Metal Additive Manufacturing Conference 2018

Wednesday 21 November 2018 - Friday 23 November 2018

Wirtschaftskammer Österreich

Book of Abstracts

Contents

Postprocessing (I) / 3

ANODIZING OF ADDITIVE MANUFACTURED ALUMINIUM ALLOYS: CHALLENGES

Dr. REVILLA, Reynier[1]

[1] *Vrije Universiteit Brussel*

Corresponding Author(s): rrevilla@vub.be

Anodizing is the most common electrochemical surface treatment applied to aluminium and its alloys for protection against corrosion. Due to the special conditions during the metal additive manufacturing process, the formation of unique microstructures with fine internal phase distributions can be achieved. These microstructures have been shown to have a considerable influence on the corrosion behavior and the mechanisms of surface treatments to improve corrosion resistance, such as anodizing. In order to understand the microstructure influence on the anodizing mechanism of these materials, additive manufactured AlSi10Mg specimens were galvanostatically anodized in H2SO4 electrolyte. As a reference, a cast alloy of approximately the same chemical composition as that of the AM specimens was used. In the cast alloy, eutectic structures are present and the silicon is distributed in large precipitates while in the AM alloy the silicon is more finely distributed. As the silicon seems to hinder the growth of the oxide layer during anodizing, the difference in phase distribution leads to differences in the anodizing behavior. Significant differences were found in the anodizing voltage–time characteristics and the resulting anodic film structure. In the additive manufactured specimens the anodic oxide growth is much more obstructed than for the cast alloy and the porous layer features look very different, following the local silicon distribution. The average oxide film thickness is significantly lower for the same anodic charge input, but a more continuous layer is formed.

Process Optimization & Control (I) / 4

INFLUENCE OF VARIOUS GASES AND GAS MIXTURES DURING LASER BEAM MELTING

Author(s): CHARPENTIER, Coralie[1]
Co-author(s): BRIAND, Francis [2] ; EFFINGER, Markus [3]

[1] *AIR LIQUIDE Research & Development*

[2] *Air Liquide Research & Development*

[3] *Air Liquide Germany*

Corresponding Author(s): markus.effinger@airliquide.com

Gases represent only a very small part of the production cost structure, but they play a crucial role for safety, process stability and for the final quality of products. Although the influence of the gas in the process is sometimes considered to be secondary during the laser beam melting process, its protective function is essential, as well as the evacuation of generated smokes and spatters in order to limit the pollution of the powder bed. In this work, our study on the influence of gas atmosphere on the process and on the quality of the manufactured parts is presented. Usually, argon or nitrogen is used to inert the chamber during the process. In this study, realized in collaboration with Poly-Shape company and the Process and Engineering in Mechanics and Materials laboratory (PIMM, Paris), various atmospheres have been studied including helium/argon mixtures as well as nitrogen with defined quality and from machine-integrated nitrogen generator. Modifications of the process have been observed, on the melt pool stability and wettability, and on the generation of particles and spatter. The atmosphere of the chamber has been controlled (oxygen, moisture and nanoparticles), powder and generated particles were analyzed and their impact on the part properties quantified.

Related Processes (I) / 5

LITHOGRAPHY-BASED ADDITIVE MANUFACTURING OF FUNCTIONAL METAL COMPONENTS

Author(s): Dr. MITTERAMSKOGLER, Gerald[1]

Co-author(s): Dr. GIERL-MAYER, Christian [2] ; Prof. BURKHARDT, Carlo [3] ; Dr. SCHWENTEN-WEIN, Martin [1]

[1] *Lithoz GmbH*

[2] *Technische Universität Wien*

[3] *Pforzheim University of Applied Sciences*

Corresponding Author(s): gmitteramskogler@lithoz.com

Lithographic additive manufacturing (AM) technologies are based on the concept of photopolymerization and are known for their process inherent high precision and good surface quality compared to other AM techniques. In this work, metallic suspensions comprising a photoreactive binder and 316L powder (50vol%) were used as starting material. After printing, the obtained green parts undergo a subsequent thermal treatment similar to what is done in metal injection molding (MIM). After this debinding stage, the structure can be sintered to a relative density of 98.5%. By this approach highly complex parts made of 316L could be manufactured showing a good geometrical accuracy and very low surface roughness; the mechanical properties of the AM structure are comparable to conventionally manufactured 316L (tensile strength > 500MPa). Since the final part is developed by a classical sintering process, the same basic microstructure as in MIM is realized.

Postprocessing (I) / 6

POST PROCESSING OF METAL PARTS MADE BY ADDITIVE MANUFACTURING

Author(s): Mr. NUTAL, Nicolas[1]
Co-author(s): Mr. COLLETTE, Jean-Paul [2] ; Mr. DUMINICA, Florin [1] ; Mr. GEORGES, Cedric [1] ; Mr. MAGNIEN, Julien [3] ; Mr. MASSE, Christian [4] ; Mr. ROBERT, Lucas [4] ; Mr. VANHUMBEECK, Jean-Francois [1] ; Mr. PAMBAGUIAN, Laurent [5]

[1] *CRM Group*

[2] *Walopt*

[3] *Sirris*

[4] *Thales Alenia Space*

[5] *ESA*

Corresponding Author(s): nicolas.nutal@crmgroup.be

In the frame of ESA's General Support Technology Programme (GSTP 6 E. 1 Clean Space Initiative), focus was set on the surface processing of metal parts made by additive manufacturing (AM). Recently, AM raised a significant interest due to the versatility of the method. Indeed, lightweight and complex shapes with integrated functions can be designed and manufactured with customizable material compositions, which are of prime importance for space and industry applications.
The potential of the AM technologies is impeded by the quite rough surface finish observed on the as-manufactured material. The surface texture of the different faces of the parts varies according to their orientations, in the hollow bodies and the structures. Besides, it is known that such a finish is likely to impact the performance of the parts but the influence of the successive post-processing steps on the final properties is not well established.
Therefore, a better understanding of the impact of surface characteristics on the material behaviour is needed to expand the use of AM for high performance parts. This study aims at proposing and testing various surface finishing techniques for metal (Ti6Al4V, AlSi7Mg and Invar) parts made by the AM technologies, in order to check their compatibility, evaluate their properties and derive guidelines for future applications. Focus is set on chemical, electrochemical and mechanical surface treatment methods.
This paper is devoted to the results of material removal on Invar, AlSi7Mg0.6 and Ti6Al4V. Attention is also paid to the impact of the achieved surface properties on mechanical properties as well as secondary properties such as hydrogen enrichment. In a second step, results of surface functionalization on Invar and on Ti6Al4V are shown.

Known Materials & Characteristics (I) / 7

MICROSTRUCTURE, PASSIVITY AND CORROSION BEHAVIOUR OF 316L STAINLESS STEEL ELABORATED BY SELECTIVE LASER MELTING (SLM)

THIEBAUT, Stéphanie[1] ; DEMESY, Michel[1] ; VIGNAL, Vincent[2] ; SOBOLEWSKA, Anna[2] ; FABAS, Aurélien[1] ; VOLTZ, Christophe[1]

[1] *CEA, DAM, Centre d'études de Valduc, Laboratoire Interactions Matériaux Procédés Environnements*

[2] *ICB, UMR 6303 CNRS - Univ. Bourgogne Franche Comté*

Corresponding Author(s): vvignal@u-bourgogne.fr

Selective laser melting (SLM) enables the elaboration of metallic alloys and the fabrication of engineering components directly from metallic powder. Such alloys have specific microstructure and therefore their corrosion behaviour is significantly different from that of alloys elaborated by classical methods (wrought structure). Referring to the limited prior work in this field, most of papers show that 316L samples elaborated by SLM exhibited better corrosion resistance than samples with wrought structure. It has also been shown that metastable pit frequency was found to increase with specimen porosity and the repassivation potential was found to decrease with specimen porosity. By contrast, pitting potential values do not change significantly with specimen porosity. The role of other metallurgical parameters (crystallographic orientation…), of the passive film and of the surface preparation has not been considered yet. In this study, the microstructure of 316L stainless steel elaborated by SLM was first investigated by means of FE-SEM/EDS (chemical composition, presence of particles or pores…), EBSD (crystallographic structure, grain orientation spread) and XRD (crystallite size, phase analysis, texture component). The native passive film formed spontaneously in air after surface preparation was also analysed using XPS and AES (composition, structure and thickness). Two surfaces were considered: the first surface (x-y) oriented perpendicular to the build direction and the second surface (x-z) perpendicular to (x-y). The corrosion behaviour of the two surfaces was then determined from potentiodynamic tests in chloride containing media (from 3.5wt.% up to saturation). Results obtained on samples elaborated by SLM were compared to those obtained on wrought structures (316L). The influence of the microstructure (surfaces (x-z) and (x-y)) and of the surface preparation (roughness and cold worked layer generated by mechanical grounding) on pit initiation and propagation was quantified from 3D surface measurements. Obtained results (pitting potential, passive current density, pit morphology…) were discussed considering the samples microstructure and the native passive film properties.

Known Materials & Characteristics (II) / 8

INVESTIGATIONS ON THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF GAS ATOMIZED HOT WORK TOOL STEELS MANUFACTURED BY SELECTIVE LASER MELTING USING POWDER BED PREHEATING.

Author(s): Mr. GIEDENBACHER, Jochen[1]
Co-author(s): Mr. HUSKIC, Aziz [2] ; Mr. OGNIANOV, Miloslav [3] ; Mr. SOMMITSCH, Christof [4]

[1] *Research & Development, University of Applied Sciences Upper Austria*

[2] *FH OÖ Forschungs & Entwicklungs GmbH*

[3] *Research & Development, voestalpine BÖHLER Edelstahl GmbH & Co KG*

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

Corresponding Author(s): jochen.giedenbacher@fh-wels.at

Selective Laser Melting, Additive Manufacturing, Hot Work Tool Steels, Carbon Content, Powder Bed Preheating, Crack Formation, X-ray Diffraction, Scanning Electron Microscopy, Microstructure, Heat Treatment

Application (I) / 9

INDUSTRIAL SOLUTIONS FOR ADDITIVE MANUFACTURING

Mr. NACHTIGALL, Frank[1]

[1] *TRUMPF*

Corresponding Author(s): frank.nachtigall@de.trumpf.com

Industrial Solutions for Additive Manufacturing Over the past two years, metal Additive Manufacturing has been maturing rapidly from applications predominantly in prototyping to full scale industrial manufacturing throughout various industrial sectors. While this process is by far not finished, it already brought significant changes to both users and suppliers of Additive Manufacturing systems. The presentation will highlight the potential of the Laser Metal Fusion technology on the basis of successful additive applications.

New Materials (I) / 10

INFLUENCE OF HEAT TREATMENT AND HIP ON PRECIPITATION HARDENING OF INTERMETALLIC-REINFORCED STAINLESS TOOL STEEL MANUFACTURED BY LASER POWDER BED FUSION

Author(s): Prof. KRAKHMALEV, Pavel[1] ; Mr. ÅSBERG, Mikael[1] ; Dr. MARTIN VILARDELL, Anna[1] ; Mrs. FREDRIKSSON, Gunnel[1]
Co-author(s): Dr. OIKONOMOU, Christos [2] ; Dr. MAISTRO, Guilio [2] ; Dr. MEDVEDEVA, Anna [2]

[1] *Karlstad University*

[2] *Uddeholms AB*

Corresponding Author(s): anna.martin@kau.se

Present research is focused on an advanced stainless tool steel used for molding of corrosive plastics manufactured by laser powder bed fusion. In comparison to other tool steels, this steel possesses superior corrosion resistance and, achieves high strength via nano-precipitations of an intermetallic phase. Deeper understanding of the precipitation process is, therefore, necessary to develop new heat treatment parameters to tailor properties and performance of the final product. The stainless tool steel grade used in this investigation was manufactured by laser powder bed fusion. As a reference, the same steel grade manufactured by conventional casting and forging was used. After manufacturing, an aging heat treatment at different temperatures and times was performed with or without HIP. Microstructure analysis and mechanical tests were performed after the aging. Mechanical tests were carried out to evaluate the influence of the heat treatments and HIP on strength characteristics. Microstructure of the steel was investigated by means of optical, and scanning electron microscopy. Intermetallic nano-precipitations were investigated by transmission electron microscopy. The influence of the manufacturing route, aging heat treatment conditions, and HIP on microstructure, grain size, size and distribution of precipitations, and mechanical properties was discussed. This investigation supports development of new heat treatment parameters to achieve desirable combination of properties and performance in advanced stainless tool steel.

Postprocessing (II) / 11

SURFACE ENGINEERING FOR PARTS MADE BY ADDITIVE MANUFACTURING

Author(s): Mr. GSCHIEL, Harald[1]
Co-author(s): Mr. HATZENBICHLER, Markus [1] ; Mr. STELZER, Nils [2] ; Mr. SCHEERER, Michael [2] ; Mr. BACA, Lubos [2] ; Mr. BONVOISIN, Benoit [3]

[1] *FOTEC*

[2] *AAC*

[3] *ESA*

Corresponding Author(s): hatzenbichler@fotec.at

It is commonly known that the additive manufacturing (AM) technology provides various advantages, such as the production of highly complex (bionic) structures that cannot be realized conventionally, the unused raw material can be recycled and no specific tools are needed. On the economical side, also the lead time saving must be taken into account. Within this project, the surface roughness of Laser Beam Melting (LBM) and Electron Beam Melting (EBM) produced parts was measured. For the LBM process, AlSi10Mg, SS316L and Ti64 powder on an EOS M280 machine and for the EBM process only Ti64 powder on an ARCAM Q20 machine have been used. In general, the "as built" – surface roughness of AM parts is rather high compared to conventional milled parts and due to the powder bed process, semi-molten particles are always attached on the side surface. In this project, various (abrasive or coating) surface treatment technologies like shot peening, (electro-)chemical polishing or anodization were applied and analyzed in order to make a proposal for the most promising surface finishing scenarios, consisting of different treatments. But not only lowering the surface roughness is important; other issues like geometry of the sample, surface quality in terms of particles and cracks or similar roughness on top and side surface have to be considered in space applications. To determine the impact of the chosen surface finishing scenarios, SEM images of the surfaces have been taken and mechanical properties like tensile strength or fatigue of "as built"- and surface treated parts were measured and compared. Furthermore, also the stress corrosion cracking behavior of the additive manufactured parts was analyzed.

Process Optimization & Control (II) / 12

THERMOELECTRIC MAGNETOHYDRODYNAMICS IN ADDITIVE MANUFACTURING

Mr. GAN, Teddy[1] ; Dr. KAO, Andrew[1] ; Prof. PERICLEOUS, Koulis[1]

[1] *University of Greenwich*

Corresponding Author(s): t.gan@greenwich.ac.uk

T. Gan, A. Kao and K. Pericleous
Centre for Numerical Modelling and Process Analysis
Old Royal Naval College, Park Row
University of Greenwich, UK, SE109LS

Abstract
Thermoelectric currents have been shown to exist in a wide range of solidification processes from rapid high undercooled growth [1] to casting and directional solidification [2]. These currents form through the Seebeck effect and are dependent on the thermal gradient. In the presence of an external magnetic field, a Lorentz force is generated through interaction of these currents and the field, driving fluid flow in the liquid melt. This type of flow, known as Thermoelectric Magnetohydrodynamics (TEMHD), is known to alter microstructural evolution through convective transport of heat and mass.
Metal additive manufacturing (AM) and related processes such as welding, share many similarities in processing conditions to undercooled growth and directional solidification. Preliminary calculations show that TEMHD may have a profound effect in AM processes due to the inherently large thermal gradients, significantly altering the melt pool morphology. However, the distribution of thermoelectric currents and the resulting behaviour of the Lorentz force is not well understood. By using a purpose built computational model that couples various physical phenomena including solidification, electromagnetism and fluid flow, this paper investigates the macroscopic behaviour of the power bed fusion AM process and how key operating parameters determine the resulting TEMHD flow.
References
[1] A. Kao, J. Gao and K. Pericleous, Thermoelectric magnetohydrodynamic effects on the crystal growth rate of undercooled Ni dendrites, Philosophical Transactions of the Royal Society A (2018), Vol 376, Issue 2113. [2] J. Wang et. al, Modification ofliquid/solid interface shape in directionally solidifying Al–Cu alloys by a transverse magnetic field, J.Mater.Sci., 48–1 (2013), 213–219.

Application (I) / 13

EVALUATING ADDITIVE MANUFACTURING TECHNIQUE TO PRODUCE DIES FOR HIGH-PRESSURE DIE CASTING

Author(s): Prof. MATTAR, Taha[1]
Co-author(s): Prof. ABDEL GHANY, Khaled [2] ; Mr. ABDEL-LATIF, Mohamed [2]

[1] *Central Metallurgical R&D Institute (CMRDI)*

[2] *CMRDI*

Corresponding Author(s): mohamed.abdel-latif@outlook.com

Additive manufacturing (AM) technology is widely used to fabricate complex 3D products directly from CAD file. Selective laser melting (SLM) is considered as the most important AM techniques that can produce high-quality Tool Steel products as dies for Aluminium High-Pressure Die Casting. Traditional techniques face significant challenges such as mold design complexity and water cooling system channels which depends on part geometry and are needed to release die temperature from molten aluminium from 650°C to around 25°C. Optimizing of additive manufacturing technology is highly demanded to meet fabrication of high-quality dies from Tool Steel. Based on the variation of scanning speed of laser, layer thickness and laser power, the Additive Manufacturing technology was adapted to produce H13 Tool steel required for Rapid tooling applications. In this work,The mechanical properties of tool steel dies were determined using tensile test, impact toughness and compression testing machines. The structure after SLM process was tracked using optical microscope as well as X-ray diffraction. The results showed the powerful effect of the scanning speed of laser, on mechanical properties and the observed structure of H13 hot work tool steels.

Process Optimization & Control (II) / 14

INVESTIGATION OF THE CORRELATION BETWEEN SIGNAL CHARACTERISTICS OF PHOTODIODE-BASED MELT POOL MONITORING AND PART QUALITY IN LASER-BASED POWDER BED FUSION OF ALSI10MG

Author(s): Ms. ROSENKRANZ, Claudia[1] ; Mr. SCHMID, Simon[2]
Co-author(s): Mr. LUTTER-GÜNTHER, Max [1] ; Dr. SEIDEL, Christian [1] ; Prof. REINHART, Gunther [3]

[1] *Fraunhofer Research Institution for Casting, Composite and Processing Technology IGCV*

[2] *Technical University of Munich, Department of Mechanical Engineering*

[3] *1.) Fraunhofer Research Institution for Casting, Composite and Processing Technology IGCV2.) Institute for Machine Tools and Industrial Management (iwb), Technische Universität München*

Corresponding Author(s): claudia.rosenkranz@igcv.fraunhofer.de

Additive Manufacturing (AM) is becoming more and more relevant in industrial small-batch manufacturing though it is still on the verge of being a widely spread manufacturing technology. The lack of holistic quality assurance and process monitoring during Laser-based Powder Bed Fusion of metals (PBF-LB/M), also referred to as Laser Beam Melting (LBM), as well as costly and time-consuming post-process quality inspection prevent the industry from a wider implementation. To meet the quality criteria for applications in the scope of high-grade products the comprehension of how process deviations within the AM process influence the quality of the resulting AM component is crucial. This paper addresses a signal sensitivity study of photodiode signals during PBF-LB/M and discusses the correlation to the quality of AlSi10Mg-parts. The variations in the signal characteristics result from changes of process parameters including laser power, layer thickness, scan velocity and hatch distance. The influence of different process features such as rotation angle and scan vector length on the photodiode signal are discussed. Furthermore, image analysis of microsections is used to classify defect types and their correlation with the signal characteristics is considered. This approach outlines the basis for future research on online process monitoring with respect to quality assurance in AM.

New Materials (III) / 15

LASER POWDER BED FUSION OF ADVANCED HIGH STRENGTH STEELS - MODIFICATION OF DEFORMATION MECHANISMS BY INCREASING STACKING FAULT ENERGY

Mr. EWALD, Simon[1]

[1] *RWTH Aachen University - Digital Additive Production DAP*

Corresponding Author(s): simon.ewald@dap.rwth-aachen.de

Within the field of Advanced High Strength Steels (AHSS), high-manganese Transformation-(TRIP) and Twinning-Induced Plasticity (TWIP) steels gained strong commercial interest by their outstanding mechanical properties. Previous studies have been shown that Laser Powder Bed Fusion (L-PBF) is a promising alternative to overcome shortcomings related to conventional processing routes of high-manganese steel. Furthermore, L-PBF offers the possibility to produce complex geometries such as lattice structures. The overall goal of this work is the combination of the deformation mechanisms of high-manganese steel with beneficial mechanical properties of lattice structures (e.g. energy absorption) and adjusting the typical deformation mechanisms of high-manganese steel by powder blends. The deformation mechanisms are modified by adding elemental Al-powder to prealloyed X30Mn22-powder to increase the stacking fault energy. Processing of different powder blends (e.g. X30Mn22Al1, X30Mn22Al2, X30Mn22Al5) and production of specimen (e.g. tensile bars and lattice structure-compression specimens) are used to compare microstructure using OM, SEM, EBSD and EDX and the related mechanical properties.

New Materials (III) / 16

FORMATION QUALITY, MECHANICAL PROPERTIES AND PROCESSING BEHAVIOR OF PURE ZINC (Zn) METAL PARTS PRODUCED BY LASERBASED MANUFACTURING FOR BIODEGRADABLE IMPLANTS

Author(s): Mr. VOSHAGE, Maximilian[1] ; Dr. WEN, Peng[2]
Co-author(s): Mr. JAUER, Lucas [3] ; Prof. SCHLEIFENBAUM, Johannes Henrich [1] ; Mr. SCHAUKELLIS, Max [4]

[1] *Digital Additive Production (DAP), RWTH Aachen University, Steinbachstraße 15, 52074 Aachen, Germany*

[2] *The State Key Laboratory of Tribology, Tsinghua University, 100084 Beijing, China*

[3] *Fraunhofer Institute for Laser Technology (ILT), Steinbachstraße 15, 52074 Aachen, Germany*

[4] *Digital Additive Production (DAP), RWTH Aachen University*

Corresponding Author(s): maximilian.voshage@dap.rwth-aachen.de

Recent studies have shown that Zn based metal exhibit promising applications for biodegradable medical implants due to the good combination of biocompatibility, biodegradation rate and mechanical properties. Only a few recent reports can be found on additive manufacturing of Zn. Either the obtained density is too low, or the process window is quite narrow due to excessive evaporation. This paper aims to clarify the effect of processing parameters on densification during the Laser Powder Bed Fusion process (L-PBF) of pure Zn, and obtain high density in a reasonable process window. Porosity results by either lack of fusion due to lack of laser energy or by gas entrapment due to excessive evaporation. The side surfaces of cubes are attached with numerous partially melted powders, which deteriorates the surface quality. The arithmetical mean height (Sa) at side surfaces can be reduced after sand blasting from 10.12 µm for as-melted status to 4.83 µm. Lattice structures are obtained stably with a strut diameter of about 500 µm. Cylinders were built up and machined later into the shape of tensile test pieces. The average values of hardness, elastic modulus, yield strength, ultimate strength and elongation are measured as 42 HV, 23 GPa, 114 MPa, 140 MPa, and 10.1% respectively for L-PBF produced pure Zn parts with density over 99.90%.

Process Optimization & Control (I) / 17

EFFECT OF SHIELDING GAS FLOW RATE ON OXIDATION BEHAVIOR AND MECHANICAL PROPERTY IN LASER METAL DEPOSITION

Author(s): Mr. EO, DURIM[1]
Co-author(s): Prof. CHO, Jung-Wook [2] ; Dr. PARK, Sun-Hong [3]

[1] *Pohang University of Science and Technology(POSTECH),Graduate Institute of Ferrous Technology(GIFT)*

[2] *Pohang University of Science and Technology*

[3] *Research Institute of Industrial Science and Technology*

Corresponding Author(s): adream@postech.ac.kr

In laser metal deposition (LMD) process, melt pool oxidation is inevitable due to its high temperature, which results in finely dispersed non-metallic inclusions in the steel matrix. These were found to strengthen the as-built AM alloy by the Orowan strengthening mechanism. Inclusion evolution in AM were also found to show strong dependency on process parameter, such as laser power, scan speed, powder chemistry and shielding gas flow rate. In this study, we systematically explore the effect of shielding gas flow rate on the mechanical property and inclusion characteristics. As shielding gas flow rate varies from 5L/min to 25L/min oxygen contents in the meltpool changed from 775ppm to 375ppm in low laser beam intensity situation and from 677ppm to 1470ppm in high laser beam intensity situation. It was found that only varying shielding gas flow rate could make a difference in tensile stress up to 90MPa.

Powder Production & Characterization / 19

THE WORLD MARKET FOR METAL POWDERS & STEELS, STATUS QUO AND OUTLOOK

Mr. BLITZ, Benedikt[1]

[1] *SMR Premium GmbH*

Corresponding Author(s): b.blitz@smr-premium.com

The Production of Metal Powders and Powder Metallurgical Steels and especially its associated production technologies like HIP, MIM and AM are and will become key future core technologies for a number of demanding products and thus for the usage in different associated industries. This presentation will highlight the actual supply and demand situation of metal powders and the manufactured metal powder steels, will introduce leading manufacturers of both powders and steels, and summarizes installed capacity and new capacity that are on the way. Finally this presentation also compares regional demand dynamics as well as highlights endues structures of today and the near future.

New Materials (I) / 20

SURFACE MODIFICATION OF AM PRODUCED STAINLESS TOOL STEELS FOR PLASTIC MOULDING TOWARDS ENHANCED TRIBOLOGICAL PERFORMANCE AND CORROSION RESISTANCE

Author(s): Dr. OIKONOMOU, Christos[1]
Co-author(s): Dr. MAISTRO, Giulio [1] ; Dr. KARAMCHEDU, Seshendra [1] ; Dr. NAHIF, Farwah [2] ; Mr. LARTZ, Marcus [2] ; Dr. SJÖSTRÖM, Johnny [1]

[1] *Uddeholms AB*

[2] *eifeler-Vacotec GmbH*

Corresponding Author(s): christos.oikonomou@uddeholm.com

Tools produced by metal Additive Manufacturing (AM) have been significantly increasing the last years, especially towards plastic moulding applications, due to the design innovation that the technology offers. The demand though from such tooling applications has been also increasing the levels of tribological performance and corrosion resistance for the tools, in order to process more complex composite materials. A solution to such demand is the surface modification of an AM produced tool to cope with these new requirements. In this context, the available information today on the behaviour and response of AM produced materials is limited. In the present study, a precipitation hardened stainless tool steel was subjected to various coating processes based on TiN, CrN, DLC and plasma nitriding treatments. The results have been compared to the conventionally produced counterpart of the tool steel in question, in terms of coating adhesion, corrosion resistance and mechanical performance. Advanced analytical and microscopic techniques were implemented for the characterization and evaluation of the analysed surfaces.

Application (II) / 21

3D METAL PRINTING FROM AN INDUSTRIAL PERSPECTIVE - PRODUCT DESIGN, PRODUCTION AND BUSINESS MODELS

Prof. ASNAFI, Nader[1]

[1] *Örebro University*

Corresponding Author(s): nader.asnafi@oru.se

This paper summarizes the current position of 3D metal printing/additive manufacturing (henceforth called 3D metal printing) from an industrial perspective. The new possibilities to design the part differently simply because the new shape can be produced and which provides benefits with respect to improved material utilization degree, reduced weight, size etc. are addressed in this paper. Different types of generative design concepts such as form synthesis, topology optimization and lattice and surface optimization are exemplified. Low volume production by 3D metal printing is discussed. High volume production by 3D metal printing of manufacturing tools and dies is described. Tool & die production is an important phase in the development of new components/product models. This phase determines both the lead time (Time-To-Production/-Market) and the size of the investments required to start the production. The lead time for the production of tools and dies for a new car body is currently about 12 months and needs to be reduced 40% by 2020. The lead time for injection molds for small and large series production must be reduced to 10 days and 4 weeks respectively. Lead time and cost-efficient metallic tools can be provided by 3D metal printing. This paper focuses on tools and dies for the manufacture of sheet metal & plastic components for the engineering, automotive and furniture industries. The paper includes Powder Bed Fusion (PBF). Digitalization through virtual tool & die design and optimization of the tool & die production combined with the PBF´s digital essence provides greater flexibility, better efficiency, tremendous speed, improved sustainability and increased global competitiveness. 3D metal printing is expected to result in several changes in the supplier chain and generate new business models. The present paper describes some of the changes 3D metal printing has led to and is expected to result in within the engineering and automotive industry in Europe during the coming years.

Opening / 22

RESULTS AND CONCLUSIONS ON METALLIC MATERIALS MADE BY AM WITHIN THE AUSTRIAN LEADER PROJECT "ADDMANU"

Author(s): Prof. BUCHMAYR, Bruno[1]
Co-author(s): Mr. PANZL, Gerhard [1] ; Mr. WALZL, Alexander [1] ; Mr. WALLIS, Christopher [1] ; Mr. HUBMANN, Reinhard [2] ; Mr. KITZMANTEL, Michael [3]

[1] *Montanuniversitaet Leoben*

[2] *FOTEC, Wr. Neustadt*

[3] *RHP-Technology, Seibersdorf*

Corresponding Author(s): bruno.buchmayr@unileoben.ac.at

In order to foster the market potential of additive manufacturing, an Austrian leader project has been established, which was sponsored by The Austrian Research Promotion Agency (FFG)over a period of three years with more than 20 research partners coming from Universities, R&D firms and industry. Mid of 2018, the project called "addmanu" was successfully completed. The project structure covered aspects of design, processing and applications of components made from metals, polymers, ceramics and hybrids. In this presentation, only metallic systems are considered, with special emphasis on new powder materials, hybrids, topolgy optimization and joints between dissimilar materials, fabrication of small channels and surface modifications. Regarding potential application fields, demonstrator examples for mechanical engineering, tools for injection moulding, light weight automotive components, nozzels for aerospace technology and composites with special properties for satellites will be shown.

Application (II) / 23

THE APPLICATION OF POWDER RHEOLOGY FOR AM POWDERS

Author(s): Mr. PANZL, Gerhard[1]
Co-author(s): Prof. BUCHMAYR, Bruno [2]

[1] *Montanuniversitaet Leoben*

[2] *Montanuniversität Leoben*

Corresponding Author(s): gerhard.panzl@unileoben.ac.at

Metal additive manufacturing (AM) processes like laser powder bed fusion (L-PBF) become a more and more frequently used fabrication method for complex shaped and highly functional metal parts in medical, aerospace and automotive industries. The feedstock used for these processes is atomized, spherically shaped metal powder which has to meet the highest requirements to ensure stability of the building process and consistent, reproducible product quality. Since the costs of powder materials are a significant cost factor of AM components, powder recycling strategies are an important opportunity to enhance the economic efficiency of the process. Primary feedstock characteristics (i.e. particle size distribution, morphology, bulk density, porosity) strongly depend on the powder manufacturer. Additionally, experiences has shown, that recycling strategies have a considerable influence on the characteristics and behaviour of the powder. VDI guideline 3405 (Page 2.3; Additive manufacturing processes, rapid manufacturing – Beam melting of metallic parts – Characterisation of powder raw material) is a basic procedure to characterise metal powders, but the recommended parameters do not provide sufficient information whether a powder is suitable for powder bed fusion processes or not. Powder rheology provides automated and reliable measurement methods of bulk material characteristics, which can point out also minor changes and establish a link to a predictable behaviour of metal powders. This study investigates powder rheology measurement methods (pressure drop method, weighted cohesion strength measurements, tensile strength measurements) and their possibility to predict proper behaviour of metal powders in AM processes.

Known Materials & Characteristics (I) / 24

FRACTURE BEHAVIOUR ASSESSMENT OF AM PROCESSED STEEL WITH THE USE OF MINIATURIZED SPECIMENS

Dr. DŽUGAN, Jan[1] ; Mr. MAŠEK, Martin[1] ; Mr. HODEK, Josef[1]

[1] *COMTES FHT a. s.*

Corresponding Author(s): martin.masek@comtesfht.cz

The paper deals with investigation of the yield and fracture locus for steels parts created by Selective Laser Melting process. Metallic parts produced by additive manufacturing techniques yield presently different mechanical behaviour from wrought materials. Moreover, the AM processes exhibit directional anisotropy of mechanical properties. The paper is going to compare plasticity

and fracture locus for wrought material and material produced by Additive Manufacturing (AM). In the case of the AM material also directional properties anisotropy of the plasticity and fracture locus is going to be addressed. Namely, build direction, horizontal and also properties of specimens build in 45°to base plate are going to be scrutinized and compared together.
Plasticity plane and fracture locus are going to be determined with the use of notch and plane bar specimens to capture wide range of triaxiality. In order to address shear behaviour also flat shear specimens are going to be employed co cover low range of the triaxialities. Testing is going to be performed under quasi-static loading conditions at room temperature. Mises and Hill material models are going to be employed here for the plastic behaviour description and fracture locus will be described using Johnson-Cook and MMC approach.
Mechanical behaviour response under multiaxial loading condition are confronted here for wrought materials and AM processed specimens produced in three build directions. Results point out anisotropic behaviour in the build directions investigated and difference in plasticity and fracture response between wrought and AM processed materials pointing out potentials and weak point of parts produced by AM.

New Materials (II) / 25

PRECIPITATION KINETICS DURING NON-LINEAR HEAT TREATMENT IN LASER ADDITIVE MANUFACTURING

Author(s): Mr. BAJAJ, Priyanshu[1]
Co-author(s): Dr. JAEGLE, Eric [2] ; Prof. RAABE, Dierk [2] ; Mr. GUPTA, Ankit [2] ; Dr. DE-GEUSER, Frederic [3] ; Mr. WILMS, Markus Benjamin [4]

[1] *Max Planck Institute for Iron Research*

[2] *MPIE*

[3] *SIMaP*

[4] *ILT Fraunhofer*

Corresponding Author(s): p.bajaj@mpie.de

Precipitation kinetics; Laser Metal Deposition; Al-Sc;

Process Optimization & Control (II) / 26

A NEW METHOD FOR DESCRIBING THE MORPHOLOGY OF POWDER LAYERS IN DIRECT LASER MELTING

Author(s): Mr. MITTERLEHNER, Marco[1]
Co-author(s): Dr. GIERL-MAYER, Christian [1] ; Dr. DANNINGER, Herbert [1]

[1] *TU Wien*

Corresponding Author(s): marco.mitterlehner@tuwien.ac.at

For additive manufacturing by direct laser melting route, proper application of the powder layers is of crucial importance. Therefore, important aspects are the typical powder characteristics such as flowability but also the nature of the top layer itself. In order to easily rate the morphology of the top layer a new method has been developed for which a self-made tester for the layer building process has been built. For the observation of the surface of the top layer a digital microscope with a large depth-of-field has been used. The height data of these three-dimensional images has then been extracted and analyzed by a self-written python program which searches for the extrema of the surface in two directions – horizontal and vertical – and calculates specific parameters out of this data. Specific orientation of the surface can be seen as well as the flatness of the surface can be rated.

Known Materials & Characteristics (III) / 27

LASER BEAM MELTING OF H13 TOOL STEEL

Author(s): Mr. WU, Liang[1]
Co-author(s): Mr. XIA, Fengchen [2] ; Mr. WITALIJ, Gridin [1] ; Dr. STEFAN, Leuders [1] ; Prof. NIENDORF, Thomas [3]

[1] *voestalpine Additive Manufacturing Center GmbH*

[2] *voestalpine addtive manufacturing center*

[3] *Universität Kassel Institut für Werkstofftechnik Metallische Werkstoffe*

Corresponding Author(s): liang.wu@voestalpine.com

H13, a type of multifunctional chromium-molybdenum carbon steel, is widely used in hot work applications. However, when applied in additive manufacturing processes, H13 suffers from process-induced defects. Thus, processing requires appropriate parameters in Laser beam melting (LBM). Based on a comprehensive parameter investigation robust LBM parameters were found. H13 can be processed additively at elevated temperatures by applying appropriate laser parameters. Besides laser parameters, this investigation focuses on the evaluation of the microstructure under different heat treatment conditions, in particular of phases and defects at all length scales from macro- to nanoscale, and subsequently, on the corresponding mechanical properties. Furthermore, the mutual relations of chemical composition, process conditions as well as microstructural and mechanical properties will be discussed and clarified illustratively using simulations. In the future, these experimentally confirmed parameters should be valid for the manufacturing of high-demanding components and be implemented for a scientific-based simulation model which allows for the prediction of laser parameters for new combinations of alloys and LBM-systems.

Known Materials & Characteristics (I) / 28

HIGH TEMPERATURE TRIBOLOGICAL BEHAVIOUR OF AISI 316L PRODUCED BY SLM TECHNIQUE.

Author(s): Dr. LANZUTTI, Alex[1]
Co-author(s): Mr. VAGLIO, Emanuele [1] ; Prof. ANDREATTA, Francesco [1] ; Mr. MAGNAN, Michele [1] ; Dr. TOTIS, Giovanni [1] ; Dr. SORTINO, Marco [1] ; Prof. FEDRIZZI, Lorenzo [2]

[1] *University of Udine*

[2] *university of Udine*

Corresponding Author(s): alex.lanzutti@uniud.it

The SLM (Selective Laser Melting) is an additive manufacturing technique (AM) that received in the more recent years an increasing interest for the production of mechanical components in many different technological fields. This technology is based on a layer by layer laser melting of metal powders deposited on a moving stage in order to obtain a controlled geometry of the component (3D printing). Many metals can be processed by using this technique such as Ti, Al or Ni alloys, tool or stainless steels. The aim of this work is to determine the tribological behaviour of an AISI 316L stainless steel produced by 3D printing and to compare these properties to the ones of a wrought AISI 316L stainless steel. The study of the wear performances at high temperature is also considered. This is a remarkable topic, mostly because these mechanical components frequently operate at high temperature. The samples, with a dimension of 20x30x6mm, were produced by SLM (Concept laser) using a chessboard laser scan. The as produced material, as well as the wrought one, were submitted to tribological tests, using a pin on disk geometry, at different temperatures (200°C, 400°C, 600°C). During the tests, the COF was acquired and monitored continuously for the whole test duration. The microstructure was deeply investigated by SKPFM, SEM, and light microscopes both at the contact point and at certain distance from it. Microhardness was also measured. The aim of these analysis was to determine the microstructural evolution of material caused by the testing temperature (thermal treatment) and the applied stresses at the contact point. The top view SEM analysis of the wear track was performed in order to determine the wear mechanism. The wear rate was calculated as a function of the testing temperature. The preliminary analyses have shown that the AM material presents a dual phase microstructure and small defects (porosities) affecting the wear behaviour. A correlation between testing temperature, microstructure evolution and the wear properties has been observed in the AM material.

Keynote (I) / 29

ADDITIVE MANUFACTURING FOR DIGITAL DENTISTRY

Prof. STAMPFL, Jurgen[1]

[1] *TU Wien*

Corresponding Author(s): juergen.stampfl@tuwien.ac.at

Additive manufacturing (AM) has developed into a promising technology allowing the parallel production of arbitrarily complex parts with high resolution. AM is especially well suited for applications which require individualized geometries. Therefore, AM shows great potential to be utilized in the field of digital dentistry where personalized and highly aesthetic parts (e.g. restorations) are demanded. Digital dentistry provides a large number of applications, involving metals as well as ceramics and polymers.
This presentation will give an overview of the state of the art in digital dentistry. Applications in restorative dentistry, orthodontics and implantology will be covered, with a focus on processing and characterization of the relevant materials. A comparison with the most relevant AM technologies (stereolithography, selective laser melting, inkjet printing) will be given in terms of quality of the produced parts, mechanical properties of the obtained parts, throughput and cost per part.

Business Models & Engineering / 30

VALUE ENGINEERING FOR 3D METAL PRINTING AND BEST PRACTISE IN DESIGN & ENGINEERING

Dr. NINAUS, Manfred[1]

[1] *M&H CNC Technik*

Corresponding Author(s): manfred.ninaus@mhcnc.com

The customer benefit is a crutial parameter in order to get traditional manufactured parts to 3D metal printed ones.
Value Engineering for 3D metal printing means to evaluate all parameters that influence the final product and its manufacturing process. Value is the ratio between customer benefit and fulfillment of functions compared to needed ressources like costs or other investments. The Value Engineering process is a guiding framework in order to get all information needed and knowledge about real barriers in requirements and those that are only traditionally existing. Breaking up the traditional barriers and reducing the requirements to the very little amount of must-be's, the value engineering process establishes grades of freedom how to make new design and engineered parts for additive manufacturing. This of course has to be carried out in an interdisciplinary approach in order to get all stakeholder requirements and then reinvent the part to be additive manufactured. Here M&H CNC will refer to the distribution cooperation with the company Altair and will give some insights. Additionally, the approaches of cost engineering have to be implemented as well as one lever for increasing the total value. Here value engineering for 3D printing provides guidance in calculation of total cost of ownership. A set of evaluation methods help to evaluate the cost reduction in addition to the functional improvement of the new part in order to get a fundamental decision whether a part is suitable for 3D metal printing respectively can be engineered for 3D printing or not. Finally, a set of good practices of design and engineering examples will proof the proper impact of the value engineering approach. here examples showing before and after situations will be brought.
The conclusion will be the statement that value engineering is a must in order to do efficient design & engineering and that generate real 3D metal printing engineered parts.

Related Processes (II) / 31

MATERIAL EXTRUSION WITH FILAMENTS FOR THE PRODUCTION OF METAL PARTS AND FEEDSTOCK

THEREFORE

Author(s): Dr. KUKLA, Christian[1]
Co-author(s): Dr. GONZALEZ-GUTIERREZ, Joamin [2] ; Mr. SCHUSCHNIGG, Stephan [2] ; Mr. CANO, Santiago [2] ; Prof. FELFER, Peter [3] ; Mr. HAMPEL, Stefan [4] ; Prof. HOLZER, Clemens [2]

[1] *Montanuniversitaet Leoben - Industrial Liaison Department*

[2] *Montanuniversitaet Leoben, Chair of Polymer Processing*

[3] *FAU Erlangen-Nürnberg, Lehrstuhl für Allgemeine Werkstoffeigenschaften*

[4] *Hage Sondermaschinenbau GmbH & Co. KG*

Corresponding Author(s): christian.kukla@unileoben.ac.at

Fused Filament Fabrication (FFF) is a type of material extrusion (ME) additive manufacturing and it is one of the most commonly used polymer-based additive manufacturing techniques. FFF can be used to shape parts with feedstocks similar to the ones used in Powder Injection Moulding (PIM). Thus green parts are manufactured which in the following steps are debinded and sintered. This process requires mostly the feedstocks in the shape of a filament, which is required for printing. The use of filaments as feeding material imposes a set of requirements on the feedstocks, such as the flexibility to be spooled, stiffness to avoid buckling and a constant diameter to ensure a constant mass flow. FFF for metals parts offers the use of a wide range of metal powders, which are already available in the market, as well as an already established process of sintering which leads to homogenous microstructure. Here an overview of the state-of-the-art of FFF for metal parts with regard to the powders, feedstocks as well as available equipment, respective processing parameters and examples for currently achieved sinter shrinkage; densities and other mechanical properties as well as achievable surface quality are given.

New Materials (III) / 33

ADDITIVE MANUFACTURING OF NdFeB PERMANENT MAGNETS BY SELECTIVE LASER MELTING

Author(s): Mr. GÖRTLER, Michael[1]
Co-author(s): Mr. HUBER, Christian [2] ; Mr. MEIER, Benjamin [1]

[1] *Joanneum Research Forschungsgesellschaft mbH*

[2] *Christian Doppler Laboratory for Advanced Magnetic Sensing and Materials, Bolzmanngasse 5, A-1090 Wien*

Corresponding Author(s): michael.goertler@joanneum.at

Due to their high maximum energy product (BH)max, rare-earth permanent magnets made of Neodymium-Iron-Boron alloy (NdFeB) are widely used in industrial applications for sensors, electric drives or energy production and storage [1].
NdFeB magnets are mainly divided into sintered and polymer-bonded magnets. On the one hand, sintered magnets have the highest maximum energy product (BH)max, on the other hand, polymer-bonded magnets enable the manufacturing of complex shapes and magnetization structures, but with a lower (BH)max [2]. In this context, it has been shown that an end-user fused deposition modeling printer (FDM) can be used to print polymer-bonded rare-earth magnets with a complex shape [3].
To produce permanent magnets that unite geometrical complexity and high (BH)max, selective laser melting (SLM) of NdFeB powder has been applied recently [4,5]. This method enables cost efficient batch productions of powerful magnets with customizable stray field distributions and enhanced functionalities like cooling channels for applications in high temperature environments.
In this work, we study the additive manufacturing of permanent magnets from conventional NdFeB powder (MQP-S-11-9-20001 from Magnequench) by selective laser melting. The scope of our work is to deepen current knowledge about the influence of laser process parameters on the magnets characteristics, novelly investigate the effects of heat treatment on its microstructure and its magnetic hysteresis curve and analyze its degradation over time.
Literature:
[1] BROWN, David; MA, Bao-Min; CHEN, Zhongmin. Developments in the processing and properties of NdFeb-type permanent magnets. Journal of Magnetism and Magnetic Materials, 2002, 248. Jg., Nr. 3, pp. 432-440.

[2] MA, B. M., et al. Recent development in bonded NdFeB magnets. Journal of magnetism and magnetic materials, 2002, 239. Jg., Nr. 1, pp. 418-423.
[3] HUBER, C., et al. 3D print of polymer bonded rare-earth magnets, and 3D magnetic field scanning with an end-user 3D printer. Applied Physics Letters, 2016, 109. Jg., Nr. 16, S. 162401.
[4] KOLB, T., et al. Laser Beam Melting Of NdFeB For The Production Of Rare-Earth Magnets. 2016 6th International Electric Drives Production Conference (EDPC), Nuremberg, 2016, pp. 34-40.
[5] JACIMOVIC, J., et al. Net Shape 3D Printed NdFeB Permanent Magnet. Net Shape 3D Printed NdFeB Permanent Magnet . Adv. Eng. Mater., 1700098.

Postprocessing (II) / 34

EFFECT OF SURFACE MECHANICAL ATTRITION TREATMENT (SMAT) ON THE MECHANICAL PROPERTIES OF AISI 316L PROCESSED BY SELECTIVE LASER MELTING (SLM)

Mr. PORTELLA, Quentin[1] ; Dr. CHEMKHI, Mahdi[2] ; Prof. RETRAINT, delphine[1]

[1] *ICD-LASMIS/University of Technology of Troyes*

[2] *ICD-LASMIS/University of Technology of Troyes - DMMS/EPF Graduate School of Engineering*

Corresponding Author(s): quentin.portella@utt.fr

Selective Laser Melting (SLM) is a metal additive manufacturing process widely used in industry for its extraordinary versatility to geometry and minimum waste of material. Mechanical properties of SLM objects depend strongly on the process parameters such as power, scanning speed, hatch space and scanning strategy. Working on these latter parameters, the material can be porous or fully-dense.
However, the high thermal gradients which are characteristic of this process induce complex distributions of residual stresses and defects such as micro-crack formation. Both have a negative impact on the geometry and mechanical properties of SLM samples. In the literature, the well-known solution proposed in order to reduce these thermal stresses present in SLM parts is a post-heat treatment.
Another possible post-treatment which is mechanical can bypass several of these difficulties. Indeed, the Surface Mechanical Attrition Treatment (SMAT) has a local impact on the sample, thanks to the generation of a nanocrystalline layer on the sample surface provided by severe plastic deformation via multidirectional and random shot impacts. The global mechanical properties of the SLM sample are thus widely improved.
The motivation of the present paper is to examine the effect of SMAT on mechanical and surface properties of AISI 316L stainless steel manufactured by SLM. The post-treated samples were characterized by Optical Microscopy (OM), Scanning Electron Microscopy (SEM), surface roughness and micro-hardness measurement techniques. In addition, X-ray diffraction (XRD) method was used to investigate the residual stress present at the surface of the untreated and treated samples.

Design / 36

ADDITIVE MANUFACTURING OF MICROLATTICE STRUCTURES AT THE RESOLUTION LIMIT OF THE SELECTIVE LASER MELTING PROCESS

Author(s): Mr. GÖRTLER, Michael[1]
Co-author(s): TRUSZKIEWICZ, Eliza [2] ; Dr. BERER, Michael [2] ; Dr. WALDHAUSER, Wolfgang [1]

[1] *Joanneum Research Forschungsgesellschaft mbH*

[2] *Polymer Competence Center Leoben GmbH*

Corresponding Author(s): michael.goertler@joanneum.at

Additive manufacturing technologies enable the efficient production of metal parts with high geometrical complexity. The highest degree of design freedom offer powder bed based methods like selective laser melting (SLM) and therefore, they are capable of fabricating components with integrated lattice structures [1]. This implementation of lattice structures can significantly enhance the parts functionality concerning lightweight design, bone-ingrowth features or catalytic properties [2,3,4].
Depending on the required load bearing efficiency and desired stiffness, the production of very thin struts and small unit cells can be necessary. However, micro lattices with defined strut diameters below 300 micron cannot be produced by industrial SLM machines by default. To manufacture thin micro lattice structures matching the CAD design, parameter studies have to be performed in advance and design rules have to be followed.
In this work, the preliminary stages of micro lattice fabrication on a commercial EOS M280 machine are presented and the manufacturability of lattice strut elements for varying inclination angle and diameter is described. Based on the identified limits, CAD design rules are given and the corresponding SLM compatible lattices are manufactured with optimized parameters. The morphology and the relative densities of the fabricated lattice structures are then compared to the CAD data and the mechanical properties are measured by compression tests.
[1] Yap, C. Y. et al. Review of selective laser melting: Materials and applications. Applied Physics Reviews 2, 2015.
[2] Yan, Chunze et al. Advanced lightweight 316L stainless steel cellular lattice structures fabricated via selective laser melting. Materials and Design 55, 2014, pp. 533-541.
[3] Tan, X. P. et al. Metallic powder-bed based 3D printing of cellular scaffolds for orthopaedic implants: A state-of-the-art review on manufacturing, topological design, mechanical properties and biocompatibility. Materials Science and Engineering C, Volume 76, 2017, pp. 1328-1343.
[4] Yadroitsev, I. et al. Manufacturing of fine-structured 3D porous filter elements by selective laser melting. Applied surface Science 255, 2009, pp. 5512-5527.

New Materials (II) / 37

DESIGNING A NOVEL Fe-Ni-Al-Ti MARAGING STEEL TAILOR-MADE FOR LASER METAL DEPOSITION

Author(s): Mr. KÜRNSTEINER, Philipp[1]
Co-author(s): Mr. WILMS, Markus B. [2] ; Mr. WEISHEIT, Andreas [2] ; Dr. BARRIOBERO-VILA, Pere [3] ; Dr. JÄGLE, Eric A. [1] ; Prof. RAABE, Dierk [1]

[1] *Max-Planck-Institut für Eisenforschung, Düsseldorf, Germany*

[2] *Fraunhofer-Institut für Lasertechnik, Aachen, Germany*

[3] *Institute of Materials Research, German Aerospace Center (DLR), Cologne, Germany*

Corresponding Author(s): p.kuernsteiner@mpie.de

Maraging steels show outstanding mechanical properties regarding strength and toughness caused by a martensitic microstructure that is strengthened by a high number density of intermetallic precipitates upon ageing heat treatment. Laser Metal Deposition (LMD; DED) is a nozzle-based Laser Additive Manufacturing (LAM) process that allows to produce custom-made parts directly from a CAD model and metallic powders. Material produced by LMD exhibits a unique thermal history: Initially the material is cooled rapidly from the liquid state in the meltpool. Subsequently, the material experiences a cyclic reheating, the so-called intrinsic heat treatment (IHT), as neighboring tracks and further layers are deposited during the LAM process.
The present study aims at exploiting this intrinsic heat treatment to produce Maraging steel parts that are already in-situ precipitation hardened during the manufacturing process, avoiding an ageing heat treatment after the LMD process. For this purpose, we atomized an Fe19Ni (at%) master alloy powder. We produced two compositionally graded specimen with varying Al and Ti concentrations ranging from 3at% to 20at% by varying the relative feed rates of the master alloy and pure element powders in the LMD process. This allowed fast and efficient screening of different alloy compositions.
We could show that indeed the IHT can be used to in-situ harden the Fe-Ni-Al [1] as well as the Fe-Ni-Ti Maraging steel system. We evaluated mechanical properties such as hardness and

related them to the precipitate number density, spatial distribution and chemistry as found from Atom Probe Tomography (APT) and High Energy X-ray Diffraction (HEXRD) experiments.
At low Al concentrations in the Fe-Ni-Al system, the solute atoms Ni and Al were distributed randomly. In contrast, at higher Al concentrations, pronounced clustering of Ni and Al occurred. We found exceptionally high number densities of up to 10ˆ25 NiAl nano-precipitates per mˆ3 at 10at% Al in the as-produced samples. Hardness of the material showed a steep increase from 300HV (at 0% Al) to 530HV associated with the high number density of those NiAl precipitates.
In the Fe-Ni-Ti system, depending on processing parameters, either η-phase (Ni3Ti) or Laves phase (Fe,Ni)2Ti precipitates formed upon IHT. The η-phase exhibited a bimodal size distribution consisting of nanometer sized spherical precipitates and a dense network of rod-shaped precipitates. The Laves phase showed rod shaped as well as roughly spherical precipitates in the size range of 100nm. In a graded sample exhibiting Laves phase, we observed a steep increase in hardness from 300HV at 0% Ti up to 700HV at 15at% Ti by precipitation of 20vol% Laves phase.
[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)

Known Materials & Characteristics (II) / 38

MATERIAL PROPERTIES OF A LASER CLADDED AND HIP'ED AEROSPACE COMPONENT

Author(s): Mr. HOLM, Mads[1]
Co-author(s): Mr. NIELSEN, Peter Tommy [1] ; Mr. COURRIER, Philippe [2]

[1] *FORCE Technology*

[2] *Terma A/S*

Corresponding Author(s): maho@force.dk

Traditionally, blast deflectors have been manufactured using conventional, subtractive machining processes using large steel forgings. Since the final product has thin walls compared to the size, only a fraction of the original material block remains in the final product. Based on these observations, laser cladding as additive manufacturing method could potentially entail a significant cost reduction producing this component. From a sourcing perspective, the requirement to store generic powder instead of component specific metal billets is a definite advantage. Whether laser cladding is applicable for this specific design, is dependent on the mechanical properties and fatigue life of the material.
This paper will investigate the mechanical properties and the fatigue life of laser cladded PH 15/5 samples, which all have been submitted to Hot Isostatic Pressing (HIP). Specimens were produced with a thickness of 3 mm and manufactured into dog bone specimens. This will be the foundation for the analysis of the material properties. The evaluation will compare results with expected values from reference materials. Furthermore, a SN-curve will be derived from the fatigue test. This will be compared to available standards and literature.

New Materials (II) / 39

INFLUENCE OF POWDER CHARACTERISTICS ON FINAL PROPERTIES OF POWDER-BED LASER ADDITIVELY MANUFACTURED ODS Fe-14Cr STEEL

Author(s): Ms. VASQUEZ, Elodie[1]
Co-author(s): Mr. GIROUX, Pierre-François [1] ; Mr. LOMELLO, Fernando [2] ; Mr. MASKROT, Hicham [2] ; Mr. CASTANY, Philippe [3]

[1] *DEN-Service de Recherches Métallurgiques Appliquées, CEA, Université Paris-Saclay, F-91191, Gif-sur-Yvette, France*

[2] *DEN-Service d'Etudes Analytiques et de Réactivité des Surfaces, CEA, Université Paris-Saclay, F-91191, Gif-sur-Yvette, France*

[3] *ISCR/CM - INSA, Institut des Sciences Chimiques de Rennes (ISCR), INSA Rennes, 20 Avenue des Buttes de Coesmes, 35708 Rennes, France*

Corresponding Author(s): elodie.vasquez@cea.fr

Additive manufacturing processes are promising technologies, currently considered as new opportunities to optimize metallic components production routes, especially in aerospace, automotive, medical and energy industries. The development of the application fields of these technologies involves an increase in the number of possible printed materials. In order to become a robust and reliable way of production of metallic functional components, mastering these technologies must still address challenges. In this framework, the study of the defects impact on final properties of designed components is essential.
To assess the potentialities of additive manufacturing in nuclear industry, ODS Fe-14Cr steels are produced by selective laser melting (SLM). ODS steels are studied due to their improved resistance under neutron irradiation thanks to a fine dispersion of nanosized Y-Ti-O precipitates. Such materials are produced by a first step mechanical alloying. The resulting powder is characterized by a non-spherical shape and are coarser than powders typically used in SLM equipment. The analyzes such as composition, density, particles size distribution, flowability and morphology are performed on this powder. The milled powder is then used to produce ODS steel parts as raw material or after some modifications such as sieving or annealing.
The objective of this work is to study the impact of the powder characteristics on the final material properties. As expected, powder characteristics strongly influence the final density of solidified parts. The choice of the thickness layer is also an important parameter that has to be related with the particle size distribution of the powder. The optimization of processing parameters (scanning speed, scanning strategy, laser power, etc…) and powder characteristics lead to a significant improvement of final material properties. In this context, last results regarding ODS steels additive manufacturing study will be presented and new insights for industrial fabrication will be given.

Known Materials & Characteristics (II) / 40

INFLUENCE OF INCLINATION ANGLE ON THE MICROSTRUCTURE AND ROUGHNESS OF DOWNSKIN OF 3D-PRINTED 316L POWDER

Dr. SKALON, Mateusz[1] ; Mr. GRUBERBAUER, Andreas[2] ; Dr. BUZOLIN, Ricardo Henrique[2] ; Mr. HÖLLER, Christian[3] ; Prof. SOMMITSCH, Christof[4]

[1] *Technische Universität Graz*

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

[3] *Institute of Production Engineering, Graz University of Technology*

[4] *Graz University of Technology*

Corresponding Author(s): mateusz.skalon@tugraz.at

The paper describes the influence of increasing inclination angle on the surface quality of the downskin of 3D-printed cubic samples via Laser Powder Bed Melting. The series of samples was printed using 316L powder with increasing inclination angle in respect to the baseplate. In order to observe a balling effect and a decreasing surface quality the samples were printed with no supporting structures placed on the downskin. The one-track tests were performed using an in-house developed test stand and characterising with linearly increasing depth of the powder bed, which enables to physically simulate specific solidification conditions during the printing procedure of samples with increasing inclination angle. A balling phenomenon was quantified and compared using the roughness test and it was found to be dependent on the inclination angle. The microstructural investigation was done using LOM, SEM and EBSD methods in order to compare the microstructural changes with respect to the changing inclination angle. The roughness comparison of cubic samples with one-track samples brought meaningful information about the influence of the solidification conditions of the molten pool on the maximum printing angle of supportless surfaces.

New Materials (II) / 41

PROCESS AND ALLOY DESIGN FOR IN-SITU PRECIPITATION STRENGTHENING OF Al-Sc ALLOYS DURING LASER METAL DEPOSITION

Author(s): Mr. KÜRNSTEINER, Philipp[1]
Co-author(s): Mr. WILMS, Markus B. [2] ; Dr. WEISHEIT, Andreas [2] ; Mr. BAJAJ, Priyanshu [3] ; Dr. JÄGLE, Eric A. [3] ; Prof. RAABE, Dierk [3]

[1] *Max-Planck-Institut für Eisenforschung, Düsseldorf*

[2] *Fraunhofer-Institut für Lasertechnik, Aachen, Germany*

[3] *Max-Planck-Institut für Eisenforschung, Düsseldorf, Germany*

Corresponding Author(s): p.kuernsteiner@mpie.de

Aluminum alloys play an important role for lightweight components for automotive and aerospace industries. Al-Sc alloys exhibit excellent mechanical properties due to the presence of coherent intermetallic Al3Sc precipitates. Zr alloy additions lead to a Zr-rich shell around the small coherent Al3Sc precipitates that slows down precipitate growth and renders the alloy resistant to precipitate coarsening. In this study, two alloys with varied Sc and Zr contents are considered, namely the commercial Al4.5Mg0.66Sc0.4Zr Scalmalloy® and an Al1.0Sc0.6Zr alloy.
Laser Metal Deposition (LMD) is a Laser Additive Manufacturing (LAM) process in which metallic powder is injected through a nozzle into the melt pool, created by a laser beam. Deposition of neighboring tracks and subsequent layers during the LMD process, leads to a cyclic reheating of already consolidated material, the so-called intrinsic heat treatment (IHT). The idea behind the present study is to exploit two key features of LAM processes, namely a high cooling rate to quench in a supersaturated solid solution and the IHT to trigger the precipitation reaction in this supersaturated solid solution. This way we were able to produce parts that are already precipitation hardened during manufacturing, eliminating the need for a post heat treatment.
We achieved high number densities of intermetallic precipitates in the range of 10ˆ21 3x10ˆ23m 3 with sizes ranging from 5-40nm by exploiting the IHT. We analyzed different IHT conditions by lifting out Atom Probe Tomography (APT) tips from different layers of a multi-layer sample: the bottom layers received maximum IHT as a high number of subsequent layers were deposited while the top layers received a minimum IHT only from neighboring tracks.
In the case of the commercial Al4.5Mg0.66Sc04Zr Scalmalloy®, the Al3Sc precipitates coarsened with increasing strength of the IHT. We found the reason for the coarsening in the absence of the expected Zr-rich shells around the precipitates. Instead, Zr was bound in micron-sized, primary precipitates and was therefore not available to form the Zr shell. In order to avoid the undesired coarsening, we optimized both, alloy composition and process. We used an alloy with increased Zr content and optimized the LMD process for a high cooling rate in order to keep enough Zr in solid solution to allow for the Zr shell formation.
In the optimized alloy (Al1.0Sc0.6Zr), the precipitates that formed were of Al3(Sc,Zr) type and did not coarsen at all. Instead, with increasing strength of the IHT, a Zr-rich shell formed around the Sc-rich precipitate core that prevented coarsening.
We evaluated mechanical properties of both alloys and related them to the precipitate number density, spatial distribution, and chemistry as found from APT and Transmission Electron Microscopy (TEM) experiments.

Known Materials & Characteristics (II) / 42

CORROSION BEHAVIOUR OF AM 316L STAINLESS STEEL

Author(s): Prof. ANDREATTA, Francesco[1]
Co-author(s): Dr. LANZUTTI, Alex [1] ; Mr. VAGLIO, Emanuele [1] ; Mr. MICHELE, Magnan [1] ; Dr. TOTIS, Giovanni [1] ; Dr. SORTINO, Marco [1] ; Prof. FEDRIZZI, Lorenzo [1]

[1] *University of Udine*

Corresponding Author(s): francesco.andreatta@uniud.it

The SLM (Selective Laser Melting) is an additive manufacturing technique (AM) that is based on a layer by layer laser melting of metal powders deposited on a moving stage in order to obtain a

controlled geometry of the component (3D printing). Many metals can be processed by using this technique such as Ti, Al or Ni alloys, tool or stainless steels. The aim of this work is to determine the corrosion properties of an AISI 316L stainless steel produced by 3D printing and to compare these properties to the ones of a wrought AISI 316L stainless steel. The samples were produced by SLM (Concept laser) using a chessboard laser scan. The as produced material, as well the wrought material, underwent a post production heat treatment at different temperatures in order to observe the material microstructural evolution. The microstructures were investigated by SEM and light microscopes as well as by SKPFM in order to determine the presence and evolution of the different formed phases as a function of heat treatments. Potentiodynamic polarization curves in 3,5 wt% NaCl were obtained at 3 different temperatures (RT, 40°C and 60°C) on polished samples. In addition, micro-cell electrochemical test were performed at room temperature. After polarization tests samples were characterized in order to determine the preferential corrosion sites. These preliminary analyses have shown that the AM material presents a dual phase microstructure as well as the presence of small defects (porosities) affecting the corrosion behaviour.

New Materials (II) / 43

SURFACE MULTIFUNCTIONALITY FOR ENHANCING FRICTION AND WEAR PERFORMANCE OF 3D PRINTED LIGHTWEIGHT COMPONENTS USING TECHNOLOGY HYBRIDS

Author(s): Dr. RODRIGUEZ RIPOLL, Manel[1]
Co-author(s): Mr. KATSICH, Christian [1] ; Dr. HATZENBICHLER, Markus [2] ; Dr. BADISCH, Ewald [1]

[1] *AC2T research GmbH*

[2] *FOTEC Forschungs- und Technologietransfer GmbH*

Corresponding Author(s): ripoll@ac2t.at

Additive manufacturing is a technology that exhibits enormous potential in several application industries. The technology allows to build up complex 3D geometries with reduced mass using lightweight materials while dramatically reducing the development time, compared to conventional manufacturing routes. In many applications, 3D printed components face the need to operate under demanding conditions thus requiring additional surface functionality to enhance their wear resistance or to control friction when sliding against other components.
In this work 3D lightweight structures with different wall thicknesses (0.75 mm to 2.00 mm) made of Maraging steel (EOS MS1, 1.2709) were realized using the Laser Beam Melting (LBM) technology. Using a 200 W Yb-fiber laser (lambda = 1080 nm) metal powder particles are welded together selectively under inert gas atmosphere according to the current cross section. After lowering the building platform by 30 μm a new powder layer is spread on it and the exposure of the next cross section starts. This procedure is repeated until the complete lightweight structure is finished. For the purpose of stress relieve annealing a heat treatment was applied on all manufactured structures.
In order to functionalize the surface of the 3D printed lightweight structures, multifunctional claddings are deposited using high power direct diode laser (HPDDL). The laser claddings are designed to fulfil several duties simultaneously, thus providing multifunctionality. Particular emphasis is set in increasing their wear resistance by the presence of hard phases and offer self-lubricating properties for controlling friction by themselves. The results obtained discuss the potential of the hybrid 3D components for operating under severe contact conditions in a wide temperature range. By providing surface multifunctionality using laser claddings, the industrial applicability of these promising 3D printed hybrid components is enlarged opening the doors to new fields of application.

Known Materials & Characteristics (III) / 44

FEASIBILITY INVESTIGATION FOR LASER POWDER BED FUSION OF HIGH-SPEED STEEL AISI M50 WITH BASE PLATE PREHEATING SYSTEM

Author(s): Ms. SAEWE, Jasmin[1]
Co-author(s): Mr. KUNZ, Johannes [2] ; Prof. BROECKMANN, Christoph [2] ; Prof. SCHLEIFENBAUM, Johannes Henrich [1]

[1] *Fraunhofer Institute for Laser Technology (ILT), Aachen*

[2] *Institute of Applied Powder Metallurgy and Ceramics at RWTH Aachen e.V. (IAPK)*

Corresponding Author(s): jasmin.saewe@ilt.fraunhofer.de

Laser-powder bed fusion (L-PBF) is an additive manufacturing process which is used in aerospace, automotive and medical applications. In these areas nickel, aluminum and titanium based alloys are already entrenched. For mechanical engineering industry only few steels are qualified for the L-PBF process which are mostly hot work tool steels with less than 0.5 wt.-% carbon content. Many applications need wear-resistant steel alloys with high hardness like high speed steels with higher carbon content. But processing these steels with L-PBF often leads to crack formation and is therefore considered as very challenging. This feasibility study demonstrates that building up dense and crack-free parts with a hardness over 60 HRC (as built) made from high speed steels (carbon content higher 0.5 wt.-%) with L-PBF is possible. Furthermore, the influence of typical L-PBF process parameters, especially preheating temperature, on the microstructure of the parts is evaluated.

Postprocessing (II) / 45

HOT ISOSTATIC PRESSING WITH INTEGRATED HEAT TREATMENT

Author(s): Ms. THIE (BOHRT), Stephanie[1]
Co-author(s): Dr. LENZ, Wolfgang [1] ; Prof. PFEIFER, Herbert [1] ; Mr. RIEHM, Sebastian [2] ; Mr. DENG, Yuanbin [2] ; Mr. RAJAEI, Ali [2] ; Ms. BIRKE, Carola [2] ; Prof. BROECKMANN, Christoph [2] ; Mr. KNAUFF, Marc [3] ; Mr. CREMER, Ingo [3]

[1] *Department of Industrial Furnaces and Heat Engineering of RWTH Aachen University*

[2] *Institute for Materials Applications in Mechanical Engineering of RWTH Aachen University*

[3] *Cremer Thermoprozessanlagen GmbH*

Corresponding Author(s): thie@iob.rwth-aachen.de

Producing additive manufactured parts often includes post processing in a hot-isostatic press (HIP) and heat treatment. This process usually requires a long cooling and reheating time, which results in a long occupancy of the machinery with a high energy consumption. To reduce the required time and costs, a new process has been designed to reduce the process time and increase the operational capacity of the machinery. This is achieved by a new HIP design with increased cooling rates. The heat treatment of thermally thin components can be carried out within the HIP-vessel. For a successful heat treatment in the new HIP vessel, predefined cooling rates are necessary. Cooling inside the pressurized vessel with supercritical atmospheres increases heat transfer coefficients and temperature homogeneity. The newly designed process includes forced convection and heat exchange inside the pressurized vessel. Fluid flow and heat transfer were designed using Computational Fluid Dynamics analyses carried out by the Department of Industrial Furnaces and Heat Engineering. The numerical model is divided into sub models to reduce the requirements in computing capacity and to be able to investigate certain parts of the process in detail. For the overall flow conditions and interdependencies, the results of the sub models are incorporated into a comprehensive model, which is able to cover the mass and energy balances of the whole process. Resulting fluid flow and temperature distribution within the vessel are compared to the results of experimental measurements. The cooling rates necessary to enable heat treatment of exemplary parts within the pressure vessel were investigated at the Institute for Materials Applications in Mechanical Engineering, where the microstructure of the hot isostatically pressed samples was studied. Coupling the simulations of the heat transfer and the fluid flow with the simulations of changes in microstructure leads to a better understanding of the process. This aims to develop a new HIP plant with integrated heat treatment having a high predictability and precise plant control.

Powder Production & Characterization (II) / 46

ADVANCES IN MARAGING STEELS FOR ADDITIVE MANUFACTURING

Author(s): Mr. ZUNKO, Horst[1]
Co-author(s): Prof. LEITNER, Harald [1] ; Dr. KAPP, Marianne [2]

[1] *voestalpine Böhler Edelstahl GmbH*

[2] *marianne.kapp@voestalpine.com*

Corresponding Author(s): horst.zunko@voestalpine.com

Maraging steels, such as 1.2709 are high strength - high toughness alloys that gain their exceptional mechanical properties by the combination of nanometer-sized intermetallic precipitates and a martensitic matrix. The martensitic microstructure is thereby not achieved by a high carbon content, but by adding nickel to the chemical composition. The lack of carbon leads in turn to good weldability and therefore makes these materials preferred candidates for additive manufacturing techniques, such as selective laser melting (SLM). Applications for SLM produced components are found especially in the tooling industry, where the implementation of inserts with intelligent conformal cooling channels in dies and moulds has already shown to drastically increase the tool lifetime. In this study different maraging steels are investigated with respect to typical powder characteristics, such as sphericity, particle size distribution, humidity or oxygen content on the one hand and the microstructure as well as the achieved mechanical properties of the respective SLM printed parts on the other hand.

Related Processes (II) / 47

FILAMENT METAL PRINTING: SINTERED METAL PARTS BASED ON FFF WITH REINFORCED FEEDSTOCK

Author(s): Mr. KITZMANTEL, Michael[1]
Co-author(s): Mr. KALTENBRUNNER, Markus [2] ; Dr. NEUBAUER, Erich [1] ; Mr. DOPPLER, Michael [2]

[1] *RHP-Technology GmbH*

[2] *Evo-Tech GmbH*

Corresponding Author(s): michael.kitzmantel@rhp-technology.com

Extrusion based additive manufacturing using the base of Fused Filament Fabrication (FFF) is one of the very promising technologies for fast and cost effective production of 3D shaped metal parts. With this technology a green body is formed with high filling content of metallic powder. In this study we investigate the commercially available co-extruded filament by BASF, UltrafuseX 316L. The surfaces of the printed bodies were kept in original condition and compared with ground to low roughness before debinding. The debinding step was performed in catalytic debinding furnace followed by a sintering study in hydrogen atmosphere. We did systematically investigate the influence of the various process parameters on the final sintered part geometry and properties to give a base on future design rules for this process. Microstructure, porosity, surface structure and roughness as well as dimensional changes of the sintered bodies were investigated and compared. By use of this 3D printing techniques stainless steel parts (and in future further metals and even ceramics) with innovative geometries are accessible, which is briefly discussed.

Related Processes (II) / 48

XL MULTI-MATERIAL AM USING AN ECONOMIC BLOWN POWDER PROCESS

Author(s): Dr. NEUBAUER, Erich[1]
Co-author(s): Mr. ARIZA, Enrique [1] ; Mr. MEUTHEN, John [1] ; Mr. KITZMANTEL, Michael [1] ; Mr. GRECH, David [1]

[1] *RHP-Technology GmbH*

Corresponding Author(s): michael.kitzmantel@rhp-technology.com

Nowadays powder bed processes such as laser or electron beam melting have been successfully introduced in various applications. Nevertheless there are many components or material concepts which cannot be realized by using these techniques.
In this work a plasma transferred arc system is used as a heat source in combination with feeding of powder for the manufacturing of 3D parts. This method allows the combination of materials, e.g. to realize multi-materials or manufacture composite materials. The process will be described in detail and examples of different materials such as Titanium alloys, Iron based alloys as well as Nickel based alloys will be presented. Using two powder feeders multi-material components and gradient structures can be realized. Material properties, application areas as well as the potential of the technology for will be presented.

New Materials (IV) / 49

PRELIMINARY STUDY OF THE PROCESSING PARAMETERS EFFECT ON THE MICROSTRUCTURE AND PROPERTIES OF TITANIUM GRADE 1 SPECIMENS FABRICATED VIA ADDITIVE MANUFACTURING

Author(s): Prof. MONTEALEGRE-MELÉNDEZ, Isabel[1]
Co-author(s): Dr. ARÉVALO, Cristina [1] ; Dr. PÉREZ-SORIANO, Eva Maria [1] ; Mr. KITZMANTEL, Michael [2] ; Dr. NEUBAUER, Erich [2]

[1] *University of Seville*

[2] *RHP-Technology GmbH*

Corresponding Author(s): evamps@us.es

Today Ti6Al4V alloy, also known as Titanium Grade 5, is in use worldwide. However, several authors studied the difficulty of its machining due to their low thermal conductivity, high chemical reactivity at high temperatures or low modulus of elasticity, which can lead to damage vibrations in the specimen. In view of the above, a manufacturing technology is developed, and it is revolutionizing the industries in recent years.
In this study, several specimen have been manufactured via AM by the use of the injection of powder using a Plasma Transferred Arc Welding technique. The seam was made from Titanium Gd5 powder, with particles of a size between 100-200 μm, on a substrate of the same material and several PTA parameters were varied and investigated. The purpose of this study is to identify the main processing parameters whose effect was more significant and notorious on the hardness, density and microstructure of the specimens. With this respect, the optimal processing conditions were found to be achieved.

Known Materials & Characteristics (III) / 51

ON THE FORMATION OF PROCESS-INDUCED DEFECTS IN H13 TOOL STEEL PROCESSED BY LASER BEAM MELTING

Author(s): Mr. XIA, Fengchen[1]
Co-author(s): Mr. WU, Liang [2] ; Mr. GRIDIN, Witalij [2] ; Dr. LEUDERS, Stefan [2] ; Prof. HU, Ming [3] ; Prof. NIENDORF, Thomas [4]

[1] *voestalpine additive manufacturing center*

[2] *voestalpine Additive Manufacturing Center*

[3] *RWTH Aachen GHI institute*

[4] *Universität Kassel Fachbereich 15 - Institut für Werkstofftechnik*

Corresponding Author(s): xia.fengchen@voestalpine.com

The tool and die industry is one of the most promising markets for Additive Manufacturing, even if there is still a lack of suitable materials. For conventional process routes, H13 tool steel is a well-established material due to its high thermo-fatigue and crack resistance, especially for applications in the high pressure die casting industry. Due to this situation, H13 is a promising

candidate material for the AM process route as well. Several kinds of defects such as pores, cracks or lack of fusion can be formed during additive manufacturing of H13. These defects might have severe influence on the properties of the manufactured products. Against this background, the current study will systematically classify process-induced defects in order to provide a catalog for additive manufactured H13. In addition, in-depth investigations under different processing conditions allow for a detailed discussion on the underlying mechanisms leading to the formation of the different types of defects. Finally, theoretical models focusing on the effects and optimization strategies derived therefrom are provided. Thereby, this study contributes to effective guidelines for robust processing of H13 using Additive Manufacturing.

Keynote (I) / 53

SURFACE FINISHING FOR 3D-PRINTED METAL PARTS: FROM SUPPORT STRUCTURE REMOVAL TO CORROSION PROTECTION

Author(s): Dr. HANSAL, Wolfgang[1]
Co-author(s): Dr. HANSAL, Selma [1] ; Mrs. SANDULACHE, Gabriela [1]

[1] *Hirtenberger Engineered Surfaces*

Corresponding Author(s): wolfgang.hansal@hirtenberger.com

The post-processing of AM metal parts is still an open issue and a crucial element in the process chain on the way to the use of additive manufacturing in industrial production. The 3D-printed metal parts leave the printer, independently from the way of printing in terms of LBM or EBM, with a whole bunch of support structures fixed to the part, adhering metal powder (especially in the case of EBM with a partly sintered powdercake) and a surface roughness that is about an order of magnitude too high for the technical application. All these issues have to be adressed by a proper post treatment of the printed metal parts. While mechanical methods are mostly work, time and cost intensive they also cannot provide a proper finishing on sterically hindered parts and inner surfaces. Here chemically based methods, such as the Hirtisation process, may provide a possibility that enables an integrated production process. While a printed part free of support structures and having a smooth surface might be ideal as prototype and demonstration part, real life industrial use brings additional issues that have to be adressed. While it is perfectly clear for classical produced metal components that wear and corrosion might affect the durability of the parts, such considerations have not yet found their way into the Additive Manufacturing world. This presentation gives a report of the results of different surface treatments of 3D-printed metal parts and will rise several questions regarding the post-finishing process including protective coatings and corrosion protection.

New Materials (IV) / 56

RECENT DEVELOPMENTS OF LIGHT ALLOY PRECURSOR MATERIAL FOR ADDITIVELY MANUFACTURED ULTRA-LIGHTWEIGHT PARTS

Mr. GRADINGER, Rudolf[1]

[1] *LKR Leichtmetallkompetenzzentrum Ranshofen GmbH*

Corresponding Author(s): rudolf.gradinger@ait.ac.at

An increasing availability of capable additive manufacturing processing technologies is in parallel needing high-performance metallic materials in order to create efficient, light weight design parts. The consortium of the M-Era.net project HiPA^{2}l has set goals to develop innovative Aluminium alloys designed for usage in wire-based arc welding AM processes. The alloying and processing research in project proposal HiPA^{2}l will take advantage of recent developments in analytical as well as numerical simulation of new alloy compositions, allowing an enhanced understanding of the expectable material behaviour both in the development of alloys as well as in the industrial phase of producing complex shaped parts.

Powder Production & Characterization (II) / 58

MICROSTRUCTURE INVESTIGATION OF POWDERS FOR ADDITIVE MANUFACTURING

Author(s): Dr. ALBU, Mihaela[1]
Co-author(s): DIENSTLEDER, Martina [1]

[1] *ZFE Graz*

Corresponding Author(s): mihaela.albu@felmi-zfe.at

Development of new materials for additive manufacturing is fundamentally linked to understanding of the atomic scale effects, which drives the micro- and nano-structure particularities. In order to avoid or exploit these effects advanced ex- and in-situ characterization methods are needed. This paper presents high-resolution scanning and transmission electron microscopy (SEM and TEM) investigations of micro- sand nano-structure of different Al based alloys in powder form. Conventional and advanced TEM methods such as energy filtered transmission electron microscopy (EFTEM) and scanning TEM (STEM) provides insight into the material's crystallography and chemistry quantitatively and at atomic resolution. STEM 2D or 3D acquisition of high angular annular dark field images (HAADF) at atomic resolution and both X-ray (EDX) and electron energy loss spectrometry (EELS) spectrum images are indispensable tools for the localization and identification of different elements and their stable and metastable phases. Therefore, the influence of different elements added in higher or very low concentration have been studied. Information regarding the recrystallization of grains, diffusion of alloying elements and nucleation of new phases at different temperatures can be gained by in-situ S/TEM observations of powder particles.

Powder Production & Characterization / 59

POWDER PRODUCTION TECHNOLOGIES

Dr. WALLNER, Stefan[1]

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

Corresponding Author(s): stefan.wallner@bohler-edelstahl.at

Production of metal powder is done since decades. Beside of some methods using crushers for powder production, the atomization of a molten liquid melt is the most common way to produce metal powders. Therefore different melting technologies (open furnace, vacuum furnace, induction melting or plasma melting, etc.) as well as atomization techniques (water, gas) can be used. Depending on the used melting and atomization technology the produced powder can differ in specific size and shape. The presentation will provide an overview of the most used technologies in melting and atomization with special focus on the production of powder for the use in additive manufacturing. A more detailed insight in the gas atomization process using closed couple atomization system will be also part of the presentation.

New Materials (IV) / 60

LASER ADDITIVE MANUFACTURING OF NIOBIUM SILICIDE-BASED HIGH TEMPERATURE MATERIALS

Author(s): Prof. DONG, Hongbiao[1]
Co-author(s): Mr. DOUGLAS, Andrew [1] ; Mr. ALLEN, Adam [1] ; Mr. FEITOSA, Leandro [1] ; Mr. QIAN, Huan [1]

[1] *University of Leicester*

Corresponding Author(s): hd38@le.ac.uk

Niobium silicide-based alloys, in the application of gas turbine blades, promise significant efficiency improvements compared to current Ni-based alloys. The higher temperature capability would allow the engine to run at a higher temperature than that of current alloys, increasing engine efficiency. Nb-Si based composites possess a lower density, due to the presence of ceramic phases

such as Nb5Si3 and/or Nb3Si. This would reduce the weight of the rotating blades. However, improvements in certain properties, such as ductility, room temperature toughness and oxidation resistance are needed. The alloy must also be cost effective to manufacture if niobium silicide systems are to reach their full potential.
This study focuses on the manufacturability aspect of the powder feeding laser additive manufacturing (LAM) process to engineering Nb-Si based alloy samples. A schematic drawing of LAM system is shown in Figure 1. In LAM process, CAD models of the components are constructed and sliced layer by layer for laser multilayer cladding, which directly forms the component shapes. LAM has the advantage of forming near-net shapes without the use of expensive cores and moulds for the reactive Nb-Si melt. Fine microstructure and even chemical composition distribution with reduced macro-segregation are obtained. With the use of power feeding system, new Nb-Si based alloys are LAMed with varying Ti, Si, Cr, Al, Hf, V concentrations. Microstructures and mechanical properties of the LAMed new alloys will be presented, the relationship between mechanical property, alloy chemistry and process variable will be analyzed and the challenges in powder feeding laser additive manufacturing of Nb-Si based composites will be reported.

Opening / 61

CHALLENGES OF ADDITIVE MANUFACTURING IN HIGH PERFORMANCE MARKETS

Mr. SEIDEL, Stefan[1] ; Dr. ROTPART, Michael[2]

[1] *Chief Technical Officer, Pankl Racing Systems AG*

[2] *Geschäftsführung, voestalpine BÖHLER Edelstahl GmbH & Co KG*

Corresponding Author(s): agnes.molnar@pankl.com, agnes.molnar@pankl.com

In a very intense and close cooperation Böhler and Pankl are jointly developing alongside the complete value chain of Additive Manufacturing in order to push the limits of AM and in order to establish the technology within the challenging fields of aerospace and high performance automotive – especially motor racing. The focus on the entire process and value chain is the key to tackle some of the hurdles within the technology. Therefore, the newly established Additive Manufacturing Competence Center in Kapfenberg is the ideal basis for such an endeavor, as its infrastructure replicates the entire value chain and enables the partners to respond very fast to customer and market demands. The close link to the University in Leoben is also supporting R&D activities and adding further resources to broaden the spectrum of AM.

Process Optimization & Control (II) / 62

COMPARISON AND VALIDATION OF TOOLS FOR SIMULATION AIDED ADDITIVE MANUFACTURING

Author(s): Mr. SEMBDNER, Philipp[1]
Co-author(s): Mr. NÖGEL, Moritz [1] ; Mr. HOFMANN, Dirk [2] ; Mr. HOLTZHAUSEN, Stefan [1] ; Mr. STELZER, Ralph [1]

[1] *Dresden University of Technology - Chair of Engineering Design and CAD*

[2] *Dresden University of Technology - Chair of Engineering Desing and CAD*

Corresponding Author(s): philipp.sembdner@tu-dresden.de

Due to the progressive development of additive production, it is increasingly possible to manufacture metallic components with free-form geometry or filigree lightweight structures in small numbers. Because of this partly complex geometry, the production simulation and the calculation of the building parts are particularly difficult. In addition, these processes are carried out very close to production process if they are applied at all.
Recently, various software tools have been developed to carry out a process simulation for additive manufacturing. These systems differ both with regard to the calculation approach (Inherent strain method, Transient calculation) as well as in the scope of functions (e.g. building orientation, support generation).

In the paper, these tools are first analyzed with regard to the functional scope. A comparison and evaluation of the tools are then carried out using selected criteria. For this purpose, special benchmark components were developed, which are presented in the paper. Furthermore, simulation studies with corresponding parameter variation and the comparison of the simulation results with real manufactured components are presented.
As a result, possible existing deficits of the simulation tools are derived in the context of the currently practiced process chain. In this regard, requirements for the further development of the simulation tools as well as a possible modification of the current process chain are discussed. The interfaces to established software tools such as Materialise Magics or current CAD systems are also taken into account to obtain for example conclusions for the design of a part or the production planning.

Related Processes (II) / 63

LASER METAL DEPOSITION (LMD) AS A COMPLEMENTARY TECHNOLOGY TO SELECTIVE LASER MELTING (SLM)

Mr. GÖRGL, Richard[1]

[1] *Joanneum Research Materials*

Corresponding Author(s): richard.goergl@joanneum.at

Besides the technology of Selective Laser Melting (SLM, 3D Metal Printing) which is becoming more and more popular, the Laser Metal Deposition (LMD) technology is another and complementary technology for additive manufacturing of metallic components. Being also a welding process in principle, LMD manufactured parts succeed in macroscopically needed properties (hardness, density, Young's modulus,. . .) While SLM scores with its unrivalled accuracy and precision, LMD allows the combination of different materials and a much more less complicated powder handling. Starting with the principles of LMD, examples both from the field of component repair and entire additive manufacturing including materials combinations are presented, and the two technologies are compared with regard to their individual strengths and limitations.

New Materials (IV) / 64

NEW PRODUCT SOLUTIONS BY USING WAAM AS A NEW TECHNOLOGY IN AM

Mr. EMMERLING, Philip[1]

[1] *FIT AG*

Corresponding Author(s): jennifer.nadenik@pro-fit.de

One remaining technical restriction in additive manufacturing to-date is size which is defined by the size of the build space. To overcome this restriction, FIT has introduced the new WAAM technology (Wire Arc Additive Manufacturing) for big metal parts. The resulting massive raw parts are to be finished by CNC milling. It is also possible to work on a pre-fabricated corpus. The WAAM build rate is significantly higher than that of any comparable powder-based technology; usable material includes all welding wires. Complex parts can be realized by the 5-axis system. In our practical every-day use the technology is continually improved.

Keynote (II) / 65

DIGITAL PHOTONIC PRODUCTION ALONG THE LINES OF INDUSTRY 4.0

Prof. POPRAWE, Reinhart[1]

[1] *Fraunhofer ILT*

Corresponding Author(s): reinhart.poprawe@ilt.fraunhofer.de

The context of future Laser Applications in modern manufacturing can be summarized by "Digital Photonic Production". The vision of designing a structure or product in the computer and creating it additively using Diode- or Solid-state lasers or by ablation with high power ultrafast lasers drives many research topics in this area. But also the integration into production chains with the challenge of meeting the demands of production along the lines of Industry 4.0 is starting to be addressed seriously. From the point of Laser technology, main fields of activity are measurement processes of quality relevant data on-line, process control mechanisms and the combination with automation as a whole. Of course, the processes themselves are under intense investigation, such as Selective Laser Melting, Laser Metal Deposition, Laser Ultrafast Ablation and Laser Polishing. The increase of productivity is the prime goal under economical aspects. New concept and performance results under this criterion will be presented. Also correspondingly increased quality of the resulting products in terms of surface roughness and distortion are key issues of consideration. To address these challenges effectively, new ways of collaboration of Public Private Partnerships PPP are believed to be successful. Examples of strategic PPP collaboration will be given, the BMBF-Research-Campus-project DPP will be displayed in its present status. Especially the research strategy in form of road mapping and collaboration in sub clusters develops to an essential factor in this innovation concept. Ultimately the development resulted in the "Innovation Center for Digital Photonic Production", a conglomerate of app. 20 companies locating their research activities in the corresponding new building in close cooperation and vicinity with ILT and the RWTH Laser University Chairs. On the very fundamental side, research topics and roadmaps identified by15 interdisciplinary collaborating RWTH-chairs in the frame of the "Research Center for Digital Photonic Production" will be demonstrated and discussed. Its home will be a corresponding building, which is under construction and will come to operation in the very near future.

Keynote (III) / 66

GENERATIVE DESIGN - NATURE AS BLUEPRINT

Mr. PIRKLBAUER, Peter[1]

[1] *Airbus Operations GmbH*

Corresponding Author(s): peter.pirklbauer@airbus.com

A key element in the creation of the new bionic partition is the rapid evolution in generative design. This capitalizes on the power of cloud computing to generate thousands of design alternatives that meet specific goals and constraints. Generative design can explore new solutions that even experienced designers might not have considered, while improving design quality and performance. Because the designs are nearly impossible to manufacture using traditional methods, additive manufacturing techniques like 3D printing are critical to generative design's success.

Opening / 67

OPENING

New Materials (I) / 69

ADVANCEMENTS IN METAL AM AND TOOLING APPLICATIONS – AN INSIGHT ON THE EFFECT OF POWDER QUALITY AND MATERIAL PROPERTIES

Author(s): Mr. SJÖSTRÖM, Johnny[1]
Co-author(s): Mr. OIKONOMOU, Christos [1] ; Mr. KARAMCHEDU, Seshendra [1]

[1] *Uddeholms AB*

Corresponding Author(s): johnny.sjostrom@uddeholm.com

Additive manufacturing is becoming more common as a manufacturing technique, but the technology is still rather new. The development of AM powder is still at an early stage and the amount of grades tailor made for additive manufacturing is limited. Most AM grades on the market are atomized standard grades and not designed for AM. This study presents what the important factors are when selecting a powder for additive manufacturing as well as the influence on quality if the powder criteria's are not met. Several AM powders from various suppliers were evaluated based on their purity and physical characteristics using digital image analysis techniques and advanced electron microscopy. The effect of such powder aspects was further evaluated on the properties of AM produced specimens. For the latter, light interferometry and cyclic polarization techniques were implemented in order to evaluate defect density and corrosion behaviour. The results show the link between powder quality and the properties of the AM specimens.
Keywords Tool steels, precipitation hardening steels, polishability, corrosion resistance, wear, microstructure development, Additive Manufacturing (AM), AM process parameters, heat treatment

Related Processes (I) / 71

3D PRINTING OF «ALUMINUM - 10 -20 WT. % ALUMINA» COMPOSITES WITH CORE-SHELL PARTICLES AS RAW MATERIALS

Author(s): Prof. GROMOV, Alexander[1] ; Mr. ARNAUTOV, Alexey[2]
Co-author(s): Mr. ZMANOVSKY, Sergey [3] ; Mr. NALIVAIKO, Anton [2] ; Mr. VLASKIN, Mikhail [4]

[1] *National University of Science and Technology "MIsis"*

[2] *National University of Science and Technology "MISiS"*

[3] *SUAL PM*

[4] *Joint Institute of High-Temperature, Russian Academy of Science*

Corresponding Author(s): aleksej.arnautov@gmail.com

The work is devoted to the advanced 3D printing of "aluminum-10-20 wt. % alumina" composite with core-shell structure. The process of core-shell "aluminum-10-20 wt. % alumina" composite preparation was based on the aluminum powders selective oxidation in water and following drying at 120 °C and calcination of the obtained "aluminum-10-20 wt. % alumina" composite at 600 °C. The process of certain thickness of alumina layers covered Al particles was studied. The kinetic parameters of the aluminum particles oxidation process along with the alumina phase transformation were studied. It was found that gamma-alumina is the only product formed on particles with aluminum core after calcination at 600 °C. Even after the thermal treatment at 600 °C the synthesized "aluminum-alumina" composites contained up to 1 wt. % of volatiles (water and hydrogen) that requires a careful selection of the SLM regimes. Various regimes of SLM for 3 D samples production from the studied composites were tested to obtain the acceptable mechanical properties of the produced samples (HB at least 170 MPa) [1]. The density, strength and hardness of the obtained "aluminum-alumina" composites were tested and the certain SLM regimes were selected for the further study.

Application (II) / 72

POWDER BED FUSION METAL ADDITIVE MANUFACTURING APPLICATION AND CASE STUDY IN OIL & GAS SECTOR

Corresponding Author(s): Kameshwaran.Swaminathan@technipfmc.com

Metal additive manufacturing (Metal AM) is a promising technology that can radically disrupt the conventional supply chain methodologies with a "make to order" approach for components in all sizes. This technology promises to disrupt conventional supply chain models without compromising on complexity in part design. Powder Bed Fusion (PBF) and Wire+Arc Additive Manufacturing (WAAM) are two of the growing technologies that cover the wide spectrum of part sizes in Oil & Gas sector. The technology is starting to be validated for standardization and repeatability

of the material properties, especially corrosion performance in the harsh environments typically seen in oil & gas production. Nickel-based alloys in particular are a noteworthy intersection of AM industry and Oil & Gas sector, given the high cost of such corrosion-resisting alloys and their wide applicability. This paper will present material properties and sour service performance of two different nickel-based alloys. Orientation of the specimen layer build-up pattern to the build plate, and its effect on mechanical and corrosion performance of the parts in NACE environmental testing will be discussed. The paper also discusses a potential case study and adaptation of the PBF AM technology into Oil & Gas industry.