and temper-back resistance at elevated temperatures relevant for HPDC. It is also shown that the “resistance to soldering”, soldering being a wear mechanism by chemical corrosion-interaction between the tool surface and the melt, for Uddeholm AM Heatvar is comparable to that of conventionally used H13 type alloys and is superior to commercially available AM steel grades. The compatibility of the developed tool steel in terms of being able to be “printed” on existing tool steel base materials, so called “hybrids”, is also discussed. The performance of the new AM tool steel grade is elucidated using a case study.

Process Optimization & Control and Quality Assurance: Process Optimization & Control and Quality Assurance - 2: Länssalen (27 November 11:00-12:20)

time	[id] title
11:00	**[53] MICROSTRUCTURE AND HIGH RESOLUTION INVESTIGATIONS OF A205 AND AlSi10Mg ALLOYS PRODUCED BY SELECTIVE LASER MELTING** *Presenter: BASSANI, Paola (CNR ICMATE)* Among additive manufacturing technologies, selective laser melting (SLM) is characterised by high solidification cooling rate. SLM can promote the formation of metastable phases and the effects of heat treatments on SLMed parts can be quite different respect to cast material. This has already been demonstrated for AlSi10Mg alloy. Not only the precipitation of hardening phases, like Mg2Si, was affected but also the cellular silicon network underwent morphological modifications, which can influence the mechanical properties. Similar behaviour could be expected for other Al based alloys, characterised by the presence of both 'stable' secondary phases and metastable phases, which contribute to precipitation hardening. In the present work, two aluminum alloys, AlSi10Mg and A205, both characterised by an high castability and good mechanical properties after thermal treatment, were studied. As built microstructure similarities and differences are discussed in view of thermal treatment optimisation. Calorimetric analysis and microhardness measurements were carried out for studying the precipitation phenomena and the mechanical properties of the alloys, respectively. Finally, a comparison between the characteristics of the SLMed parts and the initial powder was taken into account for considering the effect of different values of cooling rates.
11:20	**[28] INNOVATING WITH GAS MOLECULES IN ADDITIVE MANUFACTURING** *Presenter: FORET, Pierre (Linde)* This presentation aims to give insight how Linde, the largest gas company worldwide, has invested in Additive Manufacturing (AM) over the past years. The two main insights are the development of gas-based technologies to support the industrialization of AM and the usage of the specific advantages of the technology in the development of gas applications like burners and nozzles. Atmospheric gases play an important role in AM core printing and pre- and post-production processes. Linde is researching in collaboration with leading institutes and industrial partners from the aerospace, material and automotive industry, how the utilization of new gas molecules during printing can improve the productivity and quality of the final product. This presentation will also present how Linde is successfully exploring ways to integrate AM into the production of existing and new product lines like the LINDOFLAMM burners and the CARBOTHAN heat treatment lance, whose integrated sensors measure key parameters to enable predictive maintenance.
11:40	**[44] PREDICTIVE PROCESS PARAMETER SELECTION FOR SELECTIVE LASER MELTING MANUFACTURING: APPLICATIONS TO HIGH THERMAL CONDUCTIVITY ALLOYS** *Presenter: BAJAJ, Priyanshu (Max Planck Institute for Iron Research)* There is growing interest in Laser Powder Bed Fusion (L-PBF) or Selective Laser Melting (SLM) manufacturing of high conductivity metals such as copper and refractory metals. SLM manufacturing of high thermal conductivity metals is particularly difficult. In case of refractory metals, the difficulty is amplified because of their high melting point and brittle behaviour. Rapid process development strategies are essential to identify suitable process parameters for achieving minimum porosities in these alloys, yet current strategies suffer from several limitations. We propose a simple approach for rapid process development using normalized process maps. Using plots of normalized energy density vs. normalized hatch spacing, we identify a wide processability window. This is further refined using analytical heat transfer models to predict melt pool size. Final optimization of the parameters is achieved by experiments based on statistical Design of Experiments concepts. In this work we demonstrate the use of our proposed approach for development of process parameters (hatch spacing, layer thickness, exposure time and point distance) for SLM manufacturing of molybdenum and aluminium. Relative densities of 97.4% and 99.7% are achieved using 200 W pulsed laser and 400 W continuous laser respectively, for molybdenum and aluminium, demonstrating the effectiveness of our approach for SLM processing of high conductivity materials.
12:00	**[66] Effects of different thermal post-processing on Ti6Al4V parts manufactured by metal-Powder Bed Fusion** *Presenter: BUBB, Simon (Ulster University)* Metal-Powder Bed Fusion (PBF) is an Additive Manufacturing technique, capable of producing near fully dense metal parts with good properties and complex geometries. Especially in the case of the manufacture of titanium alloy parts by this process, a post-processing heat treatment is required, however a number of different ones are known. In this project we manufactured parts from Ti6Al4V alloy powder, using an EOS M290 PBF machine, then investigated the properties of parts in three different thermal conditions, as built, after a stress relief heat treatment, and after Hot Isostatic Pressing (HIP). Part properties considered include density (by helium pycnometry), tensile properties, hardness and metallurgy. Results obtained show little difference in parts before and after the stress-relief cycle, but a significant change to the mechanical properties (reduced UTS and higher elongation) and metallurgy after the hotter HIP cycle. No significant differences in density were measured between parts, however while the HIP process is intended to increase density by reducing voids, this will only be true if they are present before this process.

Post-Processing: Post-Processing - 1: Rikssalen (27 November 11:40-12:20)

time	[id] title
11:40	**[34] HIP AND URQ TREATMENTS ON ADDITIVELY MANUFACTURED TOOL STEEL COMPONENTS** *Presenter: MAISTRO, Giulio (Uddeholms AB)* Hot isostatic pressing (HIP) is a well-established technology for reduction of residual porosity in cast materials as well as production of powder metallurgy tool steels. With the advent of additive manufacturing, especially for the medical and aerospace industry, HIP has become a standard treatment to close residual porosity or lack of fusion defects in order to increase the performance of 3d printed components. One of the traditional draw-backs of HIP is the long cycle time, notably due to the slow cooling phase. Thus, a 3d printed component typically required an additional heat treatment after HIP. The recent development of Uniform Rapid Quenching (URQ) techniques, however, allows for (at least) the same cooling rates within HIP furnaces as in conventional heat-treatment practices. The possibility to combine HIP, austenitizing/solution annealing and tempering/ageing treatment is therefore an attractive opportunity also for the tooling industry, especially with growing interest in additive manufacturing and near-net shaping of tool inserts. However, there is currently lack of knowledge on the effects of HIP-heat treatment on microstructure and properties of additively manufactured tool steels and to what degree a URQ HIP treatment influences the final properties. In this work, we present cases of components produced by powder bed fusion techniques using different types of tool steel materials. Analysis of microstructure in as-printed state and after (URQ) HIP together with mechanical property evaluation allows to identify the type of printing defects which are solvable by HIP treatment. PM versions of the tested materials were also produced to compare the printed properties with bulk “defect free” materials. Results show that the contouring strategy is of primary importance in order to obtain the necessary closed porosity in the near-surface, otherwise HIP treatment proves to be ineffective. On the other hand, larger defects produced during printing at the center of the specimen can be effectively closed. Results show also that PM materials cannot always be used as benchmark to evaluate the “low limit”-properties of additively manufactured components.
12:00	**[67] CHALLENGES AND SOLUTIONS FOR A SIEMENS GAS&POWER INDUSTRIAL PRODUCTION CASE BASED ON EBM** *Presenter: THUNDAL, Stefan (Additive Innovation and Manufacturing Sweden)* Since 2 years or so AIM Sweden is working closely with Siemens Gas & Power in Duisburg with the goal to qualify the production of shrouded compressor impellers based on the EBM technology. This application sets up number of technical challenges that calls for solutions which are not to be found in the “std EBM toolbox”. AIM Sweden is well under way to do so and we look forward to share some of these experiences. Shrouded impellers has internal cavities or flow paths that require internal support structure. Removing these support structures and post process these surfaces to an acceptable quality is one of the key challenges. Finding a suitable post processing method is key but it has also proven to be necessary to work outside the normal contour melting strategies.

Lunch - (12:20-13:00)

Plant Visit: Siemens Industrial Turbomachinery - (27 November 13:00-17:10)