EURO PM2023 CONGRESS & EXHIBITION

Technical Programme Committee
15th February 2023

ABSTRACTS BOOK – GROUP 9

TOOLS FOR IMPROVING PM

EPMA
european powder metallurgy association

EURO PM2023 CONGRESS & EXHIBITION

Technical Programme Committee
15th February 2023

TOOLS FOR IMPROVING PM

DESIGN AND MODELLING

EPMA
european powder metallurgy association

EURO PM2023 CONGRESS & EXHIBITION

01-04 October 2023

Paper Number : EP235751775

Requested presentation type : Oral Presentation

Topic : Tools for improving PM **Subtopic :** Design and Modelling

Author : Mr Mamykin Petr (Université de Bourgogne, France)

Co-author(s) : Prof Chateau-Cornu Jean-Philippe, Prof Bernard Frederic (Université de Bourgogne, France)

Title : Modelling The First Compaction Stages Of A Metallic Powder During Load-assisted Sintering: Using DEM Simulations To Homogenise The Behaviour Of A Powder ERV

Keyword(s) :
HIP; Sintering; Simulation; Model; Cam-Clay; Leblond-Perrin-Suquet; LPS; DEM

Abstract :
The work goal is to develop a model simulating powder compaction at the beginning and during hot isostatic pressing. Such a model would increase the precision of finding the initial shape of a hip container for net-shape HIP manufacture while maintaining low computation times.To simulate the powder compaction a set of equations (constitutive laws) will be used : Cam-Clay model and the Levi-Mises. In addition, at higher temperature, the Leblond-Perrin-Suquet (LPS) model is used, as well as a number of other equations describing the thermal expansion, the creep, and change in thermal conductivity.Reference data for model development obtained experimentally from uniaxial compression tests as well as from interrupted HIP tests on a spherically shaped container. Data for characterization of shear behaviour and thermal conductivity of powder is found using discrete element method (DEM) simulations.

Innovative Aspect(s) :
Finding out powder characteristics for DEM simulations by Uniaxial compression tests, using SPS equipment.
Usage of DEM simulations in order to refine constutive law simulation model.

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Keynote ☐ Oral ☐ 1☐ 2☐ 3☐ 4☐

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EURO PM2023 CONGRESS & EXHIBITION

01-04 October 2023

Paper Number : EP235752342

Requested presentation type : Oral Presentation

Topic : Tools for improving PM **Subtopic :** Design and Modelling

Author : Mr Hellenbrand Gerrit (Werkzeugmaschinenlabor (WZL) der RWTH-Aachen University, Germany)

Co-author(s) : Dr Ing Mevissen Dieter, Dr Ing Brimmers Jens, Prof Dr Brecher Christian (Werkzeugmaschinenlabor (WZL) der RWTH-Aachen University, Germany)

Title : Tooth Contact Analyses Of Powder Metal Gears Under Consideration Of Local Material Properties

Keyword(s) :
Gear Calculation; Powder Metallurgy; PM-Gears; Densification

Abstract :
An efficient gear design requires minimal safety margins to realise a full material utilization in terms of the load carrying capacity. This leads to a necessity of increasingly accurate calculation methods for the load carrying capacity of gears. In this paper, a method for the stress calculation in the tooth contact of surface densified powder metal gears considering local material properties is presented. The approach to integrate the densification profile is realized, based on an image-processing tool that analyses metallographic microsections. These profiles serve as an input for an FE-based tooth contact analysis with consideration of the local material properties. Parallel, the fully densified surface area is calculated with an analytical approach and the results are compared to the results of the numerical calculation to build up a calculation method, with a combined approach for the resulting stress depth profile.

Innovative Aspect(s) :
The presented calculation approach takes the porosity profile of pm-gears into account for a tooth contact analysis. Within this tooth contact analysis, a combined method of numerical (FEM) and analytical calculation is processed in order to gain knowledge on the prevailing stresses in loaded powder metal gears.

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EURO PM2023 CONGRESS & EXHIBITION

01-04 October 2023

Paper Number : EP235754938

Requested presentation type : Oral Presentation

Topic : Tools for improving PM **Subtopic :** Design and Modelling

Author : Dr Abburi Venkata Kiranmayi (Hexagon | Simufact Engineering GmbH, Germany)

Co-author(s) : Dr Ing Gao Siwen (Hexagon | Simufact Engineering GmbH, Germany)

Title : Sintering Simulation Framework As A Virtual Design And Process Optimisation Tool For Sustainable Sinter-based Additive Manufacturing

Keyword(s) :
Metal Binder Jetting; Sintering Simulation; Live Setters; Pre-Compensation

Abstract :
Sinter-based additive manufacturing (AM), especially Metal Binder Jetting (MBJ) is emerging as an economical AM technology for cheaper metal parts production. Although sinter-based manufacturing has been around for over half a century, the design freedom and specific process characteristics of MBJ necessitate reliable sintering simulation. A validated simulation tool provides greater understanding of the underlying material behaviour necessary for design optimisation, process control and standardisation. Using Simufact Additive MBJ module, the macroscopic shrinkage and deformation behaviour of the material during MBJ sintering are predicted accurately. The simulation predictions are used to automatically generate pre-compensated part geometry such that the part tolerances are within quality specification after sintering. Other quality control strategies such as live setters|supports can also be assessed to identify the best strategy for a given geometry, material and process parameter combination. The simulation framework as a virtual design tool is validated on industry relevant geometries with experimental investigation.

Innovative Aspect(s) :
The automatic pre-compensation of part geometries based on sintering deformation|shrinkage as a quality control tool. Considering live setters|supports in sintering simulation in addition to part geometries. The simulation tool is agnostic as it is valid for any metallic material and process combination, independent of hardware. Validation of the simulation framework on several industry relevant geometries through experimental investigations. Automatic generation of material data required for simulation with greater accuracy.

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EURO PM2023 CONGRESS & EXHIBITION

01-04 October 2023

Paper Number : EP235755250

Requested presentation type : Oral Presentation

Topic : Tools for improving PM **Subtopic :** Design and Modelling

Author : Prof Barrière Thierry (Univ. Bourgogne Franche-Comté, FEMTO-ST Institute, CNRS|UFC|ENSMM|UTBM, Department of Applied Mechanics, France)

Co-author(s) : Dr Cheng Gang (INSA Centre Val de Loire, France), Dr Xiao Fangnao (Université Bourgogne Franche-Comté, FEMTO-ST Institute, France)

Title : Influence Of Particle Characteristics On The Mechanical Properties Of Particle Reinforced Tungsten Alloys In Compression Tests

Keyword(s) :
Particle Reinforced Alloys, Tungsten, Mechanical, Compression Tests, Numerical Simulation

Abstract :
The manufacturing processing and the mechanical properties of particle reinforced metal matrix composites are strongly dependent on their microstructural characteristics. In this research, 2D and 3D models in microscale of tungsten alloys reinforced by Zr(Y)O2 particles (W-Zr(Y)O2) were established to investigate their uniaxial compression deformation behaviours. The effects of particles contents, size and their distribution on the compressive properties of W-Zr(Y)O2 alloy were discussed. The mechanical behaviours of the reinforced W alloys were improved by increasing the content of Zr(Y)O2 particles. With the same particles content, the strength of the reinforced alloys increased with smaller size particles. With the same particle size and content, the stress concentration was reduced with more homogeneous distribution of the reinforced particles. The predicted strengths with 2D and 3D models are compared with the experiment data, and the 3D simulation exhibits higher prediction accuracy.

Innovative Aspect(s) :
Elaboration of particle reinforced W alloy by innovative technologies.
Numerical simulation of compression tests with the high-performance W alloys.
Effect of particle amount, size and distribution on the mechanical properties of W alloys.

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EURO PM2023 CONGRESS & EXHIBITION

01-04 October 2023

Paper Number : EP235755820

Requested presentation type : Oral Presentation

Topic : Tools for improving PM **Subtopic :** Design and Modelling

Author : Mr Schuppener Jannik (Chair of Materials Technologgy, Germany)

Co-author(s) : Dr Ing Benito Santiago, Prof Dr Weber Sebastian (Chair of Materials Technologgy, Germany)

Title : Optimization And Live Adaptation Of The Heat Treatment In An Industrial Heat Treatment To Different Initial States Of A PM Tool Steel And Energy-efficient Process Optimization With Requested Product Properties

Keyword(s) :
Simulation, Tool Steel, Optimization, Heat Treatment

Abstract :
Hot isostatic pressing of powder metallurgy tool steels results in high performance tools with outstanding properties. However, the successively deployed conventional heat treatments are not tailored for this manufacturing route, generating room for improvement. This work presents a simulation workflow targeting a twofold optimization of the heat treatment after the consolidation process. These two goals are (i) the determination of the most efficient treatment to guarantee a minimum hardening depth; and (ii) the improvement of the process stability regarding hardness and chemical variations resulting from the as-delivered condition. The workflow includes calculation of metastable states using MatCalc®, finite element analysis using AbaqusFEA®, and optimization routines written in Python and MATLAB®. To validate the models, a PMX153CrMoV12 ingot was treated in a laboratory furnace, with supporting dilatometry and hardness testing completing the experimental setup. The models and measurements showed great agreement, proving the suitability of the workflow for industrial deployment

Innovative Aspect(s) :
This work is the first to use the previously developed simulation model to calculate the local microstructure and mechanical properties of a complex component in different initial states depending on batch-specific and manufacturing routes. To enable this complete simulation, different models were combined with each other. For the heat transfer from the heat treatment furnace into the component as well as the distribution in the component, an Abaqus FEM simulation was combined with a MatLab optimization model to obtain the heat transfer coefficient, the microstructural changes were simulated by exact time-temperature curves for each FEM node using the software MatCalc and the resulting mechanical properties were calculated by an optimized sum function, which was developed from an extensive data set. The combination of these models and their application is a new approach.

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EURO PM2023 CONGRESS & EXHIBITION

01-04 October 2023

Paper Number : EP235760991

Requested presentation type : *Oral Presentation*

Topic : Tools for improving PM **Subtopic :** Design and Modelling

Author : Dr Ing Schneider Markus (GKN Powder Metallurgy, Germany)

Co-author(s) : Ing Radis Christos, Ing Wawoczny Dennis, Dipl-Ing Maassen Robert (GKN Powder Metallurgy, Germany),

Title : The Role Of Apparent Hardness On The Critical Defect Size Derived From Kitagawa-Takahashi Diagrams

Keyword(s) :
Da|dN-ΔK Curves; Kitagawa-Takahashi Diagram; Critical Defect Size; Sintered Steels

Abstract :
The critical defect size a0 is that defect size a which can be tolerated by the material without a loss of strength. Its magnitude is of relevance for all non-destructive testing methods because it defines the needed resolution limit. The critical defect size a0 depends on materials ductility (apparent hardness H) and on the loading ratio R. Four different sintered steels with a wide apparent hardness H range were chosen for the internal fatigue crack propagation campaign: AS 1000BMn + 2 % Cu + 0.6 % C, FD 4600A + 0.5 % C, FLD-49DH + 0.65 % C and AS 150 HP + 0.5 % C. Moreover, the sintered density ? was varied between ?=6.8 g|cm³ and ?=7.2 g|cm³. Derived da|dN-?K curves were combined with existing s-N lines ("Woehler lines") and the effect of the apparent hardness H on the critical defect size a0 was investigated.

Innovative Aspect(s) :
The derivation of critical defect sizes a0 for sintered steels is rather new and the dependency on the apparent hardness H is unknown.

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EURO PM2023 CONGRESS & EXHIBITION

01-04 October 2023

Paper Number : EP235762579

Requested presentation type : Oral Presentation

Topic : Tools for improving PM **Subtopic :** Design and Modelling

Author : Dr Lancelot Carl-Magnus (Thermo-Calc Software AB, Sweden)

Co-author(s) : Ing Markström Andreas, Dr Malik Amer, Dr Do-Quang Minh, Dr Jeppsson Johan (Thermo-Calc Software AB, Sweden)

Title : A New CALPHAD-based Finite Element Tool For Additive Manufacturing Simulation

Keyword(s) :
Thermo-Calc; CALPHAD; Additive Manufacturing (AM); Powder Bed Fusion ; Multiphysics Simulation; Finite Element Method (FEM); Solidification; Scheil Calculation; Melt Pool; Thermophysical Properties; Laser Melting

Abstract :
Thermo-Calc has spent the last few years developing new models to predict thermophysical material properties to incorporate with CALPHAD-based materials descriptions. This foundation is currently used to extract CALPHAD-based materials data for use in dedicated Finite Element simulation codes, which usually treat material properties in a highly simplified manner.This development has laid the foundation for a completely integrated simulation tool, using the CALPHAD-based descriptions of phase equilibria and physical properties, to simulate the Additive Manufacturing (AM) process.The Additive Manufacturing Module in the Thermo-Calc software was released this summer, and it gives a unique possibility to address the problem of solidification during AM, where we obtain a unified treatment of both process parameters and chemistry-dependent thermophysical properties when solving the multiphysics problem of a moving heat source that melts and solidifies metal powder.Examples are shown of the Additive Manufacturing module applied to different material classes.

Innovative Aspect(s) :
This is a FEM tool for multiphysics simulation of laser melting of additive powders with CALPHAD-based materials descriptions at the foundation, where traditionally either handbook data is incorporated, or a user needs to extract calphad data separately for processing and input. This also enables direct pairing of Scheil-Gulliver simulation of rapid solidification with the FEM tool.

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EURO PM2023 CONGRESS & EXHIBITION

01-04 October 2023

Paper Number : EP235762889

Requested presentation type : Oral Presentation

Topic : Tools for improving PM **Subtopic :** Design and Modelling

Author : Dr Aminnia Navid (University of Luxembourg, Luxembourg)

Co-author(s) : Dr Estupinan Donoso Alvaro, Prof Peters Bernhard (University of Luxembourg, Luxembourg)

Title : Modeling Of Marangoni-induced Flow In Selective Laser Melting Using Coupled CFD-DEM Approach

Keyword(s) :
Computational Fluid Dynamics; Discrete Element Method; Powder Bed Fusion; Melt Pool; Multiphase Flow; CFD-DEM

Abstract :
Computational models play a role in the optimization of metal additive manufacturing parts and in evaluating component quality. However, obtaining reliable models of this process remains a challenge due to the complex, interrelated phenomena involved. A key component of such models will be the detailed simulation of flow and heat transfer in and around the melt pool that is formed when the powder bed is melted. A Marangoni force arises at the gas-liquid interface due to the gradient in temperature, which drives high-temperature liquid to flow toward the low-temperature region. In this study, a CFD solver is coupled with an in-house developed DEM code known as eXtended Discrete Element Method (XDEM) to model the dynamics and thermodynamics of the particles. This numerical framework will help to determine how powder size distribution, laser velocity and power, among other factors, will affect the characteristics.

Innovative Aspect(s) :
Coupling of CFD-DEM where DEM also solves for the thermodynamics of the powder particles, including laser radiation and powder melting.The heat conduction between the particles is calculated explicitly based on the Vargas-Mccarthy model.The heat convection between the particles and the melt or the ambient gas is calculated explicitly for each powder particle.The particles are discretized in the radial direction, thus facilitating better capture of partial melting of the powder particles.

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EURO PM2023 CONGRESS & EXHIBITION

01-04 October 2023

Paper Number : EP235763767

Requested presentation type : Oral Presentation

Topic : Tools for improving PM **Subtopic :** Design and Modelling

Author : Mr Schenk Oliver (RWTH Aachen University, Germany)

Co-author(s) : Mr Deng Yuanbin, Dr Ing Kaletsch Anke, Prof Dr Broeckmann Christoph (RWTH Aachen University, Germany)

Title : Constitutive Modelling Of The Densification Of Astaloy 85Mo Sintered Steel During Cold Working

Keyword(s) :
Gurson Model; Densification; Rastagaev; Plasticity; Sizing; Astaloy 85Mo

Abstract :
The powder metallurgical (PM) process chain stands out by its ability to produce precise components at low cost. However, the inherent porosity of PM components, which has a particular impact on fatigue behaviour, is crucial for components such as gears. Hence, cold rolling is commonly applied to densify the surface of sintered components. This induced densification can be modelled by a constitutive law introduced by Gurson, Tvergaard and Needleman. In this work, a modified GTN model was derived to simulate the densification behaviour of Astaloy 85Mo sintered steel. The stress-strain-behaviour of sintered samples with different densities was deduced from compression tests according to Rastagaev. A synthesized description of the plasticity of the dense material was then combined with the densification behaviour during compression to obtain a density-dependent GTN model. The model was validated by comparison with experimental data on the densification during sizing and cold isostatic pressing of sintered samples.

Innovative Aspect(s) :
The set up of process steps such as sizing or cold rolling, that involve the plastic deformation of a component, often rely on empirical data or experience. A profound understanding of plastic deformation and related densification of sintered steels offers the potential to optimize these processes as well as to predict the shape and density distribution of the final component. This understanding can be gained by the presented approach that enables the precise derivation of a novel numerical model.

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EURO PM2023 CONGRESS & EXHIBITION

01-04 October 2023

Paper Number : EP235763805

Requested presentation type : Oral Presentation

Topic : Tools for improving PM **Subtopic :** Design and Modelling

Author : Mr Schenk Oliver (RWTH Aachen University, Germany)

Co-author(s) : Mr Deng Yuanbin, Dr Ing Kaletsch Anke, Prof Dr Broeckmann Christoph (RWTH Aachen University, Germany), Dr Ing Şelte Aydin (Uddeholms AB, Sweden)

Title : Multiscale Modelling Of Powder Compaction Of Astaloy 85Mo

Keyword(s) :
Drucker Prager Model; Powder Compaction; Friction; Tool Steel; Machine Learning; Multiscale; Astaloy 85Mo

Abstract :
Powder compaction is an essential part of the powder metallurgical (PM) process chain, being mainly responsible for the shape and distribution of the inherent pores of a sintered component. While the significant effects of the porosity and the pore morphology on the fatigue behaviour of PM components have been widely investigated, their numerical prediction during PM processing has rarely been performed. In this work, a multiscale model of powder compaction of Astaloy 85Mo is presented, which provides information on both density distribution and pore morphology. A modified Drucker-Prager model and a friction model were experimentally derived to simulate the compaction process for different tool steels on macroscale, providing information on the density distribution. Using machine learning, artificial microstructural images of the powder compact were generated depending on local density. Both models were combined and applied to the compaction of a gear, which delivered promising results that agree well with experiments.

Innovative Aspect(s) :
The simulation of powder compaction on the macroscale has been widely studied. However, those investigations were often limited to two dimensional simulations and commonly applied to simple geometries. Methods to predict the microstructure after compaction have rarely been proposed. The presented models and their combination offer a novel multiscale model, that provides information on both the macro- and the mesoscale of complex shaped geometries.

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EURO PM2023 CONGRESS & EXHIBITION

01-04 October 2023

Paper Number : EP235764034

Requested presentation type : Oral Presentation

Topic : Tools for improving PM **Subtopic :** Design and Modelling

Author : Dr Ivannikov Vladimir (Helmholtz-Zentrum Hereon, Germany)

Co-author(s) : Mr Munch Peter, Prof Dr Kronbichler Martin (University of Augsburg, Germany), Dr Ebel Thomas (Helmholtz-Zentrum Hereon, Germany)

Title : Large-scale Phase-field Simulations Of Solid State Sintering Of Metallic Powders

Keyword(s) :
Phase-Field; Sintering; FEM; Deal.II; HPC

Abstract :
In order to perform plausible predictive numerical simulations of solid-state sintering, it is essential to capture accurately both shrinkage and microstructure evolutions of a given material. Moreover, for the results to be meaningful and statistically relevant, one has to analyze packings containing hundreds and thousands of particles. In the current work we present a highly efficient phase-field based numerical model that is able to handle large-scale three-dimensional cases at the early and later stages of sintering. The approach is based on the classical phase-field model of Wang. Multiple novel algorithms are developed for its efficient numerical FEM implementation: fully distributed tracking of individual grains, graph colorization for minimization of the number of order parameters, problem specific preconditioners and order parameters cut-off. The microstructures obtained in the benchmark tests performed for a real material (titanium) were compared with those obtained in experiments.

Innovative Aspect(s) :
The majority of the existing phase-field approaches has been applied in the context of sintering modeling to small scale problems working thus with a few dozens of particles. The proposed model relies on the state-of-the-art techniques from the deal.II library for its numerical implementation in order to maximize the performance and robustness. Particularly, we extensively use the modern matrix-free approach, vectorization and fully distributed algorithms. This made it possible to analyze the earlier and later stages of sintering of large particles assemblies within a few hours of real time with the aid of midsize HPC clusters. Special attention was given to the efficient computation of the microstructure metrics (porosity and grain sizes distributions) for simpler and more natural comparison of the numerical results with experimental data.

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EURO PM2023 CONGRESS & EXHIBITION

01-04 October 2023

Paper Number : EP235765038

Requested presentation type : Oral Presentation

Topic : Tools for improving PM **Subtopic :** Design and Modelling

Author : Dr Lindroos Matti (VTT Research Centre of Finland, Finland)

Co-author(s) : Mr Andersson Tom, Dr Biswas Abhishek, Dr Ren Sicong, Mr Suhonen Tomi, Mr Lagerbom Juha, Mr Lindroos Tomi, Prof Dr Laukkanen Anssi (VTT Research Centre of Finland, Finland), Dr Rey Rodriquez Pilar (AIMEN, Spain)

Title : Performance Driven Design And Modeling Of Compositionally Complex AM AlCoNiFe Alloys

Keyword(s) :
Alloy Design; Micromechanics; Crystal Plasticity; Complex Alloys; Superalloy; Fatigue

Abstract :
Virtual of design of additively manufactured AlCoNiFe alloys enables optimization of material performance required at elevated operational temperatures. Compositional tailoring of the material leads to complex mixture of stable and metastable phase structures, which affect the engineering material properties. This focuses on the micromechanical modeling of AlCoNiFe alloy microstructures with crystal plasticity by utilizing preceding material design steps with Calphad analysis for the alloys suggested by neural network decision making. We evaluate key aspects of the material behavior such as strength|strain hardening, fatigue and creep responses.

Innovative Aspect(s) :
The work focuses on understanding the effect of different microstructures to desired material performance criteria such as strength|fatigue|creep, especially at elevated temperatures. Design of complex alloys enables achieve superior properties. However, calphad|ML design of the material phase structures does not guarantee good material behavior as it largely depends on the heterogeneous elasto-plastic-damage relationships at the microstructural scale; thus the work focuses on delivering a view to evaluate|rank different material options with respect to their microstructure using crystal plasticity approach. As a noteworthy remark, the materials are manufacture with additive manufacturing from the tailored powders. Some of the alloys are considered as superalloys, which introduces special needs for the used crystal plasticity models.

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EURO PM2023 CONGRESS & EXHIBITION

01-04 October 2023

Paper Number : EP235765090

Requested presentation type : Oral Presentation

Topic : Tools for improving PM **Subtopic :** Design and Modelling

Author : Mr Rajaei Ali (Institute for materials applications in mechanical engineering - RWTH Aachen University, Germany)

Co-author(s) : Prof Dr Broeckmann Christoph (Institute for materials applications in mechanical engineering - RWTH Aachen University, Germany)

Title : A Computational Approach To Determine The Load Bearing Capacity Of High Strength Sintered Gears

Keyword(s) :
Finite Element Modelling; Sintered Gears; Surface Densification; Case Hardening; Phase Transformations; Residual Stresses; Local Fatigue Strength; Multiaxial Fatigue Limit; Load Bearing Capacity

Abstract :
The performance of PM gears must be increased towards the level of the conventional high strength gears for a reliable application in automotive transmission. To this end, the potentials of the PM production of gears must be fully utilized. Surface densification and hardening of sintered gears are examples of economically plausible measures to increase the strength of these components. However, a comprehensive consideration of the strength-relevant parameters - such as geometry, porosity, hardness and residuals stresses - is required to define an optimized choice of particular material and process chain for higher gear strength. In this work, a computational approach is developed, which integrates the numerical modelling of the case hardening and the tooth loading, and the calculation of the load bearing capacity using different fatigue limit criteria. The results of the simulation are evaluated by comparing with available experimental findings.

Innovative Aspect(s) :
The innovation is provided due to the holistic nature of the calculation method. By predicting the hardness and residual stress profiles and taking the density profile into account, the influence of the variations in the surface sealing and heat treatment can be directly investigated numerically on the load-bearing capacity.

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EURO PM2023 CONGRESS & EXHIBITION

01-04 October 2023

Paper Number : EP235765189

Requested presentation type : Oral Presentation

Topic : Tools for improving PM **Subtopic :** Design and Modelling

Author : Prof Dr Cristofolini Ilaria (University of Trento, Italy)

Co-author(s) : Dr Zago Marco, Ing Uçak Onur Utku (University of Trento, Italy), Dr Vicenzi Bruno (EPMA, France), Dr Dougan Mark J. (AMES PM Tech Center SAU, Spain), Dr Schneider Markus (GKN Sinter Metals Engineering GmbH, Germany), Ing Pedersen Preben Hedegard (Sintex a|s, Denmark), Dr Voglhuber Juergen (MIBA Sinter Austria GmbH, Austria)

Title : Design For Sintering 2 Club Project - Anisotropy Of Dimensional Changes In The Compaction Plane As Affected By Compaction Strategy

Keyword(s) :
Anisotropic Dimensional Changes; Design For Sintering; Compaction Strategy

Abstract :
Design for Sintering 2 is an EPMA Club Project aimed at improving the previously developed design procedure accounting for anisotropic dimensional changes on sintering. Goal of the project is both enlarging the reference database through the fruitful cooperation of the industrial partners and investigating in depth the mechanisms responsible for anisotropic dimensional changes. This work is focused on the second part of the project, aimed at studying the influence of compaction parameters. Axi-symmetric parts characterized by different materials and geometrical parameters were produced at different green densities with different compaction strategies. Focusing the attention on the anisotropy in the compaction plane, dimensional changes were measured and evaluated, also relating them to the attainable dimensional tolerances. The influence of compaction strategy was analysed in depth, and for the different materials and geometries the more robust process conditions for dimensional precision were highlighted.

Innovative Aspect(s) :
Anisotropic dimensional changes in axial direction and in compaction direction are well known phenomenon in P&S, but anisotropy in dimensional changes in the compaction plane was scarcely investigated so far. The effect of anisotropy in the compaction plane is instead significantly affecting the precision of sintered parts, and it has to be considered in the design step.

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Keynote ☐ Oral ☐ 1☐ 2☐ 3☐ 4☐

Poster ☐ Poster & Reserve Oral ☐

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EURO PM2023 CONGRESS & EXHIBITION

01-04 October 2023

Paper Number : EP235765208

Requested presentation type : Oral Presentation

Topic : Tools for improving PM **Subtopic :** Design and Modelling

Author : Dr Ing Piotter Volker (Karlsruhe Institute of Technology (KIT), Germany)

Co-author(s) : Ing Klein Alexander, Miss Nguyen Thi Tra My, Ing Plewa Klaus, Mr Walter Heinz (Karlsruhe Institute of Technology (KIT), Germany)

Title : Particularities Of PIM Feedstock Properties Measurements

Keyword(s) :
PIM Simulation; Feedstock Flow Behavior; PIM Rheology; Simulation Verification

Abstract :
Precise and reliable simulation of Powder Injection Molding (PIM) process steps requires particular determination of material parameters. Compared to pure or low-filled polymers, however, feedstocks often show significantly different flow behavior.In this respect, recent investigations at KIT targeted the impact of Bagley pressure correction on simulation accuracy. Calculations were performed using corrected and non-corrected data followed by real injection molding experiments including pressure measurements during mold filling. As expected, precise simulation results could only be achieved if corrected pressure values were applied. In case of PIM feedstocks (50 Vol% filling of zirconia powder), however, simulation were correlated well to experimental results irrespectively whether the pressure data had been corrected or not. Conclusions on flow conditions during viscosity measurements, especially powder-binder segregation effects, will be proposed.

Innovative Aspect(s) :
Specialities of PIM feedstock flow behavior compared to pure or low-filled polymers. Simulation of PIM mold filling, differences to conventional plastics, all verified by real experimental results. In particular: Impact of Bagley correction on simulation accuracy depending on powder loading. Inferences on special feedstock flow behavior at rheologic characterization. Conclusions for improved PIM modelling.

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Keynote ☐ Oral ☐ 1☐ 2☐ 3☐ 4☐

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EURO PM2023 CONGRESS & EXHIBITION

01-04 October 2023

Paper Number : EP235765332

Requested presentation type : Oral Presentation

Topic : Tools for improving PM **Subtopic :** Design and Modelling

Author : Dipl-Ing Gaisina Vladilena (KTH Royal Institute of Technology, Sweden)

Co-author(s) :

Title : Modelling Shrinkage And Neck Evolution In Sintered Astaloy™ 85 Mo

Keyword(s) :

Abstract :
Porosity and interparticle neck size are microstructural parameters that play an important role for pressed and sintered materials. To understand the effect of sintering parameters such as time and temperature on the microstructure of a pre-alloyed sintered steel (Astaloy™ 85 Mo), a mean-field modelling approach tracking the neck size and density evolution during sintering is developed in combination with experimental studies of microstructure and the use of thermodynamic databases. Building upon a mathematical framework describing the geometrical changes in equisized particles with multiple contacts, due to the diffusion mechanisms active during solid-state sintering, the influence of sintering conditions on various aspects of particle and neck geometry is investigated. To calibrate the model, experimentally evaluated shrinkage and observed microstructures of Astaloy™ 85 Mo are also studied.

Innovative Aspect(s) :
Incorporating diffusion data from thermodynamic database (Thermo-Calc) in a sinter model with exact spherical geometry to study the evolution of sinter necks and particles that could in theory be applied to a range of compositions.Calibrating model against real commercial material and comparing the monosized model applicability for different particle size distributions.Discussion of how a literature model for the sintering of loosely compacted powder can be adapted to pressed materials with pre-existing flat contacts sintered at higher densities by considering the impact of interparticle contact on diffusion.

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EURO PM2023 CONGRESS & EXHIBITION

01-04 October 2023

Paper Number : EP235765361

Requested presentation type : Oral Presentation

Topic : Tools for improving PM **Subtopic :** Design and Modelling

Author : Mr Deng Yuanbin (RWTH Aachen University, IWM, Germany)

Co-author(s) : Dr Ing Kaletsch Anke, Prof Dr Broeckmann Christoph (RWTH Aachen University, IWM, Germany)

Title : Digital Twin Of The Binder Jetting Manufacturing Route From Powder To Component

Keyword(s) :
Binder Jetting; Discrete Element Method; Finite Element Method; Simulation; Digital Twin

Abstract :
Binder jetting is ideally suited to produce individual components, as it offers the possibility to directly achieve highly complex geometries. To assure the direct production of net-shape components with optimized process parameters, numerical models across scales were developed in this study to model and simulate each manufacturing step on the entire process chain. Using discrete element and finite element methods, the powder spreading process and the subsequent sintering process were simulated. By considering the influences of the density distribution on green bodies, the gravity, and the friction between the sintering substrate and the sintering parts, the sintering shrinkage and the final geometry could be precisely predicted. The simulation models were validated by comparison with the experimental data. With the help of the inverse optimization, the geometry of the green parts was optimized iteratively, which allows the net-shape components with the desired geometries being manufactured despite sintering distortion.

Innovative Aspect(s) :
The digital twin of the binder jetting process was applied in the product development. It allows the manufacturer to prototype a product virtually before real production. The simulation of each manufacturing step helps to achieve net-shape components with desired geometries and microstructure at the same time to save time and resources.

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EURO PM2023 CONGRESS & EXHIBITION

Technical Programme Committee
15th February 2023

TOOLS FOR IMPROVING PM

HEALTH & SAFETY

EPMA
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EURO PM2023 CONGRESS & EXHIBITION

01-04 October 2023

Paper Number : EP235765510

Requested presentation type : Oral Presentation

Topic : Tools for improving PM **Subtopic :** Health & Safety

Author : Dr Mellin Pelle (Swerim AB, Sweden)

Co-author(s) : Ms Nilsson Åhman Hanna, Dr Götelid Sareh (Swerim AB, Sweden), Mrs Danielsson Ulrika (Siemens Energy AB, Sweden), Mr Lidman Henrik (Befesa Scandust AB, Sweden)

Title : Microscopy Of Airborne Powder And Dust Particles, Captured Using A Bio-Pump Plus

Keyword(s) :
Airborne Metal Powder; Health; Safety; Microscopy

Abstract :
In this work a Zefon Bio-Pump Plus, from Cole-Parmer, was used to capture airborne metal powder and dust particles on a sticky surface. The sticky surface coats a glass slide, which is enclosed in a cheap premade cassette called Air-O-Cell. The method is optimized for capturing fungal spores, but herein we show that metal powder particles can be captured as well. SEM-EDS enable identification of the alloy that constitutes the captured particles. SEM-EDS first requires heat treatment of the Air-O-Cell cassettes; we found that 30 minutes in vacuum, at 80 °C, works well. Using the method, we found airborne powder particles in the range of 1-10 µm, in a workshop handling large quantities of L-PBF powder (15-45 µm). Such 1-10 µm particles are present in L-PBF powder despite the label. We also successully identified the correct nickel-base alloy using EDS.

Innovative Aspect(s) :
This is completely new research on an untested method, which could be useful for EHS improvements at metal powder producers and users of metal powder.

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EURO PM2023 CONGRESS & EXHIBITION

Technical Programme Committee
15th February 2023

TOOLS FOR IMPROVING PM

SUSTAINABILITY & LIFE CYCLE ANALYSIS

EPMA european powder metallurgy association

EURO PM2023 CONGRESS & EXHIBITION

01-04 October 2023

Paper Number : EP235761105

Requested presentation type : Oral Presentation

Topic : Tools for improving PM **Subtopic :** Sustainability & Life Cycle Analysis

Author : Dipl-Ing Reijonen Joni (VTT Technical Research Centre of Finland Ltd, Finland)

Co-author(s) : Mr Silva Juan, Mr Puukko Pasi, Dr Metsä-Kortelainen Sini (VTT Technical Research Centre of Finland Ltd, Finland), Mr Pulli Oskar, Mr Hahtonen Kasper, Mr Ulkuniemi Jari, Mr Niskanen Jari (University of Oulu, Finland)

Title : Comparative Life Cycle Inventory Of PBF Additive Manufacturing And CNC Machining

Keyword(s) :
Powder Bed Fusion; CNC-Machining; LCI; Sustainablity

Abstract :
Additive manufacturing is often referred to as resource-efficient or even sustainable manufacturing with very little reliable scientific data to support the claims. Here we have made a comparative life cycle inventory of the energy and raw material flows during PBF AM and CNC machining of three components having different geometrical features and functionalities: gear, impeller and manifold. The scope of this study was on the manufacturing phase of the components (from gate-to-gate). The energy and material consumptions were measured, with emphasis on providing accurate, transparent and reliable data of the most important input flows through direct measurement. For all the three studied components, PBF consumed more energy, but required less material, than CNC machining. Geometry of the component had the most significant impact on the energy and material consumption in these processes. Optimizing part geometry and process parameters in PBF to minimize resource consumption showed much potential for improvement.

Innovative Aspect(s) :
In this study we have conducted accurate, transparent and reliable collection of data for the most important input flows (energy, gas and raw material consumption) for the manufacturing processes through direct measurement. This is valuable for conducting reliable life-cycle analyses for components made with PBF or CNC machining. We have studied the effect of the part geometry on the input flows and show, that the geometry is the most important factor influencing the result. The functional unit of comparison should be therefore a geometry that fulfills the intended functionality of the component - not kg of part produced as often used in previous studies. In PBF, the layer thickness, part nesting and orientation was found to have significant impact on the consumption of resources. Furthermore, we have studied the effect of post processing (EDM, CNC) on the total input consumption during PBF manufacture, which is often neglected by previous studies.

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EURO PM2023 CONGRESS & EXHIBITION

Technical Programme Committee
15th February 2023

TOOLS FOR IMPROVING PM

DIGITIZATION

EPMA
european powder metallurgy association

EURO PM2023 CONGRESS & EXHIBITION

01-04 October 2023

Paper Number : EP235762920

Requested presentation type : Oral Presentation

Topic : Tools for improving PM **Subtopic :** Digitization

Author : Dr Hein Sebastian Boris (Fraunhofer IFAM, Germany)

Co-author(s) : Mr Sandmann Malte, Mr Gerken Felix, Mr Cogotti Andrea, Miss Reineke Lea (Fraunhofer IFAM, Germany)

Title : Integration Of In Situ Measurements To Monitor The Print Process In MBJ

Keyword(s) :
Metal Binder Jetting; In Situ Measurement; Powder Spreading; Powder Bed Temperature; Powder Binder Interaction; Green Part Density; Green Part Strength

Abstract :
Metal Binder Jetting (MBJ) gains increasing industrial attention due to its serial production potential. In order to tap the full potential of MBJ, a deep process understanding is crucial. The aim of this work is to gain a deeper insight of the influence of process parameters on the powder spreading and powder bed heating by using in situ measurements, as a way to create a basis for real-time process control and optimization. This is achieved by generating images of the powder build-up in front of the spreading roller and thermal imaging of the powder bed for each layer. An automated image processing was developed to examine the powder build-up, and the green part properties were evaluated with different powder heating settings respectively. A proper control of the powder spreading and powder bed temperature positively influences powder binder interaction and green part properties, while minimizing the scrap rate.

Innovative Aspect(s) :
The innovation of this work is the development of in situ measurement methods to quantify the impact of equipment settings regarding powder spreading and drying.

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