WORLD PM2022 CONGRESS & EXHIBITION

ABSTRACTS – GROUP 6

SINTER BASED TECHNOLOGIES

WORLD PM2022
CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225366456

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Dr Mitteramskogler Gerald (Incus GmbH, Austria)

Co-author(s):

Title: Lithography-based Metal Manufacturing (LMM)

Keyword(s):
Additive manufacturing, Metal 3D printing, Lithography-based metal manufacturing, 3D printing

Abstract:
Lithography-based Metal Manufacturing is an AM technology for the production of functional metal components with superior surface aesthetics compared to other AM technologies. LMM is based on the concept of photopolymerization, where metal powder is dispersed in a light-sensitive resin and selectively polymerized layer-by-layer by exposure with light. The printed green parts undergo a debinding step to burn off the photopolymer-based binder system. With a subsequent sintering step, mechanical properties, and microstructure equivalent to Metal Injection Molding (MIM) can be achieved. The LMM approach enables production of complex part sizes <200 g with low surface roughness, high accuracy of the details, mechanical properties, and feature resolution. LMM is developed as a complementary technology for MIM mass production for prototyping and small-scale production. Using LMM, MIM producers can support more customers efficiently in the prototyping phase and provide functional parts in hours instead of months.

Innovative Aspect(s):
The Lithography-based Metal Manufacturing technology combines, for the first time in metal AM, feature resolution, surface aesthetics, economics and mechanical properties. LMM's unique innovation relies on its proprietary feedstock formulation, suitable for all metal powders and the proprietary VAT photopolymerization technique: the butter-like feedstock is composed of a UV-sensitive resin that reacts to the incident light, triggering cross-linking of polymers which hold together the built geometry and impart strength to the green parts. This avoids distortion and shrinkage during printing, eliminating the need for support structures and strongly reducing surface roughness.

TPC Reviewer name: .....

Keynote ☐ Oral ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐

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WORLD PM2022
CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225367139

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Dipl-Ing Vogel Lucas (University Pforzheim, Germany)

Co-author(s): Prof Dr Burkhardt Carlo (University Pforzheim, Germany)

Title: Impact Of Printing Parameters On Green Density Homogeneity In Lithography-based Metal Manufacturing

Keyword(s):
Lithography-based metal manufacturing, Sinter-based additive manufacturing, Printing Parameters, Green part characterization, Dimensional accuracy

Abstract:
Lithography-based metal manufacturing (LMM) is an emerging technology for the 3D production of metal parts with high dimensional accuracy and outstanding surface quality. To reliably reproduce these properties, a better understanding of parameter characteristics correlation is necessary. One of the most important characteristics of the printed part is the green density and its distribution within the building volume. This study investigates the printing parameters degree of powder filling of the feedstock, layer thickness, coating speed, coating mode and size of the material roll, with the help of a DoE. The green parts are getting characterised by dimensions, weight and density using the principle of Archimedes. Also, the strength of the green part is investigated. As the densification during sintering works as a magnifying glass for imperfections and differences in green density of the green parts, all samples get sintered and analysed on their density and shrinkage afterwards.

Innovative Aspect(s):
This extensive study investigates the impact of printing parameters of the novel LMM technology on green parts. As the process technology is fairly new only little information about the process and machine designed by Incus GmbH is published. In this work the process gets described and insights into the correlation of part characteristics and parameters are given. Since the LMM technology is still in early stages of development, a better understanding of the impact of the parameters on critical part properties is necessary to bring the technology closer to its potential. This will help printing parts in desired dimensions with fewer loops. Understanding the parameters will help with reliable production of parts. Also it shows the limitations of the possible parameter variation. By presenting the entire process chain more challenges can be addressed and suggested solutions can be explained.

TPC Reviewer name: .....

Keynote ☐ Oral ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐

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WORLD PM2022
CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225367264

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Ing Barthel Bastian (Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, Germany)

Co-author(s): Ing Mirz Markus (Institute for Materials Applications in Mechanical Engineering, RWTH Aachen University,, Germany) ; Prof Dr Petzoldt Frank (Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, Germany)

Title: Process Development Of Grade A11 High Carbon Tool Steel For Metal Binder Jetting

Keyword(s):
Tool Steel, Metal Binder Jetting, Sintering, powder characteristics, Process development, Sintering

Abstract:
Grade A11 (X245VCrMo8-5-1) tool steel is one of the most commonly used tool steels for cold work applications as its high carbide content makes it highly wear resistant. However, its total carbon content of 2.5 % also leads to challenges in shaping by additive manufacturing, especially for LPBF. With its homogeneous temperature distribution during the consolidating sintering step, metal binder jetting (MBJ) capable to process a wide range of materials, including difficult-to-weld materials. This research focuses on the process development for grade A11 tool steel using MBJ. After the development of suitable printing parameters considering layer thickness and recoat speed, the sintering behaviour is investigated in detail. Initial sintering parameters are determined by thermoanalytical measurements. Subsequently, the impact of different sintering temperatures and atmospheres on the microstructural evolution are presented. Finally, it is shown that complex applications can be manufactured true to size and fully dense with the parameters determined.

Innovative Aspect(s):
This is the first Paper to investigate Metal Binder Jetting of Grade A11 Tool Steel and on sintering of A11 to full densification in general.

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Keynote ☐ Oral ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐

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WORLD PM2022
CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225367565

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Dr Osada Toshiko (Tokyo Metropolitan University, Japan)

Co-author(s): Prof Dr Kobayashi Satoshi (Tokyo Metropolitan University, Japan) ; Mr Takahashi Tomo (Pacific Sowa Corporation, Japan) ; Mr Kato Yoshiyuki (Kato Professional Engineer office, Japan) ; Mr Yokoyama Kenji (ExOne, K.K., Japan)

Title: Effect Of Distance Between Powders On The Printing And Sintering Properties Of Metal Binder Jet 3D Printing

Keyword(s):
Binder Jet Printing, Powder Characteristics

Abstract:
Metal binder jet 3D printing is suitable for fabricating metal parts in small quantity and many varieties in a short period of time. Fine powders for metal injection molding are used for binder jet 3D printer. Powders need to flow during recoating to the powder bed, and also after that they need to show high density for enough strength of green parts for handling. In this study, powder characteristics for binder jet 3D printing is focused, and effect of distance between powders on the printing and sintering properties of metal binder jet 3D printing is clarified.

Innovative Aspect(s):
Powder characteristics is important for metal binder jet 3D printing.

TPC Reviewer name: .....

Keynote ☐ Oral ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐

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WORLD PM2022
CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225367584

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Prof Bouvard Didier (Univ. Grenoble Alpes, France)

Co-author(s): Dr Zago Marco ; Dr Singh Gurminder ; Prof Missiaen Jean-Michel ; Mr Safar Bati Rafik ; Dr Chaix Jean-Marc ; Mr Balarabe Faisal ; Dr Avenas Yvan (Univ. Grenoble Alpes, France)

Title: Fabrication Of Copper Heat Sinks For Power Electronics By Composite Extrusion Additive Manufacturing And Sintering

Keyword(s):
Additive manufacturing, Composite extrusion, Sintering, Copper, Architectured material

Abstract:
The interest of composite extrusion modelling (CEM) for additive manufacturing of metal components is growing up due to the low cost of this process and to the possibility of using commercial MIM feedstock. In a previous study, the successive stages of the processing route of simple copper parts have been optimised with regard to the final weight density and surface roughness. The next step has consisted in fabricating components with controlled porous architecture, to be used for cooling power electronic chips with an air flow. The thermo-hydraulic properties of these components (thermal resistance, air pressure drop) have next been measured. For future practical application of this heat sink, its bonding to a copper plate has been ensured by printing the feedstock directly upon the plate and next sintering the assembly. The shear resistance of this bonding has been found to be in line with power electronics standards.

Innovative Aspect(s):
Development of a novel additive manufacturing process for the fabrication of a practical component with porous architecture.

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Keynote ☐ Oral ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐

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WORLD PM2022
CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225367722

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Mrs Reineke Lea (Fraunhofer IFAM, Germany)

Co-author(s): Mr Barthel Bastian ; Dr Hein Sebastian Boris (Fraunhofer IFAM, Germany)

Title: Analysis Of Powder Characteristics And Powder-Binder-Interaction For Process Parameter Prediction In Metal Binder Jetting

Keyword(s):
Metal Binder Jetting, Powder-binder-interaction, Process parameter prediction, Powder characteristics, Binder saturation

Abstract:
Metal Binder Jetting (MBJ) has an increasing attention in additive manufacturing because of its serial production potential. The aim of this work is to achieve the most suitable parameterization of the MBJ printing processes for specific powder-binder combinations, based on the powder characteristics and the powder-binder interaction. Depending on wetting properties and acting capillary forces, some MBJ powders need more or less binder to generate parts with optimal properties. The use of too high binder saturations generally leads to density loss due to binder application, as well as increased carbon content of the final sintered part or even loss of geometrical features. Too low saturations result in low green strength as well as low part accuracy. The economic background of the development of pre-printing tests is a reduction in the number of iteration stages in material-specific process development, which saves costs, effort as well as material resources and printing capacity.

Innovative Aspect(s):
The innovation of this work is the correlation of pre-printing measurements and printing tests to transfer this results and predict suitable parameters for new powders.

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WORLD PM2022 CONGRESS & EXHIBITION
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Paper number: WP225367982

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Dipl-Ing Zanon Matteo (Kymera International | Ecka Granules Germany, Germany)

Co-author(s): Mr Müller Armin ; Dipl-Ing Pelletiers Tom ; Dipl-Ing Croteau Joe ; Mr Murphy Nicholas ; Mr Workman Joseph (Kymera International | SCM Metal Products, USA)

Title: Metal Binder-jetting Of Aluminum-based Alloys

Keyword(s):
Metal binder-jetting, Aluminum-based alloys

Abstract:
Metal binder-jetting (MBJ) technology involves the additive build-up of "green parts" via localized deposition of liquid binder on a powder bed. Green parts are subsequently depowdered, debinded and sintered to near full density. A successful sintering becomes then the critical step for the development of both density and material properties. Aluminum-based alloys, while commonplace for laser-based technologies, have been hitherto neglected in the binder-based approach, due to their notorious oxidation sensitivity and possibly to their less visible presence in the traditional PM industry, compared to ferrous materials. By taking advantage of its multi-decade experience in mass production of PM aluminum grades, Kymera International is adapting several grades of free-sintering aluminum alloys, including those from the 6000- and other series, for use in binder jet additive manufacturing. Progress updates will be provided on the printing and sintering process and material properties after sintering and heat treatment.

Innovative Aspect(s):
Possibly the first paper ever to be published on the binder-based 3D printing of aluminum alloys. This class of materials has been hitherto considered to be highly challenging due to the sintering aspects, and although announcements were made in the press, no other scientific paper on the topic is yet to be found on this subject.

TPC Reviewer name: .....

Keynote ☐ Oral ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐

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WORLD PM2022 CONGRESS & EXHIBITION
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Paper number: WP225368437

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Dipl-Ing Teuber Robert (Fraunhofer IFAM Dresden, Germany)

Co-author(s): Dr Ing Weißgärber Thomas ; Dr Ing Andersen Olaf ; Dr Ing Studnitzky Thomas (Fraunhofer IFAM Dresden, Germany)

Title: Geometry Diversity In MoldJet®, A Sinter-based Additive Manufacturing Process

Keyword(s):
MoldJet, Metal AM, Maximum Productivity, Metal Paste, 3D Printing, Geometry spec-trum, Geometry diversity

Abstract:
The MoldJet process is a new and innovative, sinter-based additive manufacturing process that combines two generative process steps. This synergy enables an enormous variety of shapes from small filigree to large-volume 3D-printed metal parts. Many comparable AM processes specialise in just one spectrum of geometries or are limited by the printing process and following process steps. The MoldJet process offers the possibility of producing different component geometries not only simultaneously, but also without the use of support structures made of part material. In this paper, the application range of the process is presented. On the basis of evaluation geometries, it is analysed where the minimum for wall thicknesses at the printing process lies. On the other hand, component geometries with large external dimensions on the one hand and large-volume component areas on the other hand are produced and limitations with regard to the printing process are also determined here.

Innovative Aspect(s):
Wide range of part geometries in one sinterbased AM Process. High productivity in Additive Manufacturing.

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WORLD PM2022
CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225369747

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Mr Takahashi Tomo (PACIFIC SOWA CORPORATION, Japan)

Co-author(s): Dr Osada Toshiko ; Prof Dr Kobayashi Satoshi (Tokyo Metropolitan University, Japan) ; Mr Kato Yoshiyuki (Kato Professional Engineer Office, Japan) ; Mr Yokoyama Ken (ExOne KK, Japan)

Title: Flowability Control Of Water Atomized Powder By Addition Of Nano-silica Powder For Metal Binder Jet 3D Printing

Keyword(s):
Additive Manufacturing, 3D printing, metal, Binder jet

Abstract:
Gas atomized powders are mainly used in binder jet (BJ) metal 3D printing. The cost of water-atomized powders is lower than that of gas-atomized powders. And Ultrafine powders with improved surface roughness and mechanical properties are obtained through water atomization. However, the flowability of gas atomized powder is lower and the use of them in BJ 3D printing is serious issue. In this study, the flowability of water atomized powders was controlled by addition of nano-silica powder to water atomized powders with different average particle sizes.

Innovative Aspect(s):
Application of ultra-fine powders with an average particle size of less than 5 µm by water atomization to a binder jet metal 3D printer. Realization of fine metallic structure and improvement of mechanical properties after sintering with ultrafine powder.

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Keynote ☐ Oral ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐

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WORLD PM2022
CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225370324

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Dr Kukla Christian (Montanuniversitaet Leoben, Austria)

Co-author(s): Dipl-Ing Schuschnigg Stephan ; Dr Cano Santiago ; Dipl-Ing Hubmann Martin ; Prof Dr Holzer Clemens (Montanuniversitaet Leoben, Austria) ; Dr Gonzalez-Gutierrez Joamin (Luxembourg Institute of Science and Technology, Luxembourg)

Title: Simulations Of The Filament Printing Of Metal Feedstocks With Different Nozzle Designs

Keyword(s):
Material extrusion, Fused filament fabrication, Steel feedstock, Simulation, Nozzle design

Abstract:
Material extrusion (MEX), especially fused filament fabrication (FFF), is the most widespread technology for additive manufacturing, mainly for polymers. Currently, many material extrusion printers and nozzle designs are available from different manufacturers. These different nozzle designs result in different melting and flow behaviour. Therefore, their design is critical for the printing of high-quality parts. Since feedstocks and polymers have different characteristics, we evaluated the processing of an Ampersint 1558 tool steel feedstock with two different nozzle designs (nozzle with a PTFE tube insert, all-metal nozzle) using finite element method (FEM) simulations with the programs Ansys Polyflow and Autodesk Moldflow Insight. Feedstock's rheological and thermal properties were measured and used for simulation of FFF with the two nozzle designs at different printing speeds. Finally, the trends observed in the simulations were compared to experimental results, providing recommendations for the design of FFF nozzles for feedstocks.

Innovative Aspect(s):
Nozzle design for feedstocks simulation of material extrusion with filaments.

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WORLD PM2022 CONGRESS & EXHIBITION
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Paper number: WP225370377

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Dr Riecker Sebastian (Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, Branch Lab Dresden, Germany)

Co-author(s): Dr Sénéchal Ulf ; Dr Dittrich Robert ; Dr Studnitzky Thomas ; Dr Andersen Olaf ; Dr Weißgärber Thomas (Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, Branch Lab Dresden, Germany)

Title: Sinter-based Fabrication Of Ti-6Al-4V Parts By Hybrid Gel Casting Process Under Terrestrial And Reduced Gravity

Keyword(s):
Gel Casting, Fused Filament Fabrication, FFF, Ti64, Ti-6Al-4V, Light metal, Metal AM, AM

Abstract:
Manufacturing light-metal components on demand and on site is a major challenge in space. So far, some AM technologies have been considered, but working with loose metal powder or large amounts of solvents are undesirable attributes of some processes. The hybrid approach of gel casting into recyclable polymer molds fabricated using FFF presents a possible alternative for use under terrestrial and reduced gravity conditions, with low equipment requirements and no loose powder. We have investigated the production of Ti-6Al-4V components and developed a metal powder suspension for this purpose. We present sintering results with 0.1 % porosity and impurity values according to the specification, as well as demo parts that we were able to manufacture with this process chain. Filling of the molds under different gravitational conditions is a specific challenge and can be predicted with a numerical simulation to analyze the flow characteristics and check for trapped gas bubbles.

Innovative Aspect(s):
The innovative aspects of our development are: The investigation of the hybrid process chain of AM and gel casting for space application.. The new material development of Ti64 for the gel casting approach.. The suspension development for gel casting with organic content below 0.5 wt.%. Simulation of the suspension casting process in COMSOL and OpenFOAM under different gravitational conditions.

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WORLD PM2022 CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225370836

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Ms Kolli Samanwitha (KU Leuven, Belgium)

Co-author(s): Ms Beretta Margherita ; Prof Dr Vleugels Jozef (KU Leuven, Belgium) ; Mr Selema Ahmed ; Prof Dr Sergeant Peter (Ghent University, Belgium) ; Dr Rombouts Marleen (Flemish Institute for Technological Research - VITO, Belgium)

Title: Shaping Of Dense Copper Components By 3D Micro-extrusion

Keyword(s):
Additive Manufacturing, Extrusion-based additive manufacturing, Pure copper, Pressureless sintering, Electrical conductivity, Mechanical Properties

Abstract:
Additive Manufacturing (AM) of pure copper for high-performance heat exchangers and electrical systems is gaining rapid momentum owing to the exceptional combination of material properties and geometrical freedom which is limited in conventional production methods. Of the various viable technologies, 3D micro-extrusion is an indirect AM technology that enables processing a broad variety of materials, including Cu, delivering high-quality parts with desired density and properties. This study reports the shaping of parts by extrusion of a highly powder-loaded paste at room temperature followed by debinding and pressureless sintering. A complete processing route for 3D micro-extrusion of dense and highly conductive Cu components was developed from the selection of powders, feedstock paste formulation and preparation, printing parameters optimisation and post-processing strategy. The fabricated parts exhibited functional and mechanical properties competitive to the most adopted laser powder-bed fusion (LPBF) technique.

Innovative Aspect(s):
The processing challenges posed by Cu to laser powder bed fusion and the inability of other AM techniques to achieve properties comparable to conventional parts, call for a more flexible and competitive solution. 3D micro-extrusion is a versatile technique that allows processing of a wide range of materials while meeting the application requirements. The potential to deliver high-quality dense complex components at a relatively lower cost per part and high resource efficiency with minimum waste, makes 3D micro-extrusion a more cost-effective and sustainable solution. In addition, the ability to fabricate highly complex geometrical parts with minimal post-processing makes the technology stand out among the powder-based methods that are challenged in removing the entrapped powders in the closed complex features. Moreover, the possibility of high powder loading in the feedstock formulation and low binder content allows production of dense parts with high dimensional accuracy.

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WORLD PM2022 CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225370838

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Ms Beretta Margherita (KU Leuven, Belgium)

Co-author(s): Ms Kolli Samanwitha ; Prof Dr Vleugels Jozef (KU Leuven, Belgium) ; Mr Selema Ahmed ; Prof Dr Sergeant Peter ; Prof Dr Kestens Leo (Ghent University, Belgium) ; Dr Rombouts Marleen (Flemish Institute for Technological Research - VITO, Belgium)

Title: Influence Of The Sintering Parameters On The Properties Of Pure Copper Fabricated By Extrusion-based AM Technology

Keyword(s):
Pure copper, Additive Manufacturing, Extrusion-based Additive Manufacturing, Indirect Additive Manufacturing technology, Sintering, Density, Electrical conductivity

Abstract:
Copper is largely used for heat transfer devices and electrical machines where high thermal and electrical conductivities are required. Since the performance can be further enhanced through design optimization, Additive Manufacturing (AM) represents a promising solution for the fabrication of complex Cu components for these application fields. 3D micro-extrusion, in particular, is an indirect AM technology that allows the fabrication of dense copper parts using a multiple-steps approach. The shaping of a green body upon extrusion of a highly powder-loaded paste is followed by a consolidation or post-processing treatment step. This includes the removal of the binder and densification through conventional sintering. The present study investigated the impact of the post-processing conditions on pure copper components fabricated by 3D micro-extrusion of different feedstock paste formulations. Multiple sintering atmospheres and thermal cycles were tested to assess their influence on the physical and functional properties of pure Cu material.

Innovative Aspect(s):
3D micro-extrusion stands out among Additive Manufacturing techniques since it offers an innovative approach to fabricate parts with fewer limitations in the material selection. As an indirect AM technology, 3D micro-extrusion involves the shaping and consolidation of the part in two separated steps. This aspect solves the criticalities related to the use of beam based AM technologies with materials that are difficult to process. Copper has high reflectivity and heat conductivity: the former requires specific laser sources or modification of the powder, while the latter diminishes the control on the melting phase. On the other hand, in 3D micro-extrusion the fine tuning of post-processing conditions enables to control the microstructural evolution and tailor the material properties in relation to the specific application. Lastly, the possibility of choosing environmentally safe additives for the feedstock paste permits to increase the technological sustainability.

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WORLD PM2022
CONGRESS & EXHIBITION
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Paper number: WP225370845

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Mr Calves Paul (Centre Technique des Industries Mécaniques (CETIM), France)

Co-author(s): Mr Robert Maxime ; Mr Verquin Benoit ; Mr Carree Corentin (Centre Technique des Industries Mécaniques (CETIM), France)

Title: Evaluation Of The Dimensional Repeatability For Metal Binder Jetting: Method And Results

Keyword(s):
Metal Binder Jetting, MBJ, Repeatability, Interval of Tolerance, IT, Dimensionnal control, Methodology, Metrology, Production

Abstract:
Today, the building rates with Metal Binder Jetting technologies start to reach very high rates, giving good perspectives for mass production. But one remaining challenge is also to master the dimensional dispersion in production, and to guarantee an Interval of Tolerance satisfying industrial specifications and needs. This presentation will detail in a first part, the progression towards a reliable and efficient method allowing to evaluate the dimensional dispersion of Metal Binder Jetting machines. Then several results and observations, among other the Interval of Tolerance depending on some printing parameters and observables as green and as sintered, will be presented and discussed.

Innovative Aspect(s):
Metal Binder Jetting (MBJ) still have few data about the dimensionnal repeatability of the process. And that is a fundamental apsect to deal with to give perspective of serial production. This presentation propose to bring first elements about this. The innovative aspects are mainly the explanation of the way to define trials after trials a good and reliable methodology to evaluate interval of tolerances in MBJ. Then, the large number of coupons analyzed with this methodology, allows to give representative tendancies for the production. Also, It allows to see first correlations between the interval of tolerances measured and some observables.

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WORLD PM2022 CONGRESS & EXHIBITION
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Paper number: WP225370928

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Mr Calves Paul (Centre Technique des Industries Mécaniques (CETIM), France)

Co-author(s): Mr Robert Maxime ; Mr Verquin Benoit (Centre Technique des Industries Mécaniques (CETIM), France)

Title: Overview Of Industrial Applications Produced By Metal Binder Jetting: Benefits And Challenges

Keyword(s):
Metal Binder Jetting, MBJ, Industrial Application, Industrialization, Components

Abstract:
Thanks to high level of productivity, limited post process and design opportunities, Metal Binder Jetting see currently more and more cost-effective applications in production. Based on different use cases deal by CETIM since several years, as part of different support programs, the presentation will present several industrial components developed and industrialized for a production by Metal Binder Jetting process. Among other things, it will be presented for different applications: the technical interests identified, how the process challenges have been resolved to reach a satisfying industrial quality, and the cost efficiency.

Innovative Aspect(s):
The inovative aspect is mainly the presentation of several industrial applications in serial production or ready for serial production, based on experience of CETIM supporting companies since several years, in order to facilitate the industrialization of new components by Metal Binder Jetting; and the presentation of the work and of the way done to reach undustrial or industrializable products by MBJ (the presentation is more than a collection of pictures of final products).

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WORLD PM2022
CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225371265

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Dr Bose Animesh (Desktop Metal, USA)

Co-author(s):

Title: Review Of Non-Traditional Sinter-Based Metal Additive Manufacturing Technologies

Keyword(s):
Sinter-based metal additive manufacturing, Non-traditional Sinter-based AM, Hybrid AM process, Multi-material

Abstract:
Sinter-based metal additive manufacturing (AM) processes that decouples the geometric shaping and consolidation of AM have significant advantages over melt-based AM technologies (one-step consolidation and shaping). The sinter-based AM technologies, led by binder jetting, has the potential to significantly increase the productivity and attain more isotropic microstructures. Sinter-based AM includes the ability to cover a wide spectrum of productivity (prototyping, low volume serial production, high volume mass production). Currently several non-traditional sinter-based metal AM processes which are relatively less common are emerging. This paper will review some of the less common sinter-based metal AM technologies excluding binder jet and material extrusion type of AM processes.

Innovative Aspect(s):
Have not seen a review of some of the non-traditional Sinter-based metal additive manufacturing (AM) processes. This paper will not dwell on well established sinter-based AM technologies such as binder jet, material extrusion (fused filamant fabrication or bound metal deposition) but instead will focus on some of the less established sinter-based AM technologies that are emerging such as hybrid (additive and subtractive) processes, multi-material deposition, etc. The paper will serve as an important reference paper that will cover these relatively new technologies.

TPC Reviewer name: .....

Keynote ☐ Oral ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐

Poster ☐ Poster & Reserve Oral ☐

Withdraw ☐ Reason: .....

Notes to author: .....

WORLD PM2022
CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225371398

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Mr Kinai Yuta (Tokyo Metropolitan University, Japan)

Co-author(s): Dr Osada Toshiko ; Prof Kobayashi Satoshi (Tokyo Metropolitan University, Japan) ; Mr Takahashi Tomo (PACIFIC SOWA CORPORATION, Japan) ; Mr Kato Yoshiyuki (Kato Professional Engineer Office, Japan) ; Mr Yokoyama Kenji (ExOne, Japan)

Title: Metal Binder Jet 3D Printing Using Water-atomized Powders

Keyword(s):

Abstract:
Binder jet printing has a characteristic of high modeling speed. Water-atomized powders with relatively low cost can be used for binder jetting process. The use of fine powders is necessary to improve the density and strength of sintered bodies. In this study, green and sintered bodies were fabricated using water-atomized fine powders to improve density and strength of sintered bodies.

Innovative Aspect(s):
Application of water-atomized powders to binder jet metal 3D printing and improvement of density and strength.

TPC Reviewer name: .....

Keynote ☐ Oral ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐

Poster ☐ Poster & Reserve Oral ☐

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WORLD PM2022 CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225371432

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Dr Riecker Sebastian (Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, Branch Lab Dresden, Germany)

Co-author(s): Dipl-Ing Teuber Robert (Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, Branch Lab Dresden, Germany) ; Dipl-Ing Abel Johannes ; Mrs Mannschatz Anne (Fraunhofer Institute for Ceramic Technologies and Systems IKTS, Germany) ;

Title: Additive Manufacturing Of Complex NiTi Structures Using Fused Filament Fabrication (FFF) And Subsequent CNC Green Machining

Keyword(s):
Fused Filament Fabrication, FFF, Metal AM, Nitinol, NiTi, Nickel-Titanium, Sinter-based AM

Abstract:
Pseudoelastic behavior with elastic strains of up to 8 % and the shape memory effect are well-known features of nickel-titanium alloys (Nitinol). These properties are highly interesting for the fabrication of e.g. functional auxetic and programmable structures as well as for solid state joints and compliant mechanisms. To extend the current range of available geometries and to enable near-term fabrication of customized complex devices, sinter-based additive manufacturing (AM) of NiTi components via Fused Filament Fabrication (FFF) has been investigated. For this purpose, a highly filled thermoplastic filament (63 vol.-% powder) has been developed which could be printed to complex geometries using standard FFF printers. The AM post-processing steps of debinding and sintering were aiming for extraction of O, C and N to achieve the desired properties. Green state machining experiments resulted in high part quality and low surface roughness of Ra <5 µm.

Innovative Aspect(s):
The innovative aspects of our development are: Development of new NiTi filament with >60 vol.% powder loading.. AM of complex NiTi structures using FFF.. Investigation of green machining on NiTi-FFF structures and heat treatment.. Measurement of geometry and surface quality along the process chain (incl. CNC green machining).

TPC Reviewer name: .....

Keynote ☐ Oral ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐

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WORLD PM2022
CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225371433

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Dr Etiemble Aurelien (Université de Lyon, ECAM Lasalle, France)

Co-author(s): Ing Commeau Thierry ; Ing Nouveau Aurélie (Umicore Specialty Powders, France) ; Dr Simon Sandra ; Dr Rigollet Claire (Université de Lyon, ECAM Lasalle, France)

Title: Development And Characterization Of W-based Feedstock For Extrusion-based Additive Manufacturing

Keyword(s):
Additive manufacturing, Tungsten, Powder injection molding, 3D printing, Sintering

Abstract:
The applicability and expansion of the promising opportunities offered by extrusion-based technologies for the additive manufacture of metal parts (FFF, FDM or PIM-like) depends on the development of new feedstock for specialty powders. In this context, W-based feedstock was developed and characterized in this study. For these indirect processes, the feedstock is firstly extruded to form a wire and is then deposited to shape the part. Debinding and sintering operations are finally required to obtain the finished metal part. The feedstock formulation was optimized to allow and then to enhance the processability at all these steps. The printability of W-based feedstocks is demonstrated and a critical powder content, required to guarantee the efficient debinding and sintering, is established. Microstructure and mechanical properties (hardness) of sintered parts were characterized and compared to conventionally manufactured parts.

Innovative Aspect(s):
Tungsten parts are, for the first time to our knowledge, additively manufactured by an extrusion-based technology, namely PIM-like.

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Keynote ☐ Oral ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐

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WORLD PM2022 CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225371434

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Dr Yang Fei (University of Waikato, New Zealand)

Co-author(s):

Title: Thermomechanical Processing Of High Thermal Conductive Copper|diamond Composites From Powders For Future High-power Electronic Applications

Keyword(s):
Copper|diamond composite, Thermomechanical processing, Interface characteristics, Mechanical properties, Thermal conductivity and coefficient of thermal expansion

Abstract:
High-power density increases significantly with the ever-increasing miniaturization of electronic components, leading to heat dissipation is a critical problem in modern miniaturized electronic instruments. Therefore, efficient thermal management is becoming more and more crucial because the life span and dependability of electronic equipment depend strongly on its operating temperature. Copper|diamond composites are considered as promising heat sink materials as a result of their potential outstanding thermal conductivity and tailorable coefficient of thermal expansion. However, the poor chemical affinity between the copper and the diamond limits the composite's quality and performance. Introducing appropriate interface materials to the fabricated copper|diamond composite is the key to achieve high performance. In this research, I will discuss a cost-effective powder fabrication method that rapidly synthesise high-performance copper|diamond composites from powder through large plastic deformation, affecting factors that influence the thermal conductivity of fabricated materials, and the relevant underlying mechanisms.

Innovative Aspect(s):
Our research initiate the thermomechanical processing method to rapidly fabricate copper|diamond composites directly from powder, and we demonstrate that the method we developed is feasible to cost-effectively produce large-sized copper|diamond composites with acceptable thermophysical properties.

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Keynote ☐ Oral ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐

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WORLD PM2022 CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225371477

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Mr Saruta Jun (ASK Chemicals Japan Co.,Ltd., Japan)

Co-author(s): Dr Osada Toshiko ; Prof Dr Kobayashi Satoshi (Tokyo Metropolitan University, Japan)

Title: Design Of Thermosetting Binder For Metal Binder Jet Additive Manufacturing

Keyword(s):
Additive Manufacturing, 3D printing, Metal, Binder jet,Thermosetting binder

Abstract:
High green part strength is required to manufacture complicated shaped part in binder jet additive manufacturing. Commerciallt-availabe binder gives sufficient strength for coarse particle size powder, but for fine powder with good mechanical properties for sintered part it is insufficient. Sufficient green part strength is necessary for handling and depowder. In this study, we aimed to develop new thermosetting resin as a binder to increase the green part strength.

Innovative Aspect(s):
Since the green part is debound under inert gas atmosphere, the thermal decomposition condition for the binder is poor. Thus residual carbon inhibit sintering and adversely affect metal properties. Common thermosetting binder such as phenolic and epoxy resin have poor thermal decomposition property and they cannot be applied to binder jet metal additive manufacturing. We designed a thermosetting resin with good thermal decomposition property by introducing a reactive point into polymer chain.

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Keynote ☐ Oral ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐

Poster ☐ Poster & Reserve Oral ☐

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WORLD PM2022 CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225371584

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Dr Ing Studnitzky Thomas (Fraunhofer IFAM, Germany)

Co-author(s): Prof Dr Weißgärber Thomas ; Dipl-Ing Strauss Alexander (Fraunhofer IFAM, Germany) ; Dipl-Ing Jank Michael ; Dipl-Ing Büttner Dirk (DIABÜ® Diamantwerkzeuge Heinz Büttner GmbH, Germany)

Title: Ordered Diamond Arrangement In A Sinter Based AM Process

Keyword(s):
3D Screen Printing, Cutting tools, Diamonds

Abstract:
Diamond based grinding or cutting tools usually consist of randomly packed diamond particles inside a metal matrix. Nevertheless it is known that an ordered arrangement of diamonds shows much better performance with defined wear of the tool, which typically leads to a longer service life time. Several approaches and patents were already published on this topic, but due to the high complexity of the manufacturing process the market penetration is still low. Fraunhofer IFAM and DiaBü have developed a modified 3D screen printing process which allows the manufacturing of cutting beads with ordered diamond structure in a mass production process. With 3D screen printing, a user defined 3D arrangement of cavities can be built, into which the diamonds are incorporated. After closing of the cavities, the beads are debound and sintered. In the present work also results of cutting tests of beads with an ordered diamond structure will be presented.

Innovative Aspect(s):
Cutting beads are usually produced by pressing and sintering a mixture of diamonds and a metallic matrix material. This results in a random diamond arrangement which, as is known, does not have an optimal cutting effect compared to an ordered diamond distribution and leads to reduced tool life, as a randomly unfavourable diamond distribution leads to tool failure. With 3D screen printing, it is possible for the first time to economically produce such cutting beads in any diamond arrangement with millions of pieces. In addition to the application of cutting beads for stone processing, the approach can also be used for other related tasks. One example is the use in the dismantling of nuclear power plants by replacing diamonds with cubic boron nitride (CBN).

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Keynote ☐ Oral ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐

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WORLD PM2022 CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225371713

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Dr Ing Gabilondo Nieto Maitane (IMH-Advanced and Digital Manufacturing Campus, Spain)

Co-author(s): Prof Dr Castro Francisco (Independent Consultant, Spain) ; Dr Ing Cearsolo Xabier ; Ing Arrue Mario (IMH-Advanced and Digital Manufacturing Campus, Spain)

Title: The Effect Of Build Orientation And Infill Pattern On Mechanical Properties Of 316L Parts Made By Material Extrusion-based Additive Manufacturing

Keyword(s):
Metal additive manufacturing, Bound metal deposition, Process parameters, Mechanical properties

Abstract:
Material extrusion-based additive manufacturing (MEAM) is an alternative to the most common Additive Manufacturing (AM) technology for metal parts. As compared to Powder Bed Fusion (PBF) there are no loose powders or lasers during the manufacturing. However, the mechanical properties of the parts manufactured by MEAM are generally lower than those of PBF, being necessary to study the process parameters to improve their performance. The purpose of this work is to analyse the influence of build orientation (horizontal and vertical) and infill pattern (concentric and lines) on the mechanical properties of 316L parts manufactured by MEAM. Among the different MEAM processes, the selected technology was Bound Metal Deposition (BMD). The experimental results showed that although both build orientation and infill pattern influenced the mechanical properties, build orientation exerted the most important influence on mechanical properties, obtaining ultimate tensile strengths (UTS) approximately 160-170 MPa higher for horizontal specimens.

Innovative Aspect(s):
BMD is a versatile technology that enables the manufacturing of economical metal AM prototypes and low volume production parts in an office-friendly environment. However, the parts manufactured with this technology have some limitations in comparison to other methods such as PBF. One of the major concerns is attaining optimum mechanical properties, by controlling defects like high porosity and relatively poor adhesion between layers. These types of defects are usually generated during the printing step, which is based on the principle of FDM technology. Therefore, an appropriate control of the process parameters is necessary to minimize defects that may lead to inadequate performance in BMD. In addition, there are only few reports on this technology, which do not contribute to establishing the relationship between process parameters and mechanical properties in BMD.

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Keynote ☐ Oral ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐

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WORLD PM2022 CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225371760

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Dipl-Ing Asami Karim (Technical University Hamburg, Germany)

Co-author(s): Dr Ing Herzog Dirk ; Dipl-Ing Bossen Bastian ; Mr Geyer Leon ; Prof Dr Emmelmann Claus (Technical University Hamburg, Germany)

Title: Design Guidelines For Green Parts Manufactured From Stainless Steel In The Filament Based Material Extrusion Process For Metals (MEX|M)

Keyword(s):
MEX|M, Additive manufacturing, 3D printing, Metal extrusion, Sinterbased technologies, Design guidlines, Stainless steel

Abstract:
Filament-based material extrusion (MEX|M) presents a rapid and inexpensive alternative to e.g. metal injection molding, particularly for prototype production. The filament consists of metal powder in a plastic matrix and is melted and applied layer by layer until a so-called green body is created. These green parts are subsequently debinded and sintered at high temperatures to form a dense metal component. It is crucial to identify the material-specific and process-specific limits in order to be able to manufacture true to size. This paper therefore develops design guidelines for the MEX|M process for green part manufacturing for the widely used austenitic stainless steel AISI 316L (1.4404). Basic geometrical features such as walls, boreholes and overhangs are studied and influencing factors on the dimensional accuracy are assessed. Based on the results, recommendations for part design are presented.

Innovative Aspect(s):
Filament-based material extrusion (MEX|M) presents a rapid and inexpensive alternative to e.g. metal injection molding, particularly for prototype production. So far, the components are manufactured only by experienced users who have enough knowledge in the field of sintering process and 3D printing. Taking into account the subsequent process steps of MEX|M, this design guideline can help to produce successfully green parts with the desired accuracy. By examining layer thickness and roughness from the finished specimen, even inexperienced users can successfully produce components using this method and compare the results of the simulation with the functional prototypes. Using the guideline and the process it is possible to save enormous costs and time in series production.

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WORLD PM2022 CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225371778

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Ing Abid Marwa (CRITT-Matériaux Innovation, France)

Co-author(s): Ing Auzene Delphine ; Dr Ing Boudifa Mohamed ; Mr Cauwe Bruno ; Mr Popot Jean Marc (CRITT-Matériaux Innovation, France) ; Mr Buet Stéphane (EISINe, France) ; Prof Charlon Sebastien ; Prof Lacrampe Marie-France (IMT Nord Europe, France)

Title: Investigations On CIM-Like Process For Zirconia Filled With A Partially Bio-based Polymer

Keyword(s):
CIM-like, Zirconia, Feedstock, FFF process, Thermal debinding, Sintering, Bio-based polymer, Activation energy

Abstract:
Ceramic Injection Molding-like (CIM-like) has become an interesting technique to produce complex, low volume and customized parts. In this work, a new homemade and environmental-friendly feedstock, was produced by zirconia and partially bio-based polymers. The feedstock was transformed at low temperatures by common fused filament fabrication (FFF) printers. Then, polymers were removed from the printed part during a debinding step, and the ceramic particles were finally sintered. The thermal debinding step must be carefully performed to avoid the formation of defects such as cracks, blistering and residues. For this purpose, models describing the thermal degradation of polymers were used to calculate the activation energy and to design the optimal thermal debinding program based on thermogravimetric analysis (TGA). Finally, digital imaging and X-ray tomography were performed to characterize the intern morphology of sintered parts

Innovative Aspect(s):
The innovative aspect of this work firstly relates, on the elaboration of the feedstock based on a new biobased polymer, which has never been used before in the CIM-like process, in order to guarantee an environmentally friendly process. Indeed, this feedstock is easy to be transformed by common fused filament fabrication (FFF) printers at low temperature (100°C) with a lower energy consumption since the chamber temperature can be relatively low (40°C). Secondly, the substitution of chemical debinding by thermal debinding eliminates the dirty solvent treatment step. Finally, the optimization of the thermal debinding cycle using a simulation software based on model free kinetic analysis allows optimizing the debinding time.

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WORLD PM2022
CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225371863

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Dr Mancisidor Ane Miren (Lortek S.COOP, Spain)

Co-author(s): Dr San Sebastian Maria (Lortek S.COOP, Spain) ; Ing Gómez Raúl (Lortek S.COOP, Spain)

Title: Microstructural Analysis And Mechanical Properties Of Fe Based Shape Memory Alloy Manufactured By Laser Powder Bed Fusion

Keyword(s):
Shape memory alloy, Laser powder bed fusion, Process optimization, Microstructural characterization

Abstract:
Shape memory alloys (SMAs) are smart materials capable of recovering their original shape after being deformed by applying some stimuli. This effect occurs as a results of the martensitic transformation between the austenitic and martensitic phases. This unique characteristic make these materials appropriate to use in medical applications such as stents and for actuators. Fe based SMA are attractive alloys from cost perspective in contrast to the more common NiTi material. Additive manufacturing appears as a potential manufacturing process since it offers the possibility to fully exploit the attractive functionalities of SMAs. In this work, the processability of Fe based SMA by laser powder bed fusion has been studied. The microstructure has been analyzed by scanning electron microscopy and EBSD in as-built and after a heat treatment. Mechanical properties have also been determined. The resulting phase proportions responsible of the martensitic transformation is greatly dependent on the applied laser energy.

Innovative Aspect(s):
Among shape memory alloys NiTi material has been extensively analyzed and numerous investigations can be found both focused on conventional methods and additive manufacturing processes. On the contrary, few studies have been published about Fe based SMA processed by Laser Powder Bed Fusion. This technology offers the possibility to develop complex designs and fully exploit the attractive functionalities of SMAs. Nevertheless, the microstructure needs to be deeply analyzed since the martensitic transformation is highly dependent on the phase proportions present in the material. Moreover, the processing parameters and the applied laser energy can produce variations in the microstructure and thus, influence the shape memory functionality. Additional heat treatments can also be employed to modify the phase quantities towards the occurrence of the martensitic transformation. This work contributes to understand the process parameters-microstructure relationship of Fe based SMA by Laser Powder Bed Fusion.

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Keynote ☐ Oral ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐

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WORLD PM2022 CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225371888

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Mr Zissel Kai (Linde GmbH, Germany)

Co-author(s): Mr Forêt Pierre (Linde GmbH, Germany) ; Prof Dr Hryha Eduard (Chalmers University of Technology, Sweden)

Title: Binder Jetting - Reusability Of 17-4 PH Stainless Steel Powder

Keyword(s):
Binder Jetting, Powder reusability, Recycling, 17-4 PH, Powder degradation, Powder properties, Reproducibility, Processing atmosphere

Abstract:
Binder Jetting (BJT) is a binder-based Additive Manufacturing technology, where only a small fraction of the processed metal powder is bonded inside the green parts after printing. Unbound powder, which is recovered during the BJT process, is reused for printing. For powder reuse, the resulting changes in physical and chemical powder properties along with powder surface conditions strongly affect the reproducibility of the BJT process and its final part properties. In this study, powder degradation and its impact on the reusability of 17-4 PH stainless steel powder are evaluated for the BJT process. Powder characteristics are analyzed after multiple reuse cycles and along the process chain, namely drying, sieving, printing and curing. The influence of reused powder on print quality and green densities is investigated and compared to virgin powder. Furthermore, the effect of inert and reducing atmospheres on powder reusability during different BJT steps is examined.

Innovative Aspect(s):
Experimental characterization of powder degradation along the Binder Jetting process chain. Determination of the impact of powder reuse on print quality and green densities. Measurement of powder characteristics (PSD, bulk and surface chemistry, flowability, humidity) along the process chain (drying, sieving, printing, curing). Influence of inert and reducing processing atmospheres during Binder Jetting processing on powder properties.

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WORLD PM2022
CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225371909

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Ing Charpentier Nicolas (FEMTO-ST, France)

Co-author(s): Prof Dr Barrière Thierry (FEMTO-ST, France) ; Prof Dr Frederic Bernard (Institut Carnot Bourgogne, France)

Title: Developement And Optimisation Of A PLA Bio-based Feedstock For PIM-like Extrusion-based Additive Manufacturing Of Steel Tool Alloy

Keyword(s):
Additive Manufacturing, Bio-based binder, Porosity, PIM-like EAM, Steel powder

Abstract:
Bio-based binder aleviate the important carbon footprint that is created during PIM-like process with a carbon cycle for the binder. Moreover, some bio-based polymer are more suited to EAM, like PLA. This work present the different steps in developping a suitable pellets feedstock for PIM-like EAM and its optimisation to minimize porosity by tomographic observation in the final part. The final part is compared to one obtained with PIM and with traditional machining. The work is focused in the use of a steel-tool alloy powder but using the same method other materials are presented to broaden the field of application.

Innovative Aspect(s):
PIM-like Extrusion-based Additive Manufacturing allow an increase in complexity of shape, and an ease of use, not needing tooling to produce parts. The production of specific feedstock, and not using PIM feedstock provide a better mastery of the process. Moreover, this work provide additional knowledge into bio-based feedstocks.

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WORLD PM2022
CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225371923

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Ing Azurmendi Naiara (Tecnalia, Spain)

Co-author(s): Ing Lores Asier ; Dr Agote Iñigo (Tecnalia, Spain)

Title: Binder Jetting Additive Manufacturing Of M2 Tool Steel: Processability And Properties

Keyword(s):
Binder Jetting, Additive Manufacturing, Tool steel, M2, Sintering, Hardness

Abstract:
Binder Jetting Additive Manufacturing technology permits the processing of a wide range of different metallic alloys which cannot be easily manufactured by other AM means, as they may present undesired microstructures or anisotropic functional properties. For this reason, it has been found that BJ can be a suitable AM technology for processing tool steels and obtaining high quality parts with isotropic properties. In the present work, MIM grade commercial M2 tool steel powder was studied and processed by Binder Jetting under different processing conditions. After some optimization work, near full density was achieved (>99%), together with MIM-like microstructure and hardness (51 HRC). Therefore, this study demonstrates that good quality M2 parts can be obtained by means of BJ, opening new design and manufacturing possibilities for more complex and advanced tooling applications.

Innovative Aspect(s):
This work presents the following innovative points: The processability of commercial grade M2 alloy is proved by means of Binder Jetting additive manufacturing. This work should be indeed, to the best knowledge of the authors, one of the few public works on tool steel Binder Jetting up to date.. Near full density (>99%) and properties comparable to M2 parts processed by traditional sinter-based techniques are reached.. The suitability of Binder Jetting process for manufacturing tool steels with similar properties to traditional methods validates the process for manufacturing future and more advanced tools.

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WORLD PM2022 CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225371941

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Mr Greifzu Moritz (Fraunhofer-Institut für Werkstoff- und Strahltechnik IWS, Germany)

Co-author(s): Mr Peter Fabian ; Mr Tan Hong Tiat ; Mr Mehta Tarang Dineshchandra ; Mr Acharya Sohan ; Mr Stepien Lukas ; Dr Lopez Elena ; Prof Dr Brückner Frank ; Prof Dr Leyens Christoph (Fraunhofer-Institut für Werkstoff- und Strahltechnik IWS, Germany) ; Dr Marquar

Title: An Experimental Approach To Acquire Material-specific Parameters To Simulate The Sintering Process In Binder Jetting, Using In-situ Gravitational Beam Bending Tests And Dilatometry

Keyword(s):
Binder jetting, Simulation, Sintering, Stainless steel, 316L, 420S, Dilatometry, In-situ gravitational beam bending, Distortion compensation

Abstract:
Binder Jetting (BJ) is a sinter based additive manufacturing technology with several advantages over laser or electron beam based powder bed processes. This includes faster build rates, non-necessity of support structures and no introduction of thermal stress into the part during the build. On the other hand BJ parts shrink considerably during sintering making it more challenging to produce parts within tolerances. Recently, software to simulate and compensate this distortion has been commercialized. Since the algorithm behind this software is based on a phenomenological model, experiments have to be conducted to feed material parameters into this model for correct simulation of a specific alloy. Here, an experimental approach is presented using dilatometry and in-situ gravitational beam bending to perform a full characterization of two different stainless steel powders, 316L and 420S, and the extraction of the relevant data for the simulation.

Innovative Aspect(s):
Currently, only 316L stainless steel is available in the commercial simulation data base. The material was to our knowledge calibrated using published data. No calibration of a material was done folly experimentally, yet. In-situ gravitational beam bending was not used yet for calibration of simulation model for binder jetting.

TPC Reviewer name: .....

Keynote ☐ Oral ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐

Poster ☐ Poster & Reserve Oral ☐

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WORLD PM2022 CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225371945

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Ing Azurmendi Naiara (TECNALIA, Basque Research and Technology Alliance (BRTA), Spain)

Co-author(s): Dr Agote Iñigo ; Ing Lores Asier (TECNALIA, Basque Research and Technology Alliance (BRTA), Spain) ; Dr Ing Fernandes Cristina ; Ing Figueiredo Daniel (PALBIT S.A., Portugal)

Title: Binder jetting of hard metals: A comparative study of microstructure and properties of different commercial powder grades

Keyword(s):
Binder jetting, Hard metals, WC-12%Co, Sinter-hip

Abstract:
Additive manufacturing of hard metals is gaining attention due to the possibility of fabricating complex shaped parts and new functional designs. Comparing to laser-based AM processes, binder jetting appears to be more promising technology due to its low-cost, fast manufacturing process that produces stress and crack-free parts with isotropic properties. In the present work, properties of two different plasma spherodized commercial powders (AMWC701 and AMWC702 grades), have been characterized and printed with binder jetting technology. In addition, final properties of the printed parts sintered in a Sinter-HIP furnace at two different temperatures (1455°C and 1480°C) have been evaluated. Density, shrinkages, microstructure and hardness have been analysed. Best results were obtained with AMWC702 grade sintered at 1455°C, where near full density was obtained. Measured Vickers hardness was 1220 HV, which is coherent with the microstructural analysis and close to medium grained commercial products.

Innovative Aspect(s):
Additive manufacturing of Hard metals is still unsolved and needs further efforts to implement this process and obtain good quality parts. This study sheds some light on the selection of the most suitable commercially available powder for binder jetting technology. The printability evaluation, with Binder Jetting additive manufacturing technology, of two commercial grades WC-12%Co powders, as well as the sintering temperature effect of printed parts was evaluated. Although, few studies of binder jetting of hard metals have been published, up to the knowledge of the authors it is the first study that compares different commercial grade WC-12%Co powders for binder jetting and the obtained final properties at two different sintering temperatures.

TPC Reviewer name: .....

Keynote ☐ Oral ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐

Poster ☐ Poster & Reserve Oral ☐

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WORLD PM2022 CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225371969

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Dipl-Ing Limberg Wolfgang (Helmholtz-Zentrum hereon, Germany)

Co-author(s): Dr Ebel Thomas (Helmholtz-Zentrum hereon, Germany)

Title: Production Of Dense Ti-6Al-4V Parts By Composite Extrusion Modeling (CEM) With Excellent Mechanical Properties Identical To MIM

Keyword(s):
Composite Extrusion Modeling, Metal Injection Moulding, Ti-6Al-4V, Tensile tests

Abstract:
In this study, Ti-6Al-4V tensile test specimens were produced by Metal Injection Moulding (MIM) using fine powder < 20 µm and 10 wt.% binder. Specimens of the same shape and size were printed by Composite Extrusion Modeling (CEM), using the same MIM-feedstock on an AIM3D-printer with modified extrusion unit. The specimens were printed with different infill directions (longitudinal and cross diagonal). Residual porosity after sintering for one hour at 1300 °C was only 1.6% for the MIM-specimens and 1.9% for the CEM-specimens. No geometrical distortion was observed during processing. X-ray tomography of the CEM-parts showed only few larger pores of less than 100 µm. The MIM- as well as the CEM-specimens achieved the same ultimate tensile strength of 945 MPa independent of the infill print direction. The plastic elongation to fracture was 15.3% for MIM, 14.5% for CEM with cross diagonal infill and 16.5% for CEM with longitudinal infill.

Innovative Aspect(s):
3D printing often leads to internal defects, like cavities or pore strings longitudinal to the printing direction, caused by discontinuous or too low extrusion rates. This leads to bad mechanical properties especially perpendicular to the printing direction. A new extruder design, developed at Helmholtz-Zentrum hereon, for the "AIM3D ExAM 255" printer, allows the printing of dense parts with low residual porosity and excellent mechanical properties independent of the infill print direction.

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WORLD PM2022 CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225371976

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Dr Ing Studnitzky Thomas (Fraunhofer IFAM, Germany)

Co-author(s): Prof Dr Weißgärber Thomas ; Dr Ing Reuter Kay ; Dipl-Ing Strauss Alexander (Fraunhofer IFAM, Germany) ; Dr Mitteramskogler Gerald (Incus GmbH, Austria)

Title: Stereolithography Of Copper For 5G, 6G And Beyond

Keyword(s):
Stereolithography, Sinter Based Additive Manufacturing, LMM

Abstract:
New mobile communication standards such as 5G, 6G and beyond require further miniaturisation of complex components such as waveguides or filters made of pure copper. Previous manufacturing methods for 3D components have reached their limits in terms of precision and productivity. As a new sinter-based additive process, lithography-based metal manufacturing (LMM) enables the economical and high-precision production of such components with structure widths of around 100 µm. Since only steels have been available in LMM so far, the material copper was developed for LMM for the first time in this work. The entire process chain from powder selection, paste formulation and printing process parameters to debinding and sintering was investigated. Special emphasis was focused on the achievable geometries and the material properties in order to achieve high purity, excellent debindering quality and maximum sintering density for very high conductivities > 90% IACS.

Innovative Aspect(s):
The advancing miniaturisation in high-frequency communication is increasingly difficult to achieve for classic manufacturing processes. The necessary fine structure sizes are often accompanied by a reduction in productivity and an increase in costs. With the LMM, on the other hand, the necessary structure sizes around 100 µm can be produced without any problems and without process-related cost increases. In this structure size range, there are in fact no other additive processes that can realise corresponding components. The first-time development of copper for LMM also opens up the possibility of further applications in electronics such as printed miniature coils, micro heat exchangers or complex electrical contact materials. In addition, the work offers the basis for transfer to other material systems in the still young LMM process.

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WORLD PM2022 CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225372017

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Dr Sainz Shandra (CEIT, Spain)

Co-author(s): Mr Ruiz Odei ; Dipl-Ing Guruceaga Idoia ; Dr Iturriza Iñigo (CEIT, Spain) ; Mr Kernan Brian ; Mrs Morishige Ashley ; Mr Hudelson Steve ; Mr Dary Francois (Desktop Metal, USA)

Title: A Study Of The Binder Jet 3D Printed 440C+Nb Stainless Steel: Process Development Towards High Density And Hardness Level

Keyword(s):
Binder jetting, Stainless steel, Sintering, Heat treatment

Abstract:
Single Pass Jetting technology was explored using the Desktop Metal's Production System P-1 system to develop a 440C stainless steel with Nb addition. A MIM powder grade was used as the raw material and the complete process towards its densification has been defined, from the selection of the appropriate powder conditioning and printing parameters to the identification of the sintering and heat-treating cycles considering metallurgical criteria. On those grounds, C and Nb content as well as the sintering atmosphere play a critical role. Chemical analysis and metallographic characterization were performed to analyse the evolution of the porosity and the microstructure. The steps of the heat treatment were selected based on retained austenite monitoring and a target hardness of 58±1 HRC. Testing samples were printed to evaluate the tensile and impact properties of the alloy against MPIF35 standard.

Innovative Aspect(s):
The main innovative aspect is the use of Binder Jetting technology for processing this martensitic stainless steel, a material used in several applications. The work covers the material development in all the steps of the process, from the printing to the sintering and heat treatment, looking for high densification level and high hardness. Microstructural characterization and mechanical properties evaluation is included. In fact, a variant of 440C, with Nb addition, has been selected for the study. The influence of Nb, C, and sintering atmosphere have been analysed to define the sintering conditions. For that instance, thermodynamic calculations have been carried out.

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WORLD PM2022
CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225372121

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Dr Tsipas Sophia (Universidad Carlos III de Madrid, Spain)

Co-author(s): Dr Rodriguez-Garcia Nerea ; Prof Jimenez-Morales Antonia ; Prof Torralba José Manuel ; Ing Cruz Hernadez Angily Paola (Universidad Carlos III de Madrid, Spain)

Title: Composite Extrusion Modelling Of Inconel 718 Using A Sustainable Feedstock

Keyword(s):
Inconel, Sustainable Feedstock, Additive Manufacturing, Composite Extrusion Modelling

Abstract:
In terms of Additive Manufacturing (AM) methods, Composite Extrusion Modelling (CEM) stands as a promising alternative for printing materials that are not suited for other AM techniques. In this processing route, feedstocks are extruded in pellet or granulate form, avoiding difficult steps of filament production and increasing the polymeric selection for the binder composition since flexibility properties are not required for the pellet materials. In this work, Inconel 718 printed samples were produced by CEM using a multicomponent binder for the production of sustainable feedstocks. The selection the binders is based on reducing the carbon footprint, combining typical polymers used in feedstocks suitable for AM techniques with water soluble polymers. Rheological behaviour and critical loading of the feedstocks was determined in order to ensure a proper printing of the material. In addition, printing parameters were optimized and in-depth characterization of printed samples was performed.

Innovative Aspect(s):
A sustainable multicomponent binder has been used for the production of Inconel Feedstock for AM using a combination of water soluble and non-toxic degrading polymers. Feedstocks produced can be used both in traditional Injection molding methods as well as sinter-based additive manufacturing methods such as Composite Extrusion Modelling. Rheological properties of the MAX phase feedstocks have been characterised analysing torque and capillary rheology. An alternative method for the processing of Inconel alloys by AM.

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WORLD PM2022
CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225372277

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Ing Naranjo Juan Alfonso (UCLM, Spain)

Co-author(s): Dr Berges Cristina ; Ing Gallego Alberto ; Dr Hidalgo Javier ; Dr Herranz Gemma (UCLM, Spain)

Title: Filament Mechanical Properties And Rheology As Limiting Factors In Fused Filament Fabrication

Keyword(s):
Fused filament fabrication, Rheology, Printing

Abstract:
Fused filament fabrication is emerging as a promising sinter-based technology rivalling widespread beam-based approaches for the production of metal components. In the first step, a filament composed of a polymeric matrix with a high powder loading is extruded by a capillary die and deposited layer by layer to produce the desired geometry. Filament properties are critical for the printing performance, still, there is not a consensus on the range of filament properties adequate for printing. This work aims to establish threshold values for filament features leading to satisfactory printing by analyzing the rheology and mechanical properties of filaments made of powders of diverse ferrous alloys. It is concluded that besides other consequences, filament rheology and mechanical properties have a strong impact on the shear stresses developed during printing, which limit the printing speed. These parameters can be engineered by solid loading and temperature to maximize the printing process.

Innovative Aspect(s):
The relationship between rheological analysis and printing parameters has not yet been really established in the literature, while it is well known in other homologous processing technologies such as powder injection molding. The different shear rates and material pressure during printing, as opposed to injection molding, make it necessary to establish new criteria.

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WORLD PM2022
CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225372298

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Dr Herranz Gemma (UCLM, Spain)

Co-author(s): Ing Jimenez Juan ; Ing Naranjo Juan Alfonso ; Dr Hidalgo Javier ; Dr Berges Cristina (UCLM, Spain)

Title: Design And Manufacturing Of CoCrMo Prosthesis By 3D Printing

Keyword(s):
Cobalt alloys, Fused filament fabrication, Feedstock, Printing

Abstract:
Advents in additive technologies have enabled the production of tailormade prostheses for medical applications. This achievement is limited by the yet scarce available commercial materials. This work explores the use of fused filament fabrication for the production of a bone prosthesis of biocompatible CoCrMo alloy. One of the biggest challenges was the design of a highly loaded feedstock capable be turned into a coiling filament adapted to the FFF requirements. A suitable filament was successfully created and printing conditions optimized. A thorough study was carried out to determine debinding and sintering conditions, with particular focus on the dimensional precision, microstructure analysis and hardness test. Finally, the filament was tested for the processing of a kneecap with dense|porous zones.

Innovative Aspect(s):
This work explores the use of fused filament fabrication for the production of a bone prosthesis of biocompatible CoCrMo alloy.

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WORLD PM2022
CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225377331

Requested paper type: Oral Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Ing Hecker Lennart (GKN Sinter Metals Engineering GmbH, Germany)

Co-author(s): Dr Ing Höges Simon ; Dr Ing Schaak Christopher (GKN Sinter Metals Engineering GmbH, Germany)

Title: Investigation Of Printing, Sintering, And HIP-processing Of A Nickel Free Stainless Steel For Binder Jetting

Keyword(s):
Binder Jetting, Nickel free stainless steel, HIP

Abstract:
Beside using Binder Jetting in industrial or automotive applications, it is also an appropriate process for the series production of wearables, jewelry or medical products. Products with constant skin contact have high requirements regarding corrosion resistance and furthermore, the material should not cause any health issues. Common stainless steels do not fit into the second requirement due to a high Nickel amount. Sweat and other fluids can cause a Nickel release from the product surface. This released Nickel can cause allergic reactions since a Nickel-sensitivity for a relevant number of people within the population is present. To offer products without any risk of Nickel release, GKN Additive developed a nickel free austenitic stainless steel material for binder jetting. To achieve an austenitic structure, Nitrogen is used as austenite stabilizer. The present paper gives an insight into the printing, sintering, and HIP process of this new material.

Innovative Aspect(s):
Investigation and qualification of a new material for binder jetting. This will give access to new product groups for binder additive manufacturing.

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WORLD PM2022
CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225371420

Requested paper type: Poster Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Ing Lacorne Jordan (Université de Lyon, INSA Lyon, France)

Co-author(s): Dr Ing Maire Eric ; Dr Ing Boulnat Xavier (Université de Lyon, INSA Lyon, France) ; Dr Ing Etiemble Aurélien ; Dr Ing Simon Sandra (Université de Lyon, ECAM Lasalle Lyon, France) ; Dr Ing Faye Romain (Nanoe SAS, France)

Title: 3D Printing Of H13 Tool Steel Filaments : Influence Of Debinding|sintering Atmosphere On The Microstructure And The Mechanical Properties Of Sintered Parts

Keyword(s):
Additive Manufacturing, Debinding, Sintering, H13 work tool steel, Mechanical characterization

Abstract:
Additive Manufacturing is a growing sector in industrial production. Fused Filament Fabrication (FFF) technology is developing by using new materials such as filaments incorporating metal powder (40 to 60%vol) and thermoplastic binders. After 3D printing, FFF needs two more steps: debinding, where the binder is removed, and sintering, where the porous part is densified. The nature of the protective atmosphere is critical because it influences the binder removal and also the sintering|oxidation behavior of the metal powders. This work aims to study the influence of atmosphere (gas type and flow rate) during debinding and sintering on the properties of the final parts in work tool steel (AISI H13). The link between atmosphere and carbon|oxygen uptakes, porosity, microstructure, and mechanical properties will be described.

Innovative Aspect(s):
Very few studies have investigated the influence of the atmosphere during debinding and sintering on the final properties and more specifically for the tool steel H13. This study aims to fill the lack of knowledge for different atmospheres. A wide spectrum of properties is investigated such as pore size distribution (X-Ray tomography, Scanning Electron Microscopy) in green and sintered parts; microstructure, carbon and oxygen contents upon debinding|sintering steps; and finally mechanical properties (hardness and tensile behavior). This insight can be of great interest for sinter-based AM technologies: FFF, binder jetting, metal lithography, etc.

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WORLD PM2022
CONGRESS & EXHIBITION
09-13 OCTOBER

Paper number: WP225372173

Requested paper type: Poster Presentation

Topic: Consolidation technologies / **Subtopic:** Sinter based technologies

Author: Dr Ing Batin Gabriel (Technical University of Cluj Napoca, Romania)

Co-author(s): Ing Korpe Osman (Gazi University, Turkey) ; Ing Toderici Roxana-Maria ; Ing Maftei Ana-Maria ; Dr Ing Thalmayer Gyorgy (Technical University of Cluj Napoca, Romania)

Title: Preliminary Study Regarding The Obtaining Of Ceramic Feedstock Based On Recycled Polymers For FDM

Keyword(s):
FDM, PLA, Additive Manufacturing, 3D model data, Fused Deposition Modelling, Polymer filaments, Alumina particles, Polymeric binder, Feedstock, Recycled polymers

Abstract:
Additive Manufacturing is the process of joining materials particles to produce objects from 3D model data, usually layer upon layer. Fused Deposition Modelling is intensively used to print parts using polymer filaments. Recently, the industry focused on printing parts by FDM using metals or ceramics materials. The aim of this study is to obtain a ceramic filament for FDM. Alumina particles were combined with a polymeric binder consisting of recycled LDPE or LDPE|PLA. Different ratio of binder components, polymers and ceramic were used. Filaments were produced using an in-house extrusion device. The viscosity of binders and feedstocks was determined using a Rheotest viscosimeter. Tensile and bending tests were conducted to achieve the mechanical characteristics of produced filaments.

Innovative Aspect(s):
The innovation consist in using the recycled polimers for the filament.

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