Microstructure evolution of alloys during additive manufacturing

Matthias Markl, FAU, Germany

Carolin Körner, FAU, Germany

Additive Manufacturing technologies are widely applied and researched in different engineering fields. The microstructure of manufactured parts mainly influences the resulting thermo-mechanical properties. During the process the material is typically exposed to severe thermal loads, undergo phase transitions and can change its microstructure after solidification, depending on the process conditions. In order to understand the microstructure evolution of alloys during additive manufacturing processes and the response of additively manufactured parts after the process, versatile models have to be developed. Hereby, the subsequent material addition, transient temperature gradients, remelting of previous layers, melt pool dynamics, grain selection and nucleation as well as solid phase transformations are challenging issues for the prediction of the microstructure evolution.

This invited session aims to bring together scientists from different disciplines working on modeling the microstructure evolution of alloys and its effects on manufactured parts in the context of additive manufacturing.

Additive manufacturing for biomedical applications

Michele Conti, Università di Pavia, Italy

Michele Marino, University of Hannover, Germany

The session aims to update and connect researchers and users in the field of additive manufacturing for biomedical applications, highlighting the role of computational approaches for the better design of printing protocols and printed parts. Discussions on available technologies for clinical or tissue engineering applications, as well as on the characterization of biomaterials, will be promoted. The session aims to promote the integration of the overall production process, with a particular insight on the possibilities offered by *in silico* approaches for design and verification. In particular, contributions on the following specific topics of interest are welcomed:

- Patient-specific additive manufactured prostheses and implants: real cases and clinical evidence;
- Strategies for improving the biocompatibility of additive manufactured implants via surface modifications;
- Design and modelling of additive manufactured scaffolds for tissue engineering;
- Multiscale and multiphysical computational approaches for simulations of 3D bioprinting.

Modeling and simulation of powder bed additive manufacturing processes

Laura De Lorenzis, Technical University Braunschweig, Germany

Stefan Kollmannsberger, Technical University Munich, Germany

Ernst Rank, Technical University Munich, Germany

Among additive manufacturing technologies, powder bed processes, the best known examples being selective laser melting, electron beam melting, and selective laser sintering, represent a particularly difficult challenge for the analyst, due to the multi-field and multi-scale nature of the required models and simulations. This minisymposium welcomes contributions on models and computations related to this category of additive manufacturing processes. Topics include (but are not limited to) basic aspects of multifield (e.g. thermomechanical) and multi-scale formulations (from the powder-scale to the scale of the printed component), numerical implementation aspects, as well as relevant calibration/validation experiments.

Mathematical methods for optimal design of structures

Matteo Giacomini, Politecnico di Milano, Italy

Simona Perotto, Politecnico di Milano, Italy

Recent advances in 3D printing techniques have opened new opportunities for the production of structures not manufacturable with standard subtractive procedures. Fields of interest in such a direction involve, for instance, building and architectural engineering, automotive and space industry and prosthetic medicine.

The actual challenge is represented by the possibility of manufacturing structures optimized with respect to a target quantity of interest for the specific field of application. In this context, mathematical and numerical studies have allowed a significant contribution to the understanding and enhancement of additive manufacturing procedures. In particular, shape and topology optimization as well as homogenization techniques have experienced a growing interest in frontier academic and industrial research.

Goal of this session is to provide the state-of-the-art of recent mathematical methods and numerical algorithms for optimal design of structures, including (but not limited to) level-set, phase-field and density based approaches. This session is also expected to address practical issues such as manufacturing constraints and design under uncertainties, with possible contributions by industry and software companies.

Advanced numerical techniques for efficient multiscale analysis of AM processes

Joris J.C. Remmers, TU Eindhoven, Netherlands

The simulation of additive manufacturing (AM) processes often spans a wide range of time- and length scales. For most materials and AM techniques, the actual printing process takes places at the sub millimeter length scale and with specific times in order of seconds. This is in sharp contrast with the dimensions of the actual product which can be up to several meters and building times that can reach several hours to even days.

In order to accurately and efficiently simulate these processes, taking into account both material phase transitions at the microscale as well as the structural effects such as the evolution of residual stresses and geometry defects, advanced numerical techniques are required.

This session focuses on the development and application of numerical techniques to reduce the computational effort to enable an accurate analysis of the printing process. The authors are invited to submit their contributions on the following topic:

- Computational homogenisation schemes
- Model order reduction techniques
- Multigrid methods
- Adaptive discretisation techniques
- Machine learning algorithms

New trends in 4D printing

Giulia Scalet, Università di Pavia, Italy

Stefano Pandini, Università di Brescia, Italy

The so-called four-dimensional (4D) printing, which synergically combines flexibility in fabrication of objects with complex shapes and the possibility to change such shapes in response to an external stimulus, may be regarded as a frontier in the advancement of both 3D printing and stimuli-responsive material researches, and their related applications. Various backgrounds, ranging from advanced technology to material science, from mathematical modelling to thermo-mechanical testing, may contribute to the development of such research field, as well as the potentialities are manifolds.
The special session is intended to cover the last advances in 4D printing, bringing together specialists in different disciplines. Session themes will include, but will be not limited to, experimental methods, innovative materials, mathematical modeling, numerical simulations, and applications to diverse areas in engineering, medicine, robotics.

Topics:

- Innovative application;
- Material modeling;
- Multi-physics and multi-scale simulation;
- Validation and verification

Topology and shape optimization for AM-ready design

Albert To, University of Pittsburgh, USA

Fred van Keulen, TU Delft, Netherlands

Oliver Weeger, Singapore University of Technology and Design, Simgapore

Gengdong Cheng, Dalian University of Technology, China

Junji Kato, Nagoya University, Japan

Ole Sigmund, Technical University Denmark, Denmark

Additive Manufacturing (AM) and Topology Optimization (TO) may constitute a perfect marriage. AM provides the geometrical freedom to realize efficient but complex geometries coming out of TO. Nevertheless, the couple must adapt to each other's weak or challenging points. Also, the complex and multidisciplinary nature of design for AM need a wide range of developments requiring involvement of mathematicians, applied mechanicians and numerical specialists. Outstanding topics include but are not limited to:

- Efficient/simplified AM modelling schemes for incorporation in TO and shape optimization
- Design-rule based constraints and their incorporation in TO and shape optimization
- Post-processing of TO results for AM
- Automated support design
- Automated infill strategies
- Including process settings and anisotropies in TO
- Multifunctional design for AM
- How to meet industrial requirements (computation time, resolution)

The Invited Session aims at bringing together researchers and developers from academia and industry to discuss state-of-the-art and future needs in this rapidly growing field.

Thermal modelling in AM

Can Ayas, TU Delft, Netherlands

For AM to reach its full potential and further increase permitted design freedom, realisation of defect free parts with high dimensional accuracy and microstructural control are required. Control on all three considerations are dictated by the temperature evolution within the part during the AM process. The scope of this session will be thermal and of the AM process. Analytical and numerical models at the different length and time scales with different level of detail, computational methods and computational efficiency, temperature micro-structure relations, in-situ pyrometry, infra-red imaging for temperature measurements and validation of models are all in scope.

Simulation and Fatigue in metal Additive Manufacturing

Gianni Nicoletto, University of Parma, Italy

Nicolas Saintier, ENSAM Paris, France

Qualification of metal parts produced by additive manufacturing for critical load-bearing applications has to deal with many effects that potentially influence fatigue performance. The effects of surface quality, internal defects, local microstructure heterogeneity and anisotropy and residual stresses can be cited among others. The identification and mechanistic basis of the physical processes leading to crack nucleation and growth across the length scales (from micro to macro) are still major issues in many engineering fields and the establishment of quantitative prediction remains a key research challenge. While experiments provide irreplaceable insight into the link among AM process, material and performance, behavioral models and tools supporting AM part design in fatigue are expected from simulation and modeling activities. This session aims to bring together scientists and engineers addressing fatigue research utilizing experimental and modeling approaches (ideally integrated) including, but not restricted to :

- AM process - microstructure - fatigue interaction modeling
- Surface-related fatigue damage modeling
- Modeling of residual stress effects on fatigue damage and crack growth
- Multiaxial fatigue life prediction
- Fatigue crack growth under complex (including non-proportional) loadings
- Life prediction methodologies for metal AM parts
- Fatigue of meta-materials and lattice structures

Numerical modeling of cement-based elements and systems made by digital fabrication

Domenico Asprone, Università di Napoli Federico II, Italy

Costantino Menna, Università di Napoli Federico II, Italy

Leopoldo Angrisani, Università di Napoli Federico II, Italy

Recent developments in additive manufacturing, digital design, robotics, as well as in the engineering of cementitious materials, have fostered the implementation of new automated fabrication methods in construction industry, collectively known as *Digital Fabrication*. Digital fabrication processes for fabricating concrete-like products, objects and/or structures include three main categories: (i) Layered Extrusion, (ii) Binder Jetting, (iii) Slip-forming. To date, many important developments have been accomplished for layered extrusion technology, consisting in a digitally controlled moving printing head (or nozzle) that precisely lays down the concrete or mortar material layer-by-layer.
The engineering challenges associated with Digital Fabrication processes mainly regard physical and rheological requirement for concrete (including pumpability, extrudability, buildability), mechanical properties determination for hardened digitally fabricated elements, design strategies as well as the control of fabrication-related particularities, such as cold joint, anisotropy etc.

The main objective of this session is to collect current knowledge about numerical simulation strategies related to specific production routes offered by the different digital fabrication technologies. In particular, the following topics will be covered:

- rheology modeling of cement-based materials used in digital fabrication;
- modelling of the structural behavior of digitally fabricated elements (e.g. analytical formulations, numerical etc.);
- modeling of the constitutive behavior of printing materials and hardened structures;
- numerical modeling of production related peculiarities (e.g. anisotropy, cold joint, weak directions etc.);
- topology optimization strategies for concrete structures;
- reinforcement modeling in terms of scale of application and interaction with concrete.

Volumetric spline representations and Isogeometric Analysis for Additive Manufacturing

Tor Dokken, SINTEF, Norway

Gershon Elber, Technion, Israel

The emerging V-rep (Volumetric representation) technology for shape representation is based on structures of trimmed tri-variate spline blocks. The representation is well suited for the representation of variable/graded materials and anisotropic material properties integral in AM processes. V-rep is fundamentally different from traditional CAD-technologies, which only represent the boundaries of an object (B-rep). In B-rep CAD, it is assumed that the material is uniform all throughout an object, so only the surfaces must be represented. In Isogeometric Analysis (IgA), traditional shape functions used in Finite Element Analysis (FEA) are replaced by B-splines. Thus, V-rep opens for simulation in AM, based on the accurate shape representation of V-rep based CAD, and the use of higher order elements offered by IgA. This allows the execution of design and analysis operations on the same geometric representation. The mini-symposium aims at addressing solutions and challenges related to the use of V-rep and IGA for solving AM-challenges, including in the context of heterogeneous materials and porous/microstructures geometry.

Simulation in the design of AM devices

Hermes Giberti, Politecnico di Milano, Italy

In recent years, Additive manufacturing is changing production methods, creating new market niches and transforming the design methodologies of parts and their assembly.

In order to take advantage of all the opportunities offered by the wide range of additive production techniques, one needs to direct the scientific research towards the study of simulation in the processes involved in production and the topological optimisation of the components realized through this technology.

In this new technological context, the device used to implement the technology and the control structure used to ensure the precise movement thereof should not be neglected. As is well known, in the majority of cases 3D printers were derived by adapting mechanical designs, drives and controls previously developed for generic machine tools.

In order to improve the quality and the rapidity of the production an in depth analysis of the entire system is required. Simulation can be also used to take into account all these aspects with particular focus on mechatronic design.

In this special section the topics relating to design procedure, simulation of the entire production machine, as well as the evaluation of the effects in changing the control algorithms and more generally the so called digital twin creation of the production system are discussed.

The authors are invited to submit their contributions on the following topics:

- Simulation guided design of an additive manufacturing device
- A priori analysis of repeatability and accuracy
- Digital twin technologies for AM
- Mechatronically based approaches for AM

Modeling and Simulation of Advanced Manufacturing of Functional Materials

Giulia Scalet, Università di Pavia, Italy

Mohammad Elahinia, University of Toledo, Spain

Manufacturing and processing of functional materials, such as shape memory alloys (SMAs), high temperature shape memory alloys, magnetic shape memory alloys (MSMAs), magnetocaloric materials, magnetostrictive materials, functional ceramics, and so on, is heavily focused on traditional casting, thin film deposition and single crystal-growth-based techniques. With the rise of advanced manufacturing techniques such as additive manufacturing (AM, also known as 3D printing), advanced sputtering techniques and others, functional materials manufacturing, processing, characterization and modeling is changing in a similar way as for other materials now manufactured with new advanced techniques with all its advantageous and disadvantages.

This symposium seeks fundamental as well as application related contributions in the field of modeling and simulation of additive manufacturing for functional materials.

Areas of interest would especially include modeling and simulation:

- to predict the functional properties of the resulting alloys
- to simulate the fabrication and processing methods
- to assess the microstructural characteristics

Topics:

- Innovative application
- Material modeling
- Multi-physics and multi-scale simulation
- Simulation for different AM technologies
- Validation and verification

Advanced Simulation Technologies in Additive Manufacturing

Davide Baroli, University of Luxembourg, Grand Duchy of Luxembourg

Stéphane Bordas, University of Luxembourg, Grand Duchy of Luxembourg

Bernhard Peters, University of Luxembourg, Grand Duchy of Luxembourg

Additive manufacturing has only recently emerged as one of the most promising technology for manufacturing structures and rapid prototyping of new composite materials eliminating tooling costs, enabling products to be customized for niche markets or even individual customers, reducing the spare part supply chain, and allowing parts to be combined to reduce assembly costs. Products based on additive manufacturing span a large range of applications such as lightweight components for the aerospace and automotive industry, composite materials or patient specific implants for medical applications and pharmaceutical applications.
In order to optimization, assess the life cycle of smart material and the various processes in additive manufacturing and underlying physics, versatile simulation technologies have to be developed to understand the influence of many governing parameters, rheology model and toxicity on the final quality of the final part.

The mini-symposium aims at bringing together engineers and researcher from the applied e.g. industry and scientific community and providing a lively exchange of ideas regarding state of the art and future needs for simulation technologies in additive manufacturing.

Therefore, topics of the mini-symposium on “Advanced Simulation Technologies in Additive manufacturing” in the broad sense will include:

- Material and composite design
- Life Cycle Assessment
- Concurrent Multiscale formulation
- Multi-physic approaches
- Numerical methods and implementation issues
- Shape Optimization
- Industrial applications

Efficient approaches for simulating additive manufacturing

Lars-Erik Lindgren, Luleå University of Technology, Sweden

Andreas Lundbäck, Luleå University of Technology, Sweden

Albert To, University of Pittsburgh, USA

Simulating the addition of material powder/wire and the motion of the heat source in detail may be prohibitive expensive w.r.t. to required computational resources.
Contributions concerned with various simplification approaches like inherent strain, lumping of layers/welds, instantaneous heating of layers, hybrid methods etc.
Papers dealing with various numerical approaches when applied to the process are also welcome.