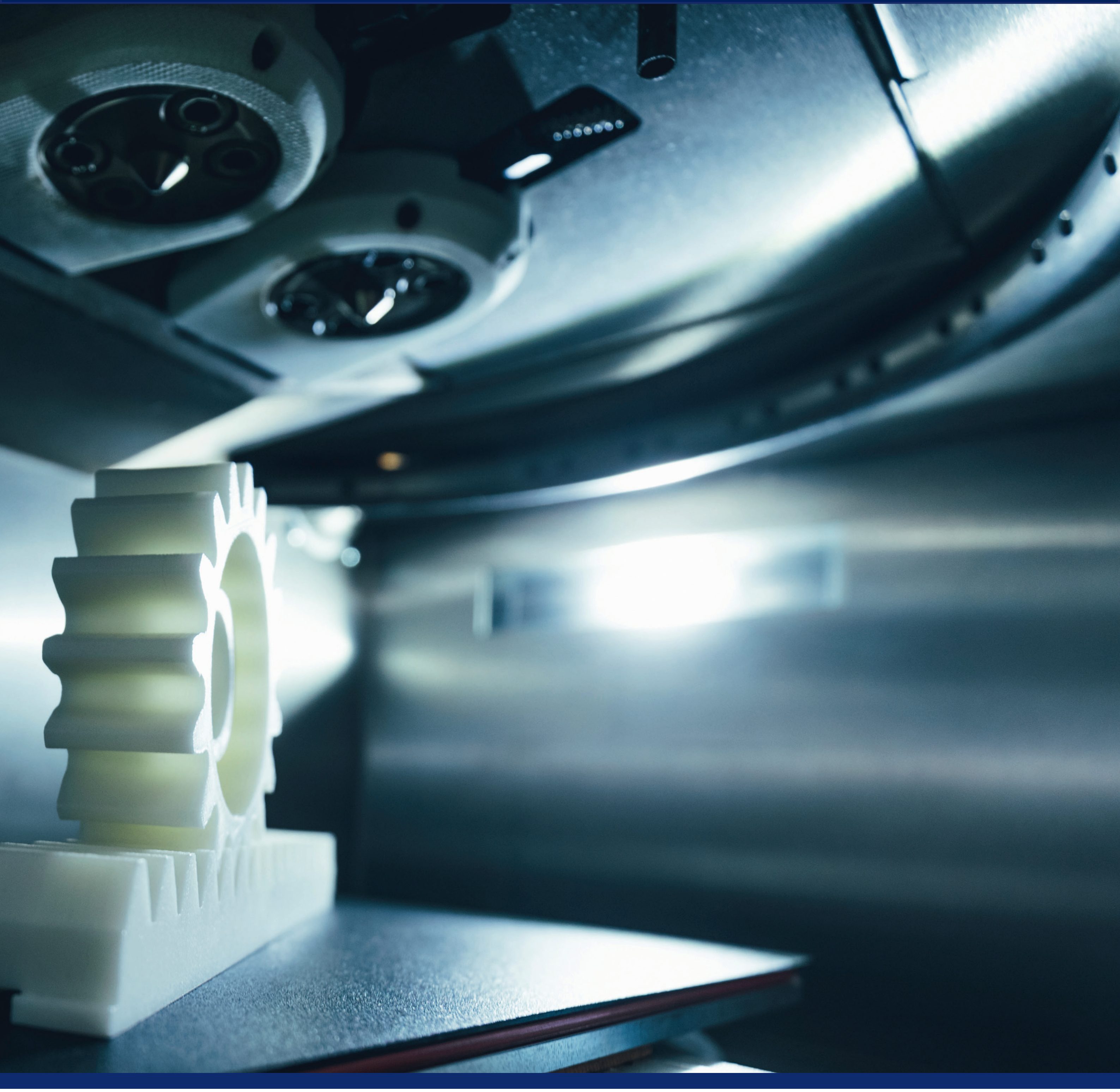
DMRC

ACADEMIC · PADERBORN UNIVERSITY

RESEARCH
INNOVATION
EDUCATION

Report 23/24



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Sources
Page 4, 33, 129, 84, 90, 114 - Designed by pikisuperstar/ Freepik”

FOREWORD

Dear members and friends of the DMRC,

it is with great pleasure that we present the annual report of the DMRC - Academic, reflecting a year of significant transformation and progress. Following our renaming last year, the DMRC - Academic has embraced structural changes to better align with our renewed focus on securing publicly funded joint projects and fostering interdisciplinary cooperation among our academic chairs. Interdisciplinary collaboration has become a cornerstone of our approach, enabling us to tackle multi-faceted challenges more effectively. By leveraging the diverse expertise within our institute, we are able to tackle large-scale projects that benefit from a holistic perspective.

Despite these changes, our commitment to close collaboration with industrial consortia remains strong. The DMRC continues to participate in application-oriented and commissioned research projects to ensure that our work remains relevant and impactful in real-world applications.

We are pleased to be able to report that our equipment pool has grown again in the last year. In addition to an Intamsys Funmat Pro 310, we have also purchased a new large-format granulate fed printer from Q.Big 3D. The gigantic print volume of 1.87 m³ enables us to carry out really "big" projects.

Furthermore, we continued to invest in education and training in the field of additive manufacturing. In this context, our student workshop, the StudentLab3D, received numerous new printers from Prusa last year, including the new Prusa XL for multi-color and multi-material printing. We have also expanded our range of lectures and, together with the VDI, are offering a new course in the certificate program for further training of engineers in the field of additive manufacturing.

We wish you much joy reading this report and sincerely thank you for your continued support.

Sincerely,
Ivo Kletetzka, Christian Elsner and Hans-Joachim Schmid

SCIENTIFIC DIRECTOR

Prof. Dr.-Ing. Hans-Joachim Schmid

MANAGING DIRECTOR

Christian Lennart Elsner, M.Sc.

Ivo Kletetzka, M.Sc.

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MOTIVATION AND AIM

Additive manufacturing processes create parts in layers and without using formative tools. In recent years, a large number of industry-relevant processes and materials have been developed. This technology may have a highly disruptive character in many industries. Additive manufacturing processes offers many benefits like:

- **Design freedom**: Shapes can be designed and manufactured that cannot be handled with established technologies.
- **Material freedom**: Material properties, which arise as a function of the raw material and the process parameters, can be influenced. Gradient material structures are possible.
- **Economic freedom**: Additive manufacturing decouples the part manufacturing costs from the part quantity and the part complexity.

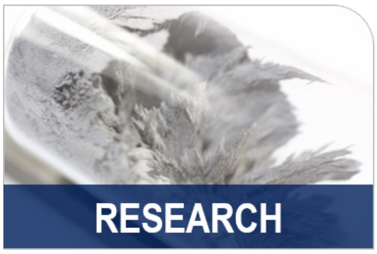
Because these freedoms often exceed the freedoms provided by established manufacturing technologies, additive manufacturing can create various and great benefits to its users. Contrary to this, it is recognized that the technology is mainly used at technology leading companies and research institutes. Small and midsized companies do hardly participate from the benefits. These limitation factors seem to reason this imbalance:

- Advantages are often unknown: Possible users do not know where additive manufacturing can gain benefits especially for them.
- Additive manufacturing is not widely integrated in the education of the related professions yet.
- Risks are often unknown: New users cannot seriously identify and rate possible (financial and technical) risks that come along with the technology.

Motivated by this significant imbalance between the provided possibilities and the weak usage of the technology the DMRC – Academic has the aim to develop additive manufacturing towards an industrial established production process.

AIM

Developing additive manufacturing toward an industrial established production process by means of internationally outstanding contributions in….



INVOLVED CHAIRS AND INSTITUTES

FACULTY OF MECHANICAL ENGINEERING

Automotive Lightweight Design

Prof. Dr. rer.nat
T. Tröster

Materials Science

Prof. Dr.-Ing. habil.
M. Schaper

Fluid Process Engineering

Prof. Dr.Ing.
J. Riese

Data Management in Mechanical Engineering

Prof. Dr.-Ing.
I. Mozgova

Design an Drive Technology

Prof. Dr.-Ing.
B. Magyar

Heinz Nixdorf Institute (HNI)

Prof. Dr.-Ing.
I. Gräßler

Applied Mechanics

Prof. Dr.-Ing. habil.
G. Kullmer

Particle Technology Group

Prof. Dr.-Ing.
H.-J. Schmid

Plastics Processing

Prof. Dr.-Ing.
E. Moritzer

Plastics Processing

Prof. Dr.-Ing.
V. Schöppner

FACULTY OF SCIENCE

Technical & Macro Molecular Chemistry

Prof. Dr.-Ing.
G. Grundmeier

FACULTY OF COMPUTER SCIENCE

Database & Information Systems

Prof. Dr.
G. Engels

ADMINISTRATION DMRC - ACADEMIC

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STRUCTURE OF THE DMRC - ACADEMIC

In order to further implement additive manufacturing, new and complex challenges need to be addressed on an ongoing basis. These challenges in turn encompass very different disciplines, which need to be fully considered: Materials science, particle technology, process expertise, mechanics, applications, design, software support and business, to name just a few. Covering these disciplines requires an in-depth understanding that is difficult to achieve through a single chair. For this reason, the Direct Manufacturing Research Center (DMRC) – Academic (formerly the Paderborn Institute for Additive Manufacturing (PIAF)) is guided by two principles - interdisciplinarity and flexibility.

To fulfill these requirements, we are structured in different layers organized around the Paderborn University. The Paderborn University with over 16,000 students and its five faculties builds the basis for all additive manufacturing related activities. As a central scientific institution, a total of 11 chairs at Paderborn University are working together at the DMRC – Academic in the field of additive manufacturing. Based on the knowledge that access to transdisciplinary research and innovation has become an indispensable competitive factor in additive manufacturing, the Direct Manufacturing Research Center (DMRC) – Academic participates in innovation projects with partners from science and industry. The tasks of the DMRC – Academic consist of inter-faculty and interdisciplinary cooperation, especially in research, teaching, the qualification of young scientists and the transfer of knowledge and technology in the field of additive manufacturing processes. In addition, the transfer of knowledge and technology between science and industry is also part of the tasks. Research at DMRC – Academic is characterized by the fact that research results are achieved through intensive cooperation between the chairs, institutes, and other research centers. The DMRC – Academic represents the AM related academic part of the Paderborn University. Public funded research projects are conducted by this organizational unit. The research activities range from basic research to application-oriented research projects.

Furthermore, the DMRC – Academic works closely with a network of industrial partners. Stakeholders from the whole AM process chain have united here and define a strategic research agenda. In cooperation with the DMRC – Academic, the industry network defines common research projects mainly in the field of precompetitive research. Due to the strong industrial background these projects are mainly application-oriented research projects. The companies driving these projects are often enabled to directly utilize these results in their commercial activities. The additive manufacturing research projects are carried out at the Paderborn University, coordinated by the Direct Manufacturing Research Center (DMRC) – Academic.

Advisory board of the DMRC – Academic

WORKING GROUPS & COMMITEES

The DMRC is actively participating in different standardization committees and industry related working groups to foster this process.

VDI FA 105 "Additive Manufacturing" – This committee started in 2003 and is focused on different additive manufacturing technologies. DMRC participates in the sub-committees regarding Plastics (FA105.1), Metals (FA105.2), Design for Additive Manufacturing (FA105.3), Legal aspects of Additive Manufacturing (FA105.5) and Safety aspects of Additive Manufacturing (FA105.6).

VDMA Additive Manufacturing – Automation. The superordinate committee targets at the whole chain of production and brings together industry and research institutes.

FVA AK Controlled electric drive – the working group is focused on applications regarding controlled electric drives.

FVA AK Additive Manufacturing – it aims at uncover new application potentials of AM in the field of drive train applications.

DVS FA 13 is a committee regarding Additive Manufacturing (metal and non-metal materials) along the whole process chain, including pre- and post-processing. Technology development, user acceptance and access to further application areas is in the center of interest the whole drive train.

BDLI – German Aerospace Industries Association – Additive Manufacturing in Aerospace (AMIAS). AMIAS is a working group consiting of the key stakeholders of the german aerospacce industry. The DMRC actively takes part in teh woriking groups design and process chain & quality.

Mobilty goes Additive – is the an international network of companies, institutions and research institutes working on industrial additive solutions. The DMRC is engaged in the working groups education and materials.

WORKING GROUPS

BDLI
The German Aerospace Industries Association
- Working groups: Design, process chain and quality, polymers

DIN
German Institute for Standardisation
- Committee: Additive Fertigung – Kunststoffe & Elastomere

DVM
German Association for Materials Research and Testing e.V.
- Committee: Additive Manufacturing

DVS
German Association for Welding and Allied Processes
- Committee: Additive Manufacturing process

FVA
Research Association for Drive Technology e.V.
- Committee: Additive Manufacturing in drive train applications

Mobility goes Additive e.V
- Working groups: Education, materials and medical

VDI FA 105.1
Association of German Engineers
- Committee: Additive Manufacturing – Polymers

VDI FA 105.2
Association of German Engineers
- Committee: Additive Manufacturing – Metals

VDI FA 105.3
Association of German Engineers
- Committee: Design for Additive Manufacturing

VDI FA 105.5
Association of German Engineers
- Committee: Legal aspects of Additive Manufacturing

VDI FA 105.6
Association of German Engineers
- Committee: Safety aspects of Additive Manufacturing

VDMA
German Association of Machine and Plant Builders
- Working group: Additive Manufacturing – Automotion

PARTNER & NETWORKS

We believe that collaboration and networks open up opportunities that could not be achieved individually. The DMRC - Academic therefore collaborates closely with external players in various constellations. These include jointly funded pre-competitive research projects with our industrial partners, large consortia in publicly funded research projects and bilateral projects. Our close cooperation with AM experts from industry ensures that our research results have real-world relevance.

Quote from Falk Heilfort, Porsche AG: "Thanks to the open and agile collaboration in overarching cooperation projects or also bilaterally, we can develop the basic principles necessary for us and incorporate them into our projects. Access to publicly funded projects also gives us the opportunity to put the foundations on a broad basis."

ADVANTAGES OF COLLABORATING WITH THE DMRC – ACADEMIC

- Access to large industrial consortia in publicly funded research projects
- Benefit from collaboratively funded research and exchange at DMRC networking events
- Cooperate with recognized AM-Experts from industry and academia
- Get access to our state of the art of production & test equipment - use the DMRC as an „extended workbench"
- All our partners can promote student theses over the DMRC. These will be supervised by the DMRC staff.
- Recruit qualified employees which are experts in additive manufacturing (Students / Scientific Staff / PHD's)
- We are a solution provider offering a flexible and interdisciplinary structure
- Benefit from 15 years of experience in additive manufacturing & get access to our knowledge base

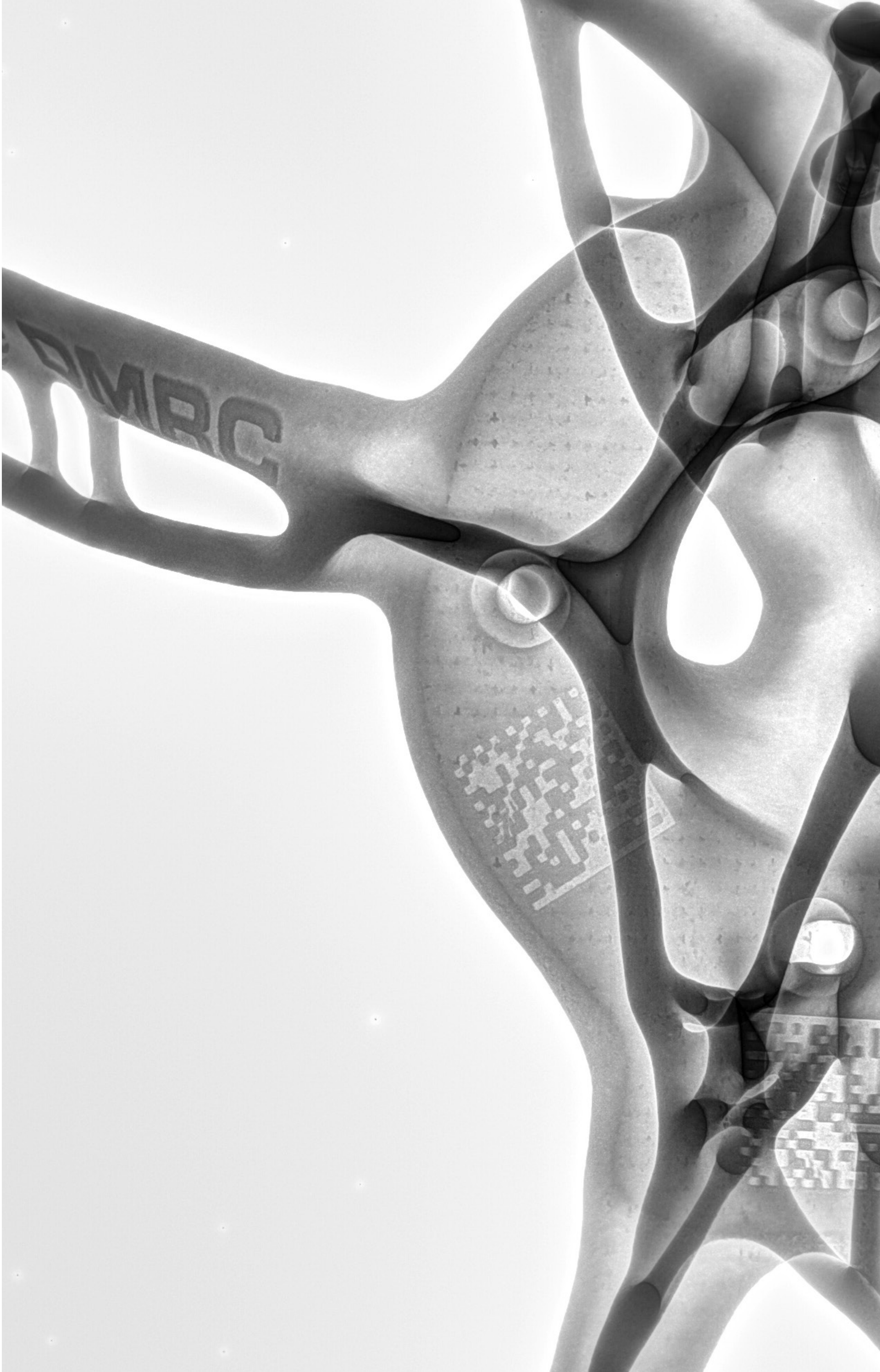
EQUIPMENT

Performing cutting-edge research and innovation does not only require a band of excellent researchers, it also presupposes an appropriate laboratory, which is equipped with a variety of the latest manufacturing technologies and modern measurement devices. To fulfil this task, the DMRC provides in total a vast number of industrial relevant manufacturing machines from six different technologies and material types. This capacity is enriched by a large number of mechanical, optical, geometrical and physical measurement equipment.

This equipment will continuously be updated and expanded depending on the technological developments. The DMRC has e.g. invested into test rigs to investigate further aspects of the future electro mobility, into an optical scanning head for the coordinate measurement machine, and further equipment for the preparation of our test specimens. In the DMRC laboratory we always strive to provide latest research results on state-of-the-art machines.

In addition, the DMRC can utilise all equipment, which is available at the chairs at the Paderborn University that work together in the DMRC. This chair equipment comprises a very wide field of different testing machines, microscopes, test rigs and even computer tomography.

Summarizing this, the total accessible equipment opens the opportunity for the DMRC partners to get access to a very wide spectrum of different additive manufacturing machines and testing equipment. To get an overview about the manufacturing machines and the testing equipment, which is installed in the DMRC, please check the next pages. The additional equipment of the chairs is listed in the section “Chairs and Institutes”.


PMRC

POWDER BED FUSION

picture: SLM

LASER SINTERING LS

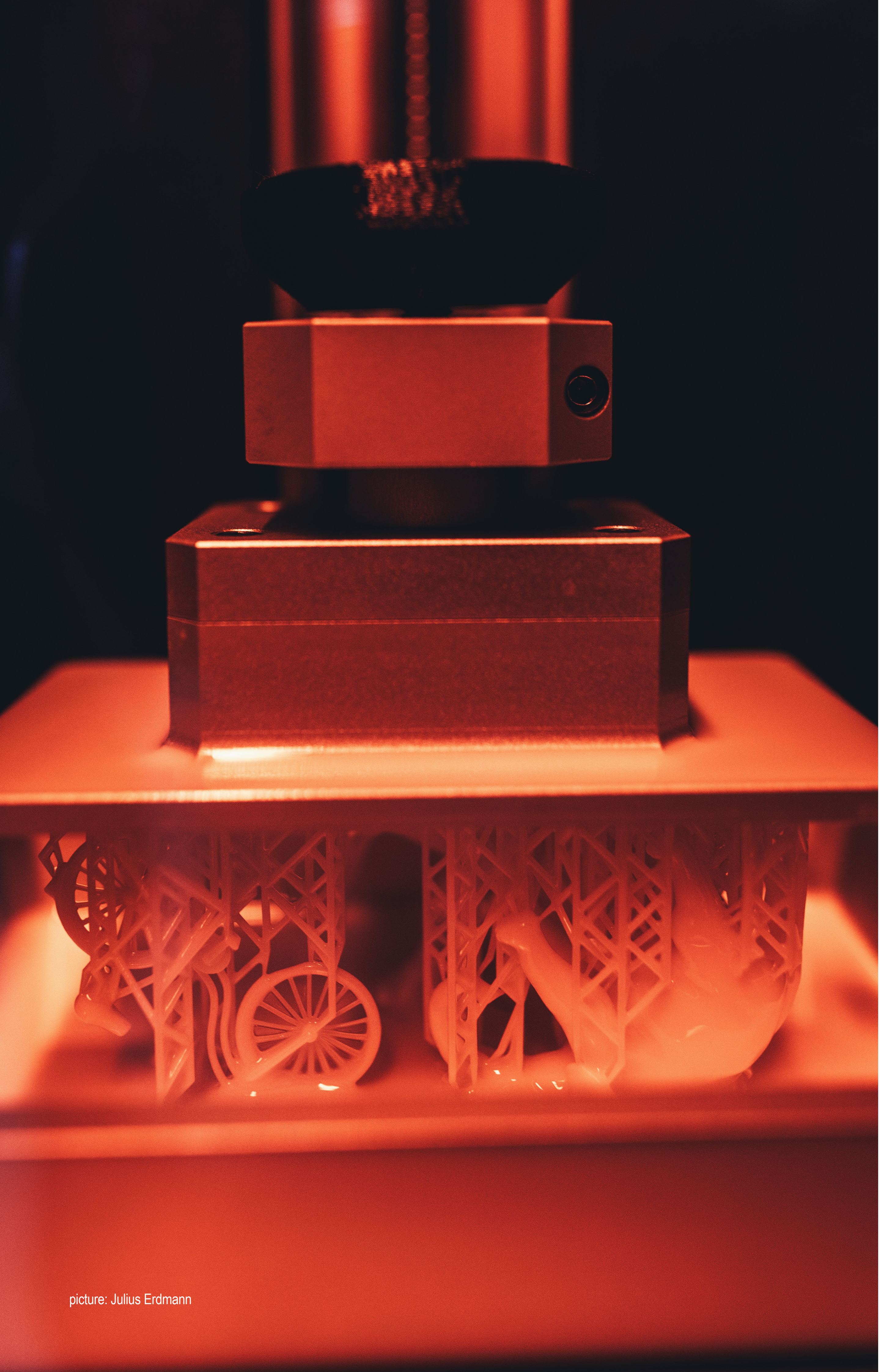
EOISINT P395
EOISINT P396
EOISINT P396 HIGH TEMP.
SINTERIT

picture: EOS

LASER MELTING

SLM 250HL
SLM 280 1.0 UPGRADE
SLM 280 2.0
SLM 280 1.0
VACUUM DRYING (IN-HOUSE DESIGN)
DRYER

picture: Matthias Groppe


picture: Julius Erdmann

MATERIAL EXTRUSION AND VAT PHOTOPOLYMERISATION

picture: BigRep


picture: Gewo3D

picture: Arburg

FUSED DEPOSITION MODELING

GEWO HTP 260 (GEWO SYSTEM)
BIGREP ONE[1]
STRATASYS FORTUS 400 MC
BIGREP STUDIO[2]
FDM MACHINE (IN-HOUSE DESIGN)
PRUSA I3 MK3S
LOW PRESSURE DRYER 30

ARBURG PLASTIC FREEFORMING

ARBURG FREEFORMER (2x)

FUSED GRANULAR FABRICATION

Q. BIG 3D QUEEN 1

DIGITAL LIGTH PROCESSING

EQ PR10 PRINTER
EQ CL36 CURE CHAMBER
EQ WASHER DW11

picture: Henkel

MEASUREMENT

picture: Zwick

PHYSICAL AND CHEMICAL ANALYSIS

EXTRUSION PLASTOMETER MFLOW
SPUTTER COATER SC7620
MOISTURE MEASUREMENT AQUATRAC
PRECISION BALANCE
RHEOMETER PHYSICA MCR 501
DSC ANALYSE – NETZSCH DSC 214 POLYMA

MECHANICAL ANALYSIS

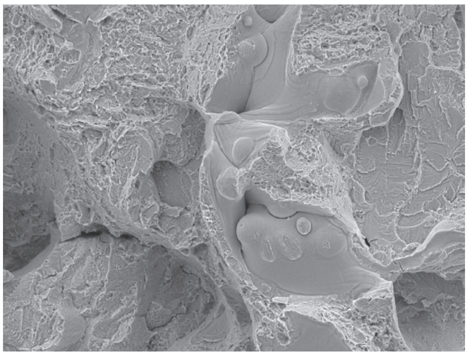
INSTRON 5569
TEST RIG FOR BENDING VIBRATIONS
ZWICK HB 250
ZWICK HC 10

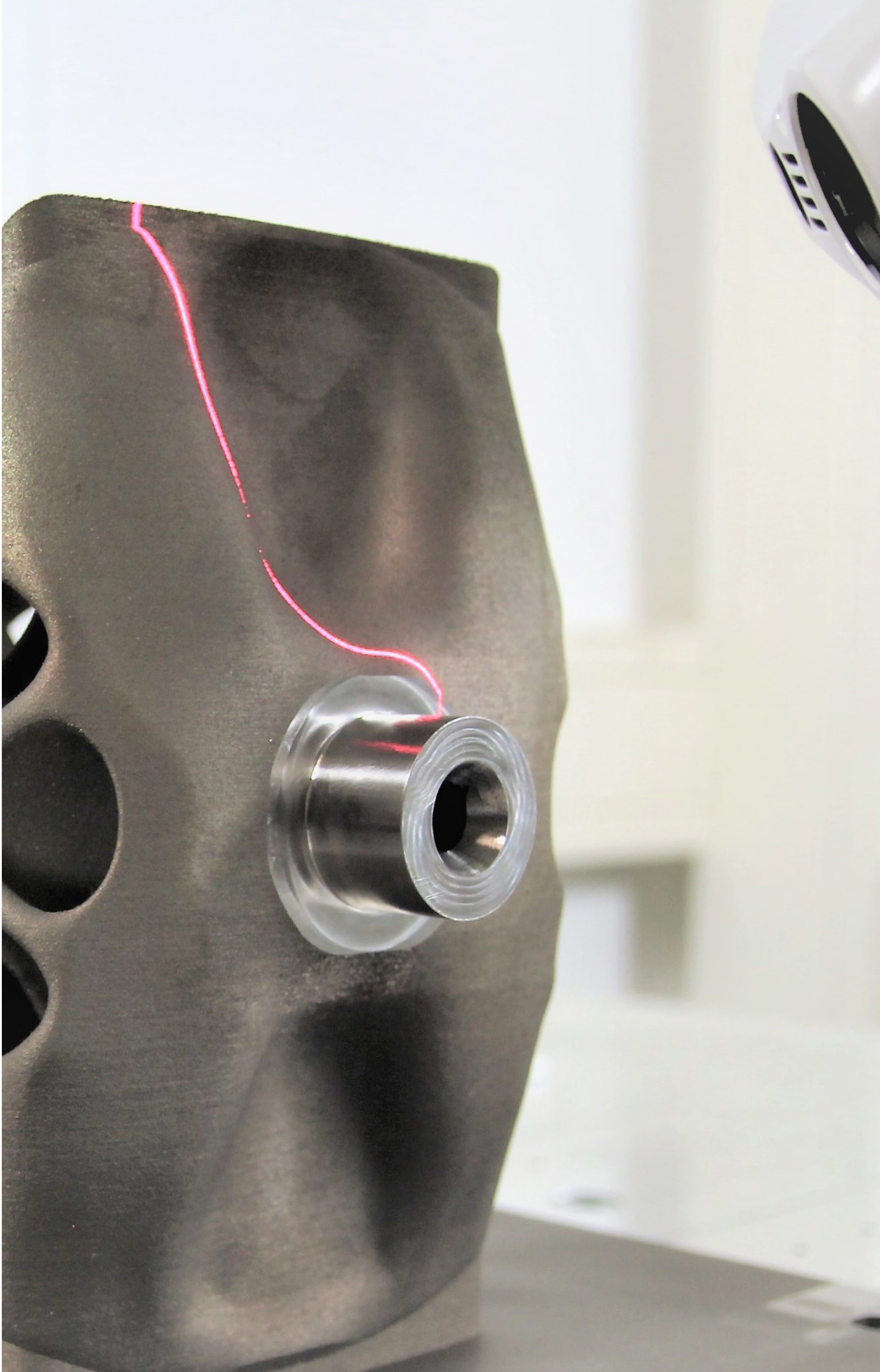
GEOMETRICAL ANALYSIS

HOMMEL ETAMIC T80000
NIKON ALTERA 8.7.6

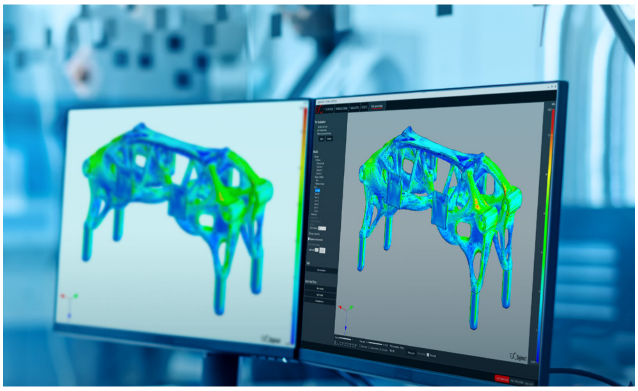
OPTICAL ANALYSIS

3D MEASURING MACROSCOPE
EXTRUSION PLASTOMETER MFLOW
PARTICAL SIZE ANALYSER MASTERSIZER 2000
SCANNING ELECTRON MICROSCOPE (SEM)
THERMAL IMAGING CAMERA P60, FLIR





AM RELATED SOFTWARE SOLUTIONS



DESIGN

SOLIDWORKS

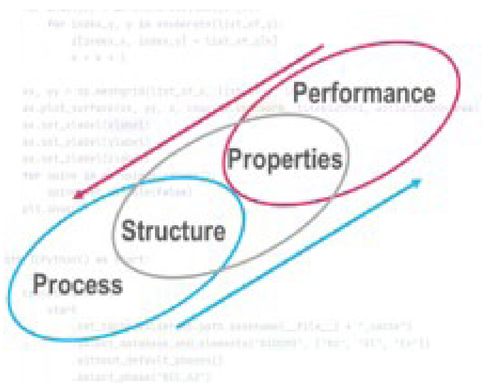
GENERATIVE DESIGN

APEX GENERATIVE DESIGN

picture: Additive Marking

DIGITAL IDENTITY

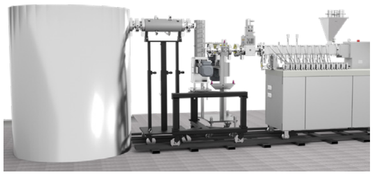
ADDITIVE MARKING SUITE



SIMULATION TOOLS

ANSYS
ABAQUS
THERMOCALC

MATERIAL PRODUCTION & AM-SPECIFIC POST PROCESSING

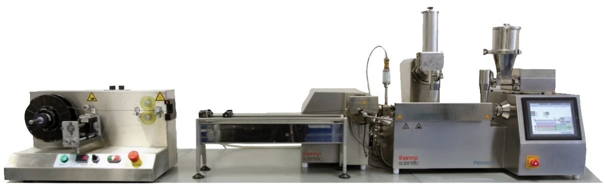


SLM POWDER

INDUCTION FURNACES (ALLOY SCREENING AND CASTING)
GAS ATOMIZER (POWDER ATOMIZATION)
SIEVING STATION AND AIR CLASSIFIER (POWDER POSTTREAT-MENT)

LS POWDER

PARTICLES FROM GAS SATURATED SOLUTION (PGSS)
CRYOGENIC MILLING AND ROUNDING (THERMAL OR MECHANICAL)



picture: Thermo Fisher

picture: Walter Trowal

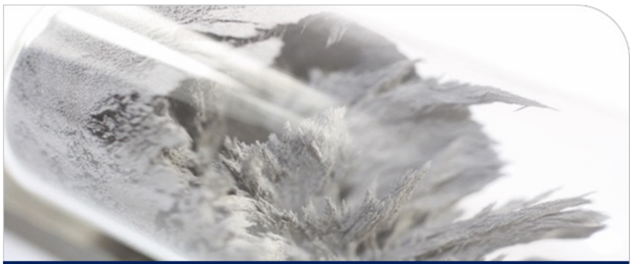
FILAMENT EXTRUSION

EXTRUSION OF ADVANCED POLYMERS
EQUIPMENT:
- MINI TWIN-SCREW EXTRUDER
- MELTING PUMP
- HAUL-OFF BELT
- MEASURING UNIT
- WINDER

SURFACE FINISHING

PWALTER TROWAL AM 2 MULTIVIBRATOR

RESEARCH FIELDS



MATERIALS AND PROCESS

DESIGN – METHODOLOGIES

APPLICATIONS

INDUSTRIALIZATION & EDUCATION

» Nowhere else can we cover such an extensive research spectrum in such depth and speed and, due to the interdisciplinary collaboration approach, with the economic efficiency at hand«

Dr. Maximilian Kunkel, Siemens Mobility GmbH

As a university-based institute, research is embedded in our DNA. The DMRC – Academic leverages its interdisciplinary structure and the expertise of numerous chairs and professors to address a wide array of research and application fields. Our activities and competences span from foundational to application-oriented research projects. Our main research field are Material development and process optimization, Design for AM, Applications and Industrialization and Education

At the DMRC - Academic, we are dedicated to advancing material for additive manufacturing. Our current research includes the development of new FeSi alloys for e-mobility applications, new Filled or flame-retardant Polymer Powder for demanding polymer applications and electrically and thermally conductive polymers for filament printing. For all these technologies, we have the capability to produce custom materials in-house, allowing us to tailor properties specifically for our research needs.

On the process optimization and innovation side, we are engaged in the large EU project “Made-3D” on multi material printing with metal powders. Furthermore, we continue to improve process paramters and process stability and are working on process monitoring and fault detection systems.

Design for AM is another strong point of the DMRC - Academic. We focus on developing design methodologies and tools that fully exploit the unique capabilities of additive manufacturing technologies. Our aim is to enable the creation of complex, high-performance components that are optimized for additive production.

The development of AM components and applications is at the heart of our research activities. A notable application we are currently working on is 3D printed drive units. By leveraging the design freedom of additive manufacturing and our newly developed materials, we are able to create drive units that offer increased efficiency and reduced weight.

Industrialization and education are crucial to the widespread adoption of additive manufacturing technologies. We integrate the latest research findings and innovations into our educational programs, ensuring that our students and industry partners are equipped with cutting-edge knowledge and skills. Our teaching and training activities range from fundamental courses to advanced seminars and are aimed at a diverse audience from academia to industry professionals.

START UP'S

The success of the German economy largely depends on its future employees. Thus, four new start-ups were founded by former DMRC scientists. The former "AMendate GmbH", which was acquired by the Hexagon Group, focuses on making future products lighter and more bionic, while "Additive Marking GmbH" works to ensure that the manufacturing stages of 3D printed components remain easy to follow throughout. And "AMproved GmbH" is the first professional online market for Additive Manufacturing, offering pragmatic solutions for industrial use. AME aims to holistically optimize products in the fields of lightweight construction, engineering expertise and 3D printing to help companies to meet market pressures.

Like the DMRC itself, the goal of all these start-ups is the industrial implementation of this technology.

HEXAGON | MSC Software

The team of **AMendate**, which was successfully acquired by Hexagon in 2019, is developing a fully automatic optimisation software for additive manufacturing: MSC Apex Generative Design. Its innovative generative design algorithm quickly generates lightweight, yet robust structures tailored for additive manufacturing. The lightweight design does not only save material but also production time and thus costs. Developed from the user's perspective, this software meets all engineering requirements: A high resolution guarantees detailed structures, and the stress-based optimisation creates bionic shaped geometries with an even stress distribution. The result is directly manufacturable designs which can be transferred to Nurbs-based CAD standard files with just a few clicks.

MSC Apex Generative Design gives design engineers an error-free, directly print-ready component that meets every requirement. The integrated optimization workflow with a high degree of automation and clever algorithms enable designers without special simulation knowledge to quickly generate proper Design for AM geometries, all within one software. And combined with further powerful tools from Hexagon, a holistic end-to-end solution can be realized!

ADDITIVE MARKING

Additive Marking addresses the challenge of labelling additively manufactured components to ensure they are traceable throughout the entire product lifecycle. The digital process chain, which may be assured using Blockchain technologies, for example, can be combined with the physical world in this way. This is of interest for spare parts that have previously been made using injection moulding or similar procedures and were marked by the mould used in the process. As the moulds succumb to wear and tear and demand declines, these parts are now increasingly being made as required using 3D printing. But also, for research and development, test units, for example, must be clearly allocated for the purpose of positioning and orientation in the Additive Manufacturing system.

In the case of safety-critical components, e. g. in aerospace, for medical applications or in automobile manufacture, the need to mark components to ensure traceability goes without saying.

AMproved is the contact for all operators of metal L-PBF Additive Manufacturing technologies. As an online marketplace, it offers not only I/O devices, spare parts and accessories, but also innovative solutions to improve quality and efficiency. It offers everything needed in day-to-day production, or in other words everything you need for your shopfloor. There is a container system adopted especially for Additive Manufacturing purposes which makes it possible to store and handle the powders used in the process and keeping the powder away from oxygen and moisture. And if moisture does get into the powder, AMproved also offers the appropriate vacuum drying system. With the developed drying system, the powder can be dried to a residual moisture of 3% within a very short time. In addition, the system has been approved by TÜV for safety.

Advanced Mechanical Engineering GmbH aims to show companies a way to do business innovatively and sustainably through efficiency gains. Since its founding in the summer of 2020, the company has been based in the Center for Production Technology (ZfP) at the Phönix West Industrial Park in Dortmund. The wide-ranging knowledge of AME GmbH's employees in the fields of lightweight construction, engineering expertise and 3D printing helps companies to meet market pressures. Thereby function, target and geometry of a component determine the type of manufacturing and not vice versa! The range of services includes CAD designs, FE calculations as well as structural optimization and a training program. AME GmbH thus supports its customers throughout the entire product development process, from the idea to the component. A wide range of projects from various industries have already been successfully completed and have enriched the wealth of experience within the company and with customers.

RESEARCH

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GRANULATE FED 3D PRINTERS

Variable Fused Granular Fabrication (VFGF) is an innovative additive manufacturing process that produces com-ponents by depositing plastic granules in layers using a variable diameter nozzle. This technology makes it possi-ble to create fine outer surfaces and thicker inner structures in a single process step, which, in contrast to conven-tional filament-based additive man-ufacturing, eliminates the need for expensive and time-consuming semi-finished filaments.

PROJECT OVERVIEW

DURATION

08/2024 – 12/2024

PARTNER

- Q.Big 3D

FUNDED BY

Direct Manufacturing Research Center (DMRC)

RESEACHER

Research Leader
Prof. Dr.-Ing. Elmar Moritzer
Research Assistant
Mohammed Abuzaid, M.Sc.

Motivation

The rapid development of additive manufacturing is open-ing up new horizons in production technology by overcom-ing con-ventional manufacturing limits and creating innova-tive design possibilities. The Variable Fused Granular Fabrication (VFGF) process in particular shows great potential to complement and expand conventional additive processes thanks to its flexibility and variety of materials.

The motivation behind this project is the desire to push the bound-aries of VFGF technology. The process enables the production of large prototypes and small batches, which makes it particularly attractive for industries such as aero-space, medical technology and the automotive industry. By using granules as the starting material, VFGF offers an enormous variety of materials, which opens up new appli-cation possibilities.

A key aspect of the project is the variable nozzle diameter, which enables short production times with high resolution. This is particularly important in order to further improve the efficiency and precision of additive manufacturing. In view of the increasing demand for tailor-made and complex components, there is a need to further develop and opti-mize this technology.

This project has several advantages for the DMRC. In-sights will be gained into the possibilities of additive manu-facturing with granulate-based 3D printers, which will strengthen the scientific basis for future developments. In addition, valuable scientific results on a selected plastic in the new process will be compiled. By estimating the me-chanical properties and material behavior, precise guide-lines for the processing of critical geometries can be cre-ated, which expands the application possibilities of the technology.

By investigating variable nozzle diameters and their influ-ence on component properties, as well as introducing new materials and optimizing geometric accuracy, the project not only aims to achieve technological advances, but also to strengthen the competitiveness and sustainability of manufacturing processes. The knowledge gained can be groundbreaking for the further development of VFGF tech-nology and thus lay the foundation for future innovations in additive manufacturing.

Aim

The aim of the project is to characterize the material and process-specific influencing variables in the VFGF pro-cess. Through a detailed investigation of these factors, a deeper understanding of their effects on the manufacturing process is to be developed. Another focus of the project is the determination of the process-specific component prop-erties in the context of the VFGF process. The special properties and quality parameters of components manu-factured using this process will be analyzed and evaluat-ed. Finally, the aim is to expand the range of applications for the VFGF process in order to maximize the potential uses and cost-effectiveness of this technology in practice.

Proceeding

In the first work package, a market analysis of 3D printers that are suitable for the use of granulate is carried out. For this project, the machine “Queen 1” from Q.Big3D will be used. A review of possible materials (new or already ap-proved) for the Queen 1 will be carried out, with PLA and PA6 GF25 already approved.
In the second work package, an already printable material is selected. Key process parameters such as tempera-tures and printing speeds are determined. The samples are then evaluated in terms of their optical properties and density.
In the third work package, up to two parameter sets, e.g. “Detail” and “Turbo”, are considered. The influence of the adjustable nozzle diameter is investigated. Furthermore, the mechanical properties for the xy and z orientation are evaluated.
In the next work package, a profitability analysis will be carried out for the use of the “Queen 1” machine in the production process. In addition, the previously determined machining parameters are transferred to more demanding geometries to test their suitability and stability. It will be analyzed how these parameters handle complex shapes such as thin walls. In addition, the process limits will be investigated to understand how physical and mechanical constraints influence the parameters.
Furthermore, strategies for the production of components with challenging geometrical properties will be developed.
Finally, a final report will be produced summarizing all results and evaluating the effectiveness of the implement-ed strategies and process parameters. It will serve as a basis for future optimizations and projects.

FIGURE 1 Machine for granulate printing (Source: Q.Big 3D)

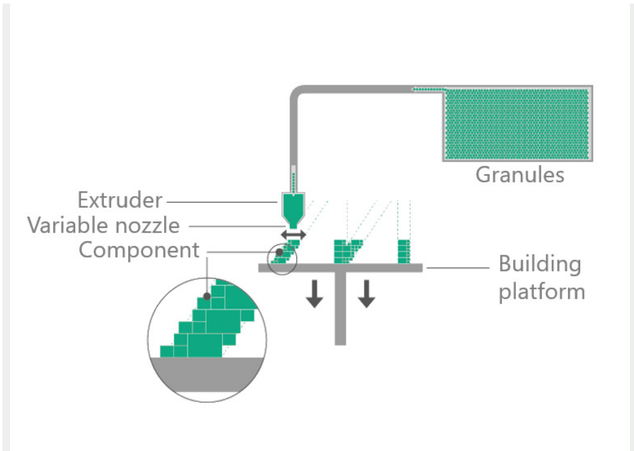

FIGURE 2 Variable Fused Granular Fabrication (VFGF).
(Source: https://www.qbig3d.de/xxl-3d-drucker/)

ADDITIVE MANUFACTURING OF ELECTRIC MACHINES: RESEARCH ON THE POTENTIAL OF ADDITIVE MANUFACTURING IN PM SYNCHRONOUS MACHINE ROTORS

Metal components and assemblies can be manufactured layer by layer using Additive Manufacturing (AM). The process principles provide both design freedom and new possibilities regarding the material. The aim of this research project is to systematically investigate the potentials of additive manufacturing processes in electrical engineering, especially in rotors of permanent-magnet excited synchronous machines (PMSM). This project is a cooperation between the DMRC and the IAL (Institute for Drive Systems and Power Electronics) of Leibniz University Hannover.

PROJECT OVERVIEW

DURATION

03/2019 – 11/2020

PARTNER

- Paderborn University (KAt, LWK)
- Leibniz University Hannover (IAL)

FUNDED BY

DFG – German Resaerch Foundation

RESEACHER

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DFG Deutsche Forschungsgemeinschaft
German Research Foundation

Motivation

Efficient drive systems are becoming more and more important in context of increasing automation in both private and industrial sectors. Electric motors in particular are interesting for many applications, but must meet the respective requirements. Additive manufacturing processes offer a high design freedom and a low influence of component complexity on unit costs. Accordingly, special solutions with a high functional density and component complexity can be manufactured economically.

The overall objective of this research project is to investigate the potential of additive manufacturing (AM) in electrical engineering. The existing design characteristics of rotors in permanent magnet synchronous machines (PMSM) are to be expanded by using AM. This requires design guidelines for the processing of soft magnetic materials. At the same time, the rotor-sided inclination and the surface structure of the rotor including its connection to the torque-transmitting structures will be implemented in an additively manufactured demonstrator (Figure 1).

Approach

In order to be able to exploit the above-mentioned potential, a suitable material must be identified. This is done in two steps. First, parameter studies are carried out on one selected iron-cobalt and two iron-silicon alloys. This is followed by the determination of mechanical and magnetic properties before and after heat treatment. Based on the results of the material research, the effects of rotor-side inclination on additively manufactured PMSM rotors with buried magnets as well as concepts for the suppression of eddy current losses on the surface of PMSM rotors by means of AM will be investigated.

The resulting rotor design is going to be functional and suitable for production. It will display the benefits of AM in the field of PMSM rotors. For this purpose, an inclination with axially straight magnetic pockets is to be realized. Such a concept is only economically conceivable because of the progressive development of AM processes and is an example of the newly gained possibilities in the design of electrical machines.

Project status

The alloys CoFe50 and FeS2.9 were chosen for the project to enable a comparison to the currently most common materials in electrical machines. Furthermore, the alloy FeSi6.5 was chosen to show the potential of AM. FeSi6.5 has the highest permeability in the iron-silicon phase diagram and a reduced electrical conductivity, which reduces the formation of electrical eddy currents and thus the resulting losses. FeSi6.5 showed the greatest potential with a maximum permeability of 7056 and exceeds the achieved values of FeSi2.9 by 254%. Due to its solid design and high electrical conductivity, FeCo50 has higher eddy current losses.

During the subsequent manufacturing of specimen, the brittle FeSi6.5 led to uncontrollable stress cracks in larger components. Therefore, FeSi2.9 is further used in this project.

Parallel to the material investigations, the possibility of implementing rotor functions by a AM-oriented design was investigated. Simulations of the electromagnetic flow in the active part of a conventional rotor show material areas that are not used optimally. The adapted active part allows a more homogeneous material utilization with regard to the flux density. In addition, torque fluctuations can be reduced by torsion of the external pole shoes when using axially straight permanent magnets.

Besides the optimization of the active part, which is essential for the electromagnetic function, the mechanical requirements have already been analyzed. The integration of the active part in the mechanically loaded structure eliminates the need for form-fitting or force-fitting connection areas and replaced them by using material connections. This results in more design options and lightweight, heavy-duty structures, such as hollow structures. In particular dynamic tests of the torsional fatigue strength have to be carried out. These are necessary to characterize the material properties of additively manufactured FeSi2.9 and to take AM-specific features such as surface roughness into account. The collected knowledge is implemented in an overall design of a rotor demonstrator. The final rotor shape (Figure 1) reduces the mass by 52% compared to the conventional reference rotor. At the same time, the mass inertia of the rotor (incl. magnets) is reduced by 31%. At the same time, the mass inertia of the rotor (incl. magnets) is reduced by approx. 31.1%. At the same time, the mass inertia of the rotor (incl. magnets) is reduced by approx. 31.1%. This was achieved by a hollow shape of the rotor, which is limited to mechanically and electromagnetically functional material areas while complying with manufacturing limits. By inclining the pole shoe areas over the axial length, the torque ripple can be reduced by about 90% with axially straight permanent magnets (Figure 2).This project (project number: 406108415) was kindly founded by the DFG (German Research Foundation).

FIGURE 1 Sectional view of the optimised AM rotor

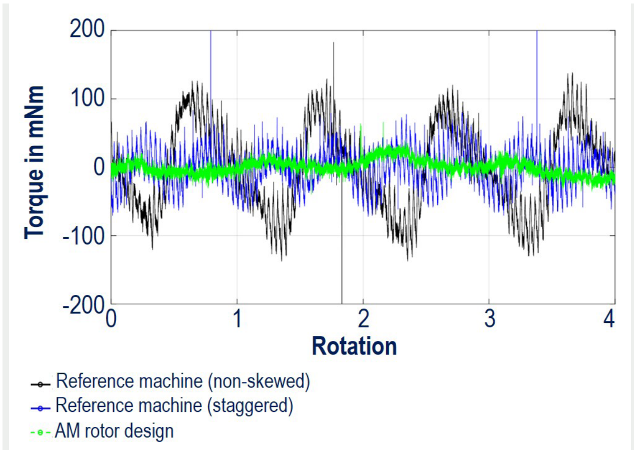

FIGURE 2 Experimentally determined results for torque ripple in comparison to the reference machines (unslanted / staggered)

ADDITIVE MANUFACTURING OF ELECTRIC MACHINES: RESEARCH ON THE POTENTIAL OF ADDITIVE MANUFACTURING IN SYNCHRONOUS RELUCTANCE ROTORS

Metal components and assemblies can be manufactured layer by layer using Additive Manufacturing (AM). The process principles provide both design freedom and new possibilities regarding the material. The aim of this research project is to systematically investigate the potentials of additive manufacturing processes in electrical engineering, especially in rotors of synchronous reluctance rotors (SR). This project is a cooperation between the DMRC and the IAL (Institute for Drive Systems and Power Electronics) of Leibniz University Hannover, founded by the DFG (German Research Foundation).

PROJECT OVERVIEW

DURATION

05/2022 – 06/2025

PARTNER

- Paderborn University (KAt, LWK)
- Leibniz University Hannover (IAL)

FUNDED BY

DFG – Deutsche Forschungsgesellschaft
DFG – German Research Foundation

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DFG Deutsche Forschungsgemeinschaft
German Research Foundation

Motivation and approach

Efficient drive systems are becoming more and more important in context of increasing automation in both private and industrial sectors. Electric motors are interesting for many applications but must meet the respective requirements. Additive manufacturing processes offer a high design freedom and a low influence of component complexity on unit costs. Accordingly, special solutions with a high functional density and component complexity can be manufactured economically.

The motivation for this research project is to investigate the potential of additive manufacturing (AM) in electrical engineering. The potentials of AM on the function of permanent magnet synchronous machines (PMSM) could be shown in previous projects. Application-orientated and targeted motor development begins with the selection of the motor type. For this reason, this project will focus on synchronous reluctance motors. Specific functional advantages and the absence of rare earth magnets are potential benefits of this type of motor. Further potentials will be identified and investigated, which relate to AM.

The basis is a function-orientated development and selection of materials for rotor manufacturing. The process-specific freedom of design offers new possibilities for functional optimisation but, like every manufacturing process, is also subject to specific limits (Figure 1) that must be determined and considered in the rotor design.

Investigation on the material

An alloy of Iron with 6.5 wt.% Silicon (FeSi6.5) was initially chosen for building the rotor's active part. FeSi6.5 offers higher permeability and near zero eddy current losses compared to the conventionally used FeSi3 alloy. However, additively manufacturing large components of FeSi6.5 is a challenge, due mainly to the formation of brittle intermetallic phases during cooling that make it susceptible to severe cracking. This problem is circumvented by employing a heated build chamber, capable of being heated to up to 800°C. Further, the FeSi6.5 rotor is combined with the case hardening steel 1.6587 or 18CrNiMo7-6 as the shaft material. Identification of build parameters that yield sound weld quality at

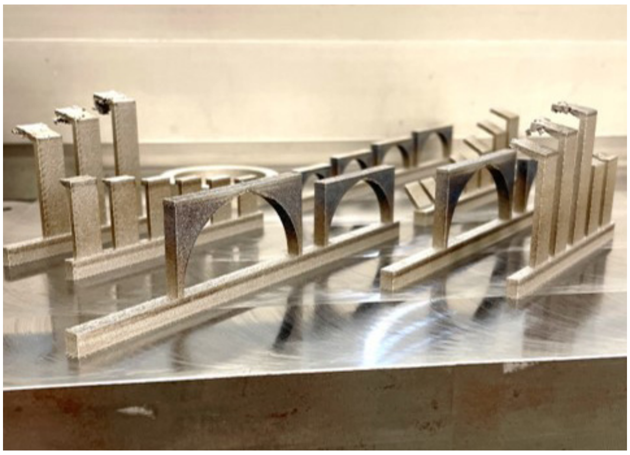

FIGURE 1 Specimen to identify the design limits

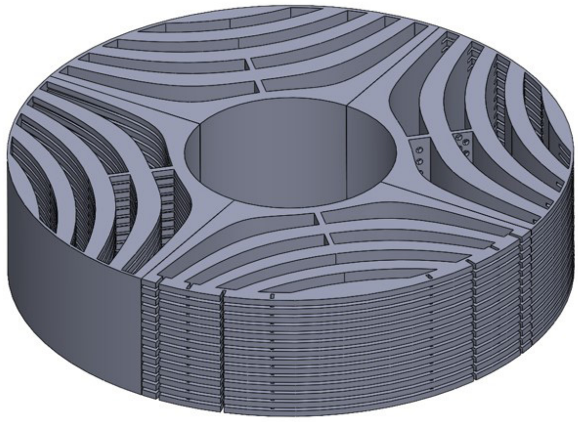

FIGURE 2 Model (CAD) of different design variants of the active part

the multi-material interface and the design of heat-treatment schedules which result in the best compromise between the functional properties of the two materials are also being actively investigated. For the transfer to the demonstrator, it has been discovered that it is possible to manufacture FeSi6.5 in the high-temperature chamber, but that a material combination with 18CrNiMo is not possible under conventional heating conditions due to temperature-related residual stresses. For manufacturing the demonstrator, the rotor is therefore built entirely from FeSi3, since the entire rotor exceeds the available installation space of the high-temperature chamber.

Rotor design

In the development of the rotor design, different functions and functional areas must be combined. At the same time, there are limitations with regard to the materials and the manufacturing process that must be taken into account.

In conjunction with the stator in the housing, the active part fulfils the electromagnetic function, the conversion of electrical into mechanical power. Conventionally, this area is formed by a series of individual metal sheets in order to avoid eddy current losses in particular. The desired production of the active part as a coherent part offers the possibility of combining the active part and the conventional shaft and thus utilising the advantages of a load and function-oriented design using AM in all three spatial directions, not only in the active part but in the whole rotor.

For the design of the active part, design features that can have an influence on the electromechanical function are identified. The simulative investigations, which were continuously supported by experimental tests to determine the material characteristics, form the basis. The investigations have shown that the optimum active part base body determined by simulation can be additively manufactured without any problems in many areas. However, physical limits must still be observed. For example, the base body of the functionally optimised active part must be reinforced by means of stray bars to ensure that it fulfils its function reliably. In particular, the centrifugal forces acting at full rotor speed would otherwise lead to mechanical failure of the rotor. Since the active part is manufactured as one coherent part, this reinforcement can be optimised and separated over the axial length of the active part. In order to suppress the eddy currents, a circumferential slot is required in the circumferential surface of the active part. This slotting is possible in terms of manufacturing technology but is associated with challenges due to the orientation in the installation space. As this results in free overhangs during layer-by-layer processing, this can lead to significant deviations in shape and dimensions. The deviations can be reduced by means of appropriate support.

Current status

The simulation results are currently being combined and finalised in the rotor design. The design will then be manufactured and tested experimentally in order to compare the simulation and experiment. The additive manufacturing process will take place in Paderborn at the DMRC, while the experimental testing of the demonstrator will be carried out in Hanover.

This project (project number: 465089065) is kindly funded by the DFG (German Research Foundation).

DIRECT SCREW FASTENING OF ADDITIVELY MANUFACTURED PLASTIC COMPONENTS

Additive manufacturing is still limited in regard to long manufacturing times and high costs for expanding building spaces. Direct screwing allows smaller components to be assembled into larger components and attachable to assemblies with high functional integration. Thus, large building spaces can be avoided and integration into serial production is possible. Currently, there are no recommendations directly applieable to additively manufactured components. The layered manufacturing process results in highly anisotropic components. So, the strength of the components strongly depends on the build orientation. The results show, that are indeed geometries, which show a uniform strength independent of the build orientiation.

PROJECT OVERVIEW

DURATION

PARTNER

FUNDED BY

IGF - DFW

RESEACHER

Research Leader
Prof. Dr.-Ing. Volker Schöppner
Research Assistant
Christian Held, M. Sc.

Introduction

Additive manufacturing (AM) is steadily gaining in importance [1]. For prototyping applications, additive manufacturing allows for the implementation of tension and stiffness optimized geometries, and highly functioning integrated parts. However, additive manufacturing is limited by long manufacturing times, limited material combinations and disproportional acquisition costs for expanding building spaces.

Integration of additively manufactured plastic components into assemblies can reduce the time-to-market of the product. Thus, a more adaptable and flexible response to ever faster changing markets is possible. The continuous developments in the field of additive manufacturing and the growth of the market have reduced manufacturing costs over time. Material and facility acquisition costs have decreased because of larger building spaces and increased building rates. As a result, cheaper manufacturing costs have a significant influence on serial manufacturing. [2]

Most additive components are made of plastic [3] and commonly manufactured through fused-deposition-modeling (FDM). Likewise, direct screwing is the most commonly used mechanical joining process for plastic components [4]. To effectively use additive components in a product, they have to be joined with other components into an assembly. The predestined joining process for the task is direct screwing because joints with dissimilar materials are realizable without thermal influence. Additionally, direct screw joints have high connection forces at low acquisition costs. By joining with direct screwing, additively manufactured components can be combined with other processes and materials to create hybrid products in an economically viable way [5]. Direct screwing is prominent for small series production and the manufacture of large products on small facilities. This is economically favorable because of a disproportional relation between facility acquisition cost to building space size.

Preliminary investigations at the Kunststofftechnik Paderborn (KTP) [6] show that the limited applicability of the guideline for direct screwing of injection molded thermoplastic components by the Deutscher Verband für Schweißen und verwandte Verfahren e.V. (DVS-Richtlinie 2241-1 [7]) to additively manufactured com-

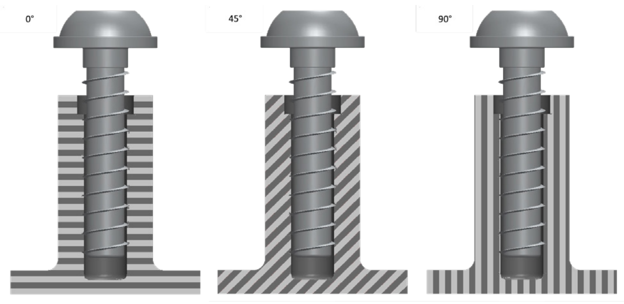

FIGURE 1 Typical screw boss geometry and build orientations

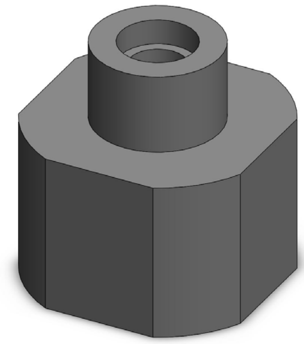

FIGURE 2 Shape optimization to neglect influence of build orientations.

ponents. Additive components are built in layers which results in a process-dependent anisotropy considered in the layout and design. Moreover, omitted restrictions from injection molding offer great optimization potential for additive components. [8, 9]

Aim of the reserch

The goal of the research is to provide initial design and application recommendations for the direct bolting of additively manufactured components. For this purpose, screw bosses will be produced by FDM, AKF and SLS according to DVS guideline 2241. These will be produced in 0°, 45° and 90° orientations to investigate the influence of the anisotropic, directional properties. After characterization, different geometry and shape variations are tested, considering the design freedom. The goal is to find a suitable geometry that does not exhibit directional properties.

Proceeding

At the beginning of the project, a screw dome geometry based on DVS-2241 was selected. This geometry was used to determine suitable production parameters for the three processes used (FDM, AKF, SLS). A variation of this geometry was not investigated because, on the one hand, only small deviations were possible due to the machine and, on the other hand, deviations would lead to faulty production. The domes were produced in nominal sizes of 6, 5, and 4 mm. These refer to the nominal diameters used for the screws of the same size. The joint was first characterized with the bosses. It was found that bosses with a 0° orientation (screw axis parallel to the installation direction) had the lowest strength, and bosses with a 90° orientation (screw axis perpendicular to the installation direction) had the highest strength. The reason for this is delamination between 2 layers, which occurs earliest at 0° and cannot occur at 90°. In order to avoid strength differences and premature failure due to delamination, several geometry variations were initially tested. In particular, the outer diameter was increased and the core hole diameter was reduced. Adjusting the core hole diameter slightly increased strength in all orientations, while increasing the outer diameter dramatically increased strength. However, both variants continued to fail due to delamination at 0° and 45°.

Investigation of the failures showed that the delamination always occurred at the transition between the tube and the flange, below the screw. Design changes were made to strengthen this area. A variant with ribs and a variant where the screw is immersed in the flange were designed and tested. The ribs had no effect because the rib structure is also layered and can delaminate. However, the countersink showed promising results. The countersinking and the resulting passage of the screw through the critical area made it possible to measure the same strength in all orientations.

Therefore, it is strongly recommended that the tube be lowered into the actual component or below the joint.

In addition to the room temperature tests, tests were also conducted at -40°C and 70°C. Compared to injection molded parts, additive molded parts show less loss of strength. This is due to increased diffusion forces between the layers. At -40°C, there is neither a loss nor an increase in strength, as is common for plastics at low temperatures. This is attributed to an increased notch factor between the layers due to increased embrittlement.

Preload relaxation studies have shown that the orientation of the installation space has no effect on relaxation. The recommendations of DVS-2241 can be followed.

In addition, repeated assembly was tested. Normally, direct screw joints can withstand 10 repeated screwings. Due to the higher porosity, the recommendation for additive components is reduced to 5 repeated screw connections.

The results were then incorporated into initial design and application recommendations, bringing the project to a successful conclusion.

DEVELOPMENT AND MODELING OF THE THERMAL CONDUCTIVITY OF HIGHLY THERMALLY CONDUCTIVE POLYMER COMPOUNDS FOR THE FDM PROCESS

The prevailing trend towards an increasing number of variants and shorter product life cycles challenges product development to create an increasing number of products faster and more cost-effectively. One way of meeting these constantly changing market requirements is rapid tooling. Areas of application can be found primarily in injection molding and deep-drawing mold construction. One of the advantages for injection mold making is the low development and production costs of additively manufactured mold inserts. In this context, this project focuses on the development of thermally conductive polymers and the modeling of thermal conductivity as a basis for the use of polymers for the flexible production of injection mold inserts.

PROJECT OVERVIEW

DURATION

08/2021 – 01/2024

PARTNER

- Argus Additive Plastics GmbH

FUNDED BY

German Federal Ministry for Economic Affairs and Climate Action (BMWK)

RESEACHER

Research Leader
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Research Assistant
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Aim

The aim of the project is the development of highly thermally conductive polymer compounds for the production and use of injection mold inserts manufactured in FDM for small series production. The purpose of the project is to enable the advantages of the FDM process for the production of injection molds to be exploited significantly by using a thermally conductive polymer. This is intended to utilize the potential of the material properties adapted by the material modifications both in the FDM process (during the production of the injection mold insert) and in the subsequent injection molding process. A key parameter here is the thermal conductivity of the materials used in order to reduce cycle time. The aim is to process materials that have at least 10-times the thermal conductivity of conventional polymers.

The sub-project at the DMRC - Academic generally comprises the development of a model for the simulation of heat transfer in additively manufactured tools. With regard to the importance of heat transfer mechanisms, the thermal conductivity of the materials is considered as a relevant material parameter. Consequently, the various material-related and process-related influencing factors on the thermal conductivity must be considered for the development of the model.

Material Qualification

First, the thermally conductive polymer compounds developed are characterized with regard to material-related influencing factors, such as the filler volume fraction or particle morphology. In this context, the influence of the type of filler, filler morphology and filler size are analyzed in order to be able to identify a suitable filler. It is shown that, in addition to the type of filler, the filler morphology also has a significant influence on the resulting thermal conductivity. Most fillers fundamentally lead to an increase in the thermal conductivity of the structures produced using the FDM process. Taking into account the embrittlement of the materials, this results in a tension field of requirements and properties that must be considered and investigated during material development.

Following characterization, the polymer compounds are processed into filament form. The focus here is particularly on sufficient

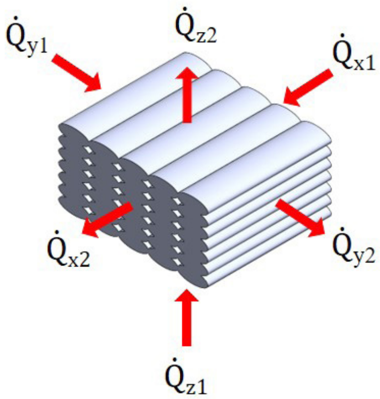

FIGURE 1 Anisotropic heat transfer in structures manufactured using the FFF process

FIGURE 2 GEWO HTP260 as the machine used for the investigations

dispersion of the additives in the matrix material to achieve homogeneous filament properties and to ensure spoolability while maintaining a constant diameter.

Investigation of the Processability

Important influencing factors for evaluating processability, such as the essential process parameters, are considered by examining the resulting weld seam strength and warpage behavior. In general, an increased filler volume leads to increased embrittlement of the material and a reduction in weld seam strength. The material properties can be influenced by the process parameters. As a result, suitable essential process parameters are defined for the production of complex structures. In addition to the weld seam strength between the component layers, the adhesion between the material and the build platform is analyzed. An increased component size increases the tendency for shrinkage-induced detachment of the components from the build platform. It is therefore essential to select a suitable combination of build platform and print material.

Model to Predict the Thermal Conductivity

Furthermore, the resulting material-related and process-related material properties are determined with a focus on thermal conductivity. The characteristic strands and layered structure are particularly important here. A specific porosity is created due to the volume flow, the nozzle geometry and the movement of the nozzle. This results in anisotropic material properties, which can be enhanced by the orientation of the filler particles. In addition to the influence on the mechanical properties, this can also be observed for the thermal conductivity. The results of the investigation show that other parameters also have an influence on the material properties and must therefore be examined. These include the cross-sectional area of the deposited strands and the test temperature.

The recorded material-related and process-related properties are used to set up a model to predict the thermal conductivity of structures manufactured using the FDM process. For this purpose, the causes of the resulting, direction-dependent material behavior are to be described based on experimental investigations. Important parameters here include particle orientation and particle dispersion in the matrix. Finally, the quality of the model is verified by validating with experimental data.

Manufacturing of Injection Mold Inserts

Finally, a prototype injection mold insert is developed in the project to evaluate the defined performance parameters of the material. On the one hand, this should prove the manufacturability of complex geometries with the developed material and, on the other hand, demonstrate an application in which an increased thermal conductivity of the polymer insert is advantageous. The cycle time and the service life of the prototype are of particular interest. Here, 150 process cycles are targeted. The mold insert must be designed with regard to the target values as well as the processability in the FDM process. During production, shrinkage during and after processing can be cited as a critical parameter. In addition to adapting the component geometry to reduce shrinkage, the FDM process also offers the option of reduced surface filling. This setting reduces the weight, the production time and the amount of shrinkage. This can improve process stability during the production of the tool insert. However, this leads to a reduction in the thermal, mechanical and thermo-mechanical properties as well as the media tightness. These boundary conditions should be considered when designing the component, while taking into account the specific requirements of the application.

INFLUENCE OF THE ANISOTROPIC MATERIAL BEHAVIOR OF ALSI10MG PRODUCED BY SLM PROCESS UNDER MULTIAXIAL STRAIN

The anisotropy within additive manufactured components is strongly influenced by process parameters such as laser power, exposure speed and exposure strategy. Pronounced anisotropic material properties in terms of yield strength, tensile strength or elongation at break are available in the literature for additively manufactured materials for uniaxial loads, but biaxial loads have not yet been considered. In real components, external loads usually cause complex stress states. A prediction of the component behavior therefore requires the description of the material behavior in a wide range of relevant stress states up to fracture.

PROJECT OVERVIEW

DURATION

01/2024 - 06/2026

PARTNER

FUNDED BY

German Research Foundation (DFG)

RESEACHER

Research Leader
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Research Assistant
Christian Bödger, M.Eng.

DFG Deutsche Forschungsgemeinschaft
German Research Foundation

Aim

In this research project, the mechanical behavior of materials additively manufactured from the aluminum alloy AlSi10Mg using the PBF-LB/M process is to be investigated. The aim of this study is to investigate the relationships between anisotropy and stress triaxiality.

The stress states are introduced in quasi-static tests through defined sample geometries and are loaded until failure occurs. In particular, the question arises as to what extent the variables causing the uniaxial tensile stress, such as the melt pool morphology, but also the areas within the melt pool (fine grain area, coarse grain area, HAZ) bear the multiaxial load. For example, it is conceivable that columnar Si structures have a preferred direction in the build-up direction and significantly reduced load-bearing capacity in the transverse direction. Globular structures, such as those found within the heat-affected zone, could exhibit a tendency towards isotropic deformation behavior in this respect. An understanding of these fundamental relationships is essential for the load-compliant design of additively manufactured components so that process parameters and thermal post-treatment can be specifically adjusted according to the required component requirements.

Process-related influences, such as the local variance of defect densities, for example, pose a particular challenge. The current state of knowledge demonstrates anisotropy in additively manufactured components made of AlSi10Mg depending on the build-up and load direction under uniaxial load. The effect of quasi-static multiaxial loading has not been sufficiently investigated. This research gap is being addressed in this project. These fundamental questions are to be determined by means of quasi-static tests under different loading conditions between uniaxial compression and biaxial tension up to fracture.

The direction-dependent material properties result from the specific microstructure of the material. For a better understanding of anisotropy, the microstructure must be investigated and characterized using suitable measurement methods in addition to the mechanical behaviour. In order to determine the effect of anisotropy on material failure, the failure modes, e.g. failure of or between individual structural layers, should be investigated under

different load conditions.
Based on the material characterization, requirements for mathematical models for transfer to numerical simulation are to be defined. Building on this methodological work, the results should lead to a knowledge base which, on completion of the project, will allow unfavorable microstructures and conditions to be avoided and favorable ones to be adjusted through targeted parameter selection during production.

Procedure

The use of flat tensile specimens results in three degrees of rotational freedom. The orientation of the material layers dominates the material failure in the specimen. For the development of a methodology to characterize the anisotropic material failure, specimens are arranged only in the x-z plane. Within this plane, the specimens are examined in 22.5° steps. For a clear specimen orientation, a degree of rotational freedom remains in the longitudinal direction of the specimen via the angle γ. The influence of γ on the anisotropic material behavior is to be determined in preliminary tests on tensile specimens. The results of the preliminary tests can be seen in Figure 1 and show that the angle of 0° results in the worst material properties.
In the next step suitable shear specimen geometries are developed on the basis of the direction-dependent preliminary tests. These complete the range of flat tensile specimens for quasi-static material characterization. The geometries should realize a load path that is as proportional as possible under pure shear and have a low susceptibility to edge cracking.

The focus is on the anisotropy of the material failure. The microstructure of suitable samples from the material characterization is then investigated. The investigation focuses on the failure modes, i.e. interlayer or translayer fracture of the samples.
Based on the material characterization and the findings from the microstructure investigations, requirements for mathematical models are defined. For this purpose, an evaluation of existing mathematical models will be carried out. The simulative and experimental results will be compared.
After comparing the prediction quality of existing material models, the requirements for the modeling of additively manufactured samples under multiaxial loading can be defined. For example, it may be necessary to pursue stochastic approaches that describe the pre-damage caused by inhomogeneous pore distribution, failure strain, etc., using specific distribution functions.

Outlook

The development of corresponding independent models for the modeling of components manufactured using the PBF-LB/M process is to be intensified after completion of the project.
This project also relies on quasi-static tests for anisotropic material characterization. With a focus on the application of PBF-LB/M aluminum in the automotive environment, highly dynamic load scenarios, such as vehicle crashes, must also be taken into account.
A follow-up project could pursue the characterization of the direction-dependent material behaviour under dynamic loads by applying and extending the methodology developed in this project.

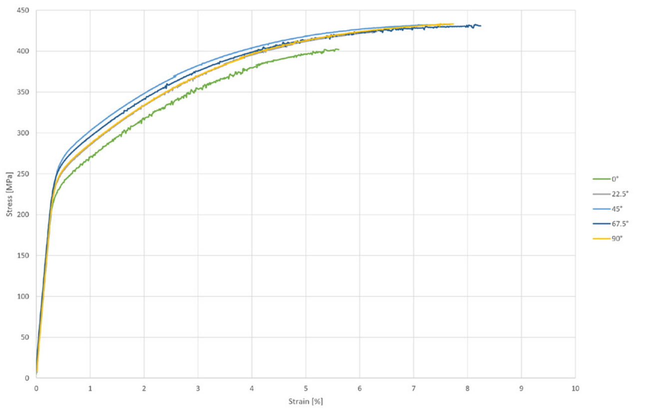

FIGURE 1 Tensile tests results of the γ-angle

BIKINI – BIONICS AND AL FOR SUSTAINABLE LNTEGRATION IN PRODUCT DEVELOPMENT FOR RESOURCE EFFICIENT LIGHTWEIGHT DESIGN

To reduce climate change impact, CO_2 emissions must be reduced. One of the key technologies is lightweight design. Most CO_2 savings can be achieved during the product use phase – especially in the area of mobility – through weight reduction. In the BIKINI project, bionic design algorithms and AI based assistance services are developed to support product development. Examples subsume semi-automated requirement extraction and sustainability assessment. The project started in July 2021, comprises a project volume of around four million euros for a period of three years and is funded by the Federal Ministry for Economic Affairs and Energy (BMWK).

PROJECT OVERVIEW

DURATION

07/2021 – 07/2024

PARTNER

- EDAG Engineering GmbH
- FEYNSINN EDAG Production Solutions GmbH & Co. KG,
- Additive Marking GmbH
- Eviden Germany GmbH
- Alfred-Wegener-Institute
- Krause DiMaTec GmbH
- Untrouble / rhaug GmbH, Paderborn University (HNI-PE / Data management in mechanical engineering (DMB))

FUNDED BY

Federal Ministry for Economic Affairs and Energy (BMWK)

RESEACHER

Project Coordinator:
Dr.-Ing. Jan Leilich (EDAG Engineering GmbH)
Research Leader
Prof. Dr.-Ing. Iris Gräßler
Prof. Dr.-Ing. Rainer Koch
Research Assistant
Philipp Hesse
Manuel Ott
Klaas Tuschen

Topic and aims of the project

It is a challenge for Germany and its companies in the 21st century to reduce the impact of climate change while increasing economic performance and maintaining its own quality expectations "Made in Germany". One of the key technologies for achieving this goal is lightweight design . It enables weight reduction and lowers the associated CO_2 emissions. This is particularly relevant for the mobility sector. The CO_2 intensive production and recycling processes cannot be ignored. Holistic development approaches need to be developed, which enable sustainable products over the entire life cycle. Vertical and horizontal process chain have to be considered.

To address this issue, research institutes, IT partners and engineering service providers from different branches and research areas founded the BIKINI consortium: EDAG Engineering GmbH, Additive Marking GmbH, Eviden Germany GmbH, Alfred-Wegener-Institut, Krause DiMaTec GmbH, Untrouble and Paderborn University.

BIKINI – Bionics and AI for sustainable integration in product development for resource efficient lightweight construction

Current evaluation criteria for lightweight design products such as costs and performance are expanded to include sustainability aspects such as holistic CO_2 emissions, resources used in the manufacturing process and recyclability of materials. This is achieved through an AI & algorithm supported development process. Established discipline-specific models such as CAD design are networked with new elements such as bionic lightweight design algorithms. Eight core areas are defined. The implementation of these areas enables the efficient development of lightweight products which are sustainable considering the complete product life cycle.

Core areas are:

- model and knowledge based **advanced requirements engineering** taking into account requirement dependencies and AI based analysis to avoid unnecessary use of resources in prototyping and product use.
- 3D structure and performance analysis of construction

principles of **biogenic lightweight structures** of plankton organisms as well as generation of bionic lightweight construction algorithms.
- concepts and methods for the synergetic combination of skills for **intuitive human machine collaboration** through the integration of AI in engineering processes.
- **automated sustainability assessment** of a product design in the early phases of the development process using a sustainability- oriented lifecycle assessment.
- increase in **production flexibility** by taking into account a product life phase dependent production selection already in the development phase in order to achieve decentralized, application oriented and thus resource saving on demand production.
- **production integrated labelling** to reflect production and usage data back into development via digital twins and for life cycle tracking.
- building a **knowledge base** with semantic models to represent the design knowledge, the dependencies of information models in the context of sustainable development and the semantic annotation of the design artefacts.
- configurable combination of the modules to a **holistic AI & algorithm supported development process** for development optimization with regard to lightweight construction with simultaneous process acceleration through automation.

Research areas of Paderborn University

The chair for Product Creation at Heinz Nixdorf Institute is responsible for the development of a model and knowledge based **advanced requirements engineering approach:** natural language requirements are efficiently extracted from specification sheets and usage scenarios. The results are formalized in order to reduce effort and costs in develop¬ment. To assess the risk of changes in the requirements as well as the change handling, the formalized requirement dependencies are integrated into a change and risk management approach.

In addition, a fully automated evaluation module is developed to compare alternative component designs with regard to **requirement fulfillment and sustainability** by the team of Prof. Dr.-Ing. Iris Gräßler. For sustainability assessment, factors on ecological sustainability are identified over the whole product life cycle. These influence factors are integrated into a generative design tool. Being able to evaluate requirement fulfillment and sustainability on a fully automated level, product development can be done highly iterative and with a systematic optimization of development results.

The chair for Data management in mechanical engineering (DMB) develops different approaches during the project in the fields of **sustainability assessment** and AI use in **structural optimization processes.** To design a comprenhensive sustainability assessment process, a two-stage web tool is implemented by first conducting LCC-analysis. Secondly based on the former analyses a holistic LCA-process is implemented. In cases of AI and structural optimization various lightweight principles are improved and a data model is derived . Supported by AI the whole product development process is designed more efficiently.

The joint project starts in July 2021 for a period of three years with a project volume of around four million euros.

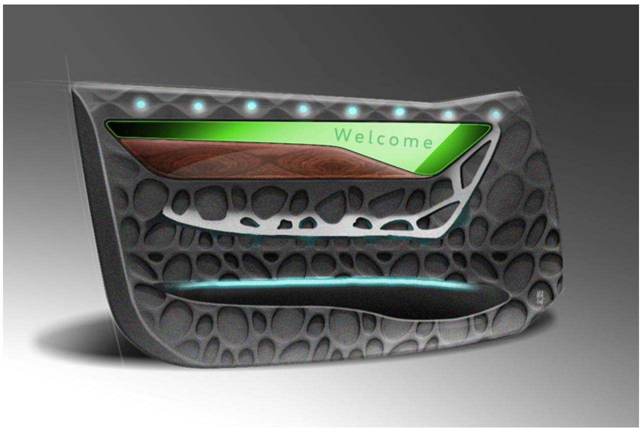

FIGURE 1 Door module demonstrator, which is generatively developed according to bionic construction principles (Copyright EDAG Engineering GmbH)

BIOCOMPATIBILITY-OPTIMIZED COATING AND LOAD-ADAPTED DESIGN OF ADDITIVELY PROCESSED TITANIUM ALLOYS

The properties of additively manufactured biomedical components made of copper modified titanium alloys coated by PVD are investigated. The focus of the investigation is on TiAl6Nb7+xCu (α+β) with varying copper contents processed by selective laser melting. The base alloy Ti6Al7Nb has the required mechanical properties and corrosion resistance for use as an implant and can be further increased by adding copper as an alloying element. The mechanical properties, corrosion and fatigue behavior is determinded by means of material analysis and mechanical characterization. The biocompatibility is increased by PVD coatings and verified by biological investigations (e.g. cell adhesion, cell culture growth or bio-film formation).

PROJECT OVERVIEW

DURATION

04/2023 – 04/2025

PARTNER

- Technical University of Dortmund, Chair of Materials Engineering (LWT)
- University of Veterinary Medicine Hannover, Foundation (TiHo)

FUNDED BY

Deutsche Forschungsgemeinschaft (DFG)

RESEACHER

Research Leader
Prof. Dr.-Ing. habil. Mirko Schaper,
Prof. Dr.-Ing. Wolfgang Tillmann,
PD Dr. med. vet. Habil. Jessica Meißner
Research Assistant
Dennis Milaege, M. Sc.

DFG Deutsche Forschungsgemeinschaft
German Research Foundation

Objective

Materials used for biomedical applications, such as permanent or bioresorbable implants, require adapted mechanical properties as well as biocompatible features. Titanium alloys build a passivating titanium oxide layer and therefore, have a high corrosion resistance along with an excellent biocompatibility and adequate mechanical properties. TiAl6V4 alloys are already established in biomedical engineering. Due to the addition of niobium and, in consequence, the impact on the hexagonal close packed (hcp) α- und body-centred cubic (bcc) β-phase, the performance of such an alloy can be enhanced. By adding copper as an alloying element, the mechanical and biocompatible properties of the addresed alloy Ti6Al7Nb can be adapted, so that the requirements for biomedical applications can be achieved and improved.

The aim of this research project is to manufacture a customized prosthesis with multi-functional surface areas to increase the compatibility and functionality of the implant. The biocompatibility and load-compliant design of the implant is achieved using an adapted PBF-LB/M printing strategy to create porous and geometrically defined surfaces with subsequent PVD coating. In addition to ensuring processability, the mechanical properties of PBF-LB/M processed Ti6Al7Nb are to be investigated regarding higher strength, ductility and anisotropy by adding copper (Cu) as an alloying element. The specific effect of Cu is to be investigated and the resulting properties are to be improved in terms of coatability and biocompatibility.

The Chair of Materials Science (LWK) analyses the processing parameters for the additive manufacturing of TiAl6Nb7+xCu- (α+β). In addition, the LWK will investigate the mechanical properties for quasi-static and for dynamic loading as well as the corrosion resistance of the alloys and coating systems. The Chair of Materials Engineering (LWT) in Dortmund examines the coating parameters and various layer architectures concerning the effects of the stress states of the coating. The University of Veterinary Medicine Hannover, Foundation (TiHo) examines the influences of the coatings regarding biocompatibility, cell adhesion and biofilm formation.

Approach

For manufacturing components with powder-bed-based selective laser melting the process parameters have to be adapted for each alloy Ti6Al7Nb+Cu design. To analyze the microstructure optical light, scanning electron and transmission electron microscopy are employed, including various techniques as electron backscatter diffraction and X-Ray diffraction. The microstructure of additively processed material influences the mechanical properties, e.g. strength and ductility. In addition, the mechanical properties are assessed by experiments under different loading conditions, for example tensile tests. The long-term stability under cyclic mechanical loadings is determined with low-cycle fatigue (LCF) and high-cycle fatigue (HCF) tests. Corrosion tests are conducted in Ringer's lactate, 0.9% NaCl and modified simulated body fluid (m-SBF) solutions to identify promising coating systems and to characterize the corrosion properties of the alloys and coatings.

Outlook

The aim of this research project is to investigate the processability, coatability and biocompatibility of TiAl6Nb7+Cu components manufactured by selective laser melting. The correlation of the microstructure and mechanical properties as well as the influence of the adapted process parameters and coatings on the fatigue behavior will be determined. Finally, the biocompatibility and degradation characteristics under conditions similar to those experienced in the human body are examined.

The patient specific implants have to provide sufficient mechanical and chemical properties and the coatings have to be reproducibly and durable for the application in the human body.

References:
[1] The Use of Additive Manufacturing in the Custom Design of Orthopedic Implants; Marie Cronskär (2011).

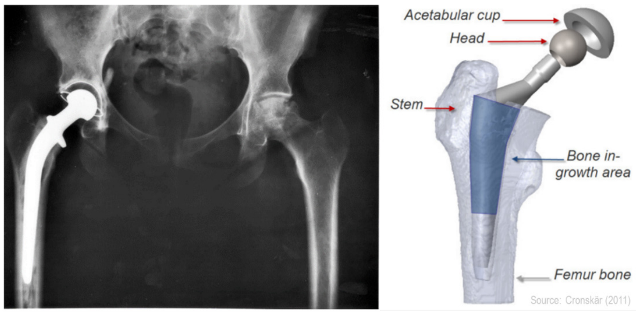

FIGURE 1 X-ray of a total hip replacement (left) and schematic overview of the different parts of an permanent implanted hip endoprosthesis (right); [1].

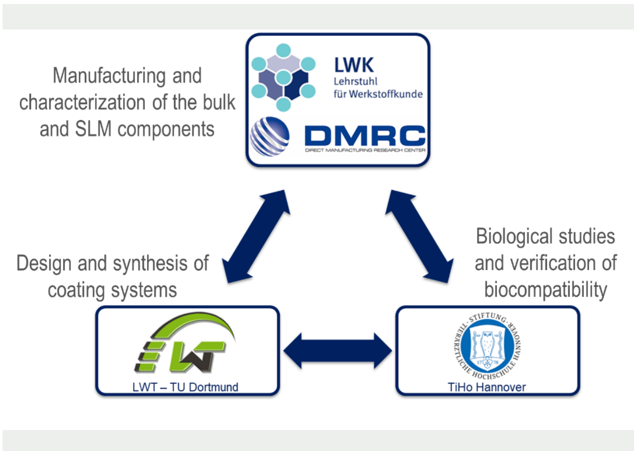

FIGURE 2 Organization and responsibilities within the DFG project.

DEVELOPMENT OF AN ELECTRICALLY CONDUCTIVE RUBBER ELASTIC COMPOUND FOR THE FFF PROCESS

The continuously increasing demands in mechanical engineering require an expansion of the application areas for materials. Therefore, plastic technology is also motivated to explore new applications for plastics, including the use of plastics as conductors in electrical applications. Plastics are generally considered as non-conductors and are mainly used as insulators in electrical components. However, by mixing electrically conductive fillers into the plastic, the electrical conductivity can be increased, which opens up these new areas of application. The aim of this project is therefore to develop an electrically conductive compound that can be processed using the FFF process.

PROJECT OVERVIEW

DURATION

11/2023-01/2026

PARTNER

FUNDED BY

German Federal Ministry for Economic Affairs and Climate Action (BMWK)

RESEACHER

Research Leader

Prof. Dr.-Ing. Moritzer

Research Assistant

Maximilian Karl Franz Salm, M.Sc.

Motivation

Nowadays, lightweight construction is becoming increasingly important for the mechanical engineering industry. Furthermore, products need to be available faster and faster. In order to meet the high demands placed on materials, processes and components, many industries are motivated to exploit new material and production possibilities. Under these conditions, the demand for new types of materials, such as electrically conductive plastic compounds or efficient and fast production options, such as additive manufacturing, are increasing. The motivation behind the project is to develop a material that meets these high requirements and further advances the use of plastic in components.

Aim

The aim of the project is to develop a flexible, electrically conductive material based on a thermoplastic elastomer, that can be used for the Fused Filament Fabrication process (FFF). The material to be developed aims to combine the advantages of the additive manufacturing and newest material technology. This makes it possible to produce single prototypes or even small series batches of elastic and electrically conductive parts efficiently and fast. In this project, the most relevant material parameter is the electric conductivity of the material. This parameter is maximized by mixing electrically conductive fillers into the plastic matrix. The use of ferrous and non-ferrous type fillers will be discussed and examined. The project also aims to gain a better understanding of the electric conductivity in anisotropic additive manufactured parts.

Material selection and processing of the compound

First, the polymer matrix and the different fillers are selected. The Shore hardness, which allows the conclusions to be drawn about the elasticity of the polymer matrix, is an important material parameter that must be considered when selecting the matrix. In the selection of fillers, the electric conductivity of the filler and the compatibility with the FFF-process, should be taking into account. After the material and filler selection, both components are mixed using a mini twin-screw extruder and transferred into filament form. The following aspects should be invested and elaborated in

FIGURE 1 The Thermo Fisher Process 11 mini twin-screw extruder is used for the compounding process

FIGURE 2 The FFF-machine INTAMSYS Funmat Pro 310 is used for parameter set optimization

this part of the project:

- Setting up a process profile for the twin-screw extruder
- Stabilize the filament extrusion and wind-up process
- Determine the maximum filler volume fraction considering the processability of the compound
- Maximize the electrical conductivity of the compound by increasing the volume fraction of the filler

Investigation of Processability

Following the compound and filament extrusion process, the compound with the highest electrical conductivity is analyzed regarding the processability via the FFF-process. Important factors in this part of the investigations are:

- Shrinkage behaviour of the material
- Weld seam strength
- Print bed adhesion

Development of Parameterset for FFF-process

The last part of the project is the development of a parameterset for the FFF-process. For this task, the final formula of the compound with a then verified processability is measured in a test laboratory. All material properties that are important for the FFF-process are measured. For example:

- Temperatures (Melt and Glass Transition Temp.)
- Viscositiy
- Moisture Absorption behaviour

Based on these measurements an initial parameter set is set up and further developed. Important process temperatures, like the nozzle-, bed-, and chamber temperature are further optimized. The printing speed is also examined and advanced. When processing thermoplastic elastomers, because of the critical stringing behaviour, which results of the low viscosity, crucial process parameters are the retraction settings. The retraction settings control the pullback length and speed of the filament when the nozzle is moved without an active extrusion. Without a reverse rotation of the feed unit, a disabled retraction, thermoplastic elastomers tend to drip out the nozzle and create strings, which can cause defects in the printed part. In the development of the parameter set a focus is set on optimizing the retraction settings. The aim is a full parameter set that creates reproducible parts.

DIGITAL APPROVAL OF 3D-PRINTED COMPONENTS FOR RAIL VEHICLES

The ongoing shift towards increased mobility and the growing importance of both local and long-distance public transport have underscored the need for a continuous and reliable infrastructure. This project aims to address the critical requirement for the timely availability of infrastructure components, ensuring their economic and ecological efficiency. The downstream approval process for these components currently causes significant delays, which this project seeks to mitigate through improved documentation, process qualification, and system monitoring.

PROJECT OVERVIEW

DURATION

10/2023-09/2026

PARTNER

- Additive Marketing GmbH
- IMA Materialforschung und Anwendungstechnik GmbH
- Mobility goes Additive e.V. Siemens Mobility GmbH
- TÜV NORD Systems GmbH & Co. KG

FUNDED BY

BMWK

RESEACHER

Research Leader
Prof. Hans-Joachim Schmid
Research Assistant
Dr. Florian Hengsbach

Project motivation

The primary motivation for this project is driven by the need for the mobility of the future, which demands the continuous availability of infrastructure objects. Ensuring short response and delivery times for various components in the right quantities is essential. This must be done while adhering to economically and ecologically efficient conditions, particularly concerning spare parts supply. The current downstream approval processes for these components add complexity and delays, necessitating a more streamlined approach.

Objectives

The sub-project aims to develop detailed documentation aligned with the FKM guideline, ensuring complete reproducibility of results within the database. This effort involves a thorough scientific analysis of existing guidelines, such as evaluating the necessity of using new powder for each construction job. Additionally, a comprehensive document will be created, detailing the numerous manufacturing and dynamic test parameters to ensure the urgently needed traceability.
Another crucial goal of the sub-project is the process qualification of the DMG MORI LT30 system. Given the numerous influencing and disturbance variables in additive manufacturing, the process qualification will adhere to existing standards to ensure reproducible mechanical parameters. Both the detailed documentation for obtaining dynamic characteristic values and the process qualification of the additive manufacturing system are vital for the creation of the database and the adaptation of the FKM guideline.

Role and Objective of the DMRC

The Direct Manufacturing Reasearch Center (DMRC) is integral to supporting process monitoring systems as part of the planned project. The DMRC focuses on reliably correlating monitoring signals with the resulting component quality, supported by predictions from process simulations. To achieve this, µCT recordings are conducted, allowing for well-founded correlations with the measured signals from the process monitoring systems. These µCT images are integrated into the database, thus serving as a

crucial quality criterion.
The final objective of the DMRC in the planned project is to validate the hypotheses and recommendations from the DZSF research report. This involves technical validation of the hypotheses to ensure their accuracy. Based on these investigations, concrete recommendations for quality-relevant steps along the entire additive manufacturing process chain will be developed.

Conclusion

This project aims to enhance the efficiency and reliability of infrastructure components in the mobility sector through improved documentation, process qualification, and advanced monitoring systems. By addressing both scientific and practical aspects, the project lays the groundwork for a more resilient and responsive infrastructure essential for meeting future mobility demands.

Outlook

Looking forward, this project is poised to significantly enhance the reliability and efficiency of mobility infrastructure. By developing comprehensive documentation aligned with the FKM guideline and qualifying the DMG MORI LT30 system, the project will streamline procedures, ensuring reproducibility and traceability in additive manufacturing. The DMRC's role in integrating µCT recordings into the database will bolster quality assurance, while validating hypotheses from the DZSF research report will establish a solid technical foundation. These advancements will minimize response and delivery times for essential infrastructure components, supporting both economic and ecological objectives.
Moreover, the project's outcomes will set new standards within the additive manufacturing industry, fostering continuous improvement and innovation. This will not only enhance current practices but also pave the way for future advancements. Ultimately, the project will create a more resilient and responsive infrastructure, crucial for meeting the evolving demands of future mobility efficiently and sustainably.

FIGURE 1 DMG MORI LASTERTEC 30 SLM 2nd Generation

DEVELOPMENT OF ENERGY AND RESOURCE-EFFICIENT MANUFACTURING ROUTES OF FORMING TOOLS FOR STAINLESS STEEL TUBE PROCESSING

The research project focused on understanding and addressing failures in the pipe bending process. By developing measurement methods to track forces and stresses, and using simulations to optimize instrument placement, the team identified key factors contributing to tool failure. Studies of tool coatings and sensor data provided insights, leading to the development of standard tests and the setup of a test rig to compare materials. The research explored substitutes like TiCN coatings, ceramics, and various alloys, emphasizing laser metal deposition. Ultimately, selected materials like Stellite 6, Stellite 21, and 1.4301 were tested in both laboratory and practical environments.

PROJECT OVERVIEW

DURATION

08/2021-01/2024

PARTNER

- WAFIOS AG

FUNDED BY

Bundesministerium für Wirtschaft und Klimaschutz

RESEACHER

Research Leader
Prof. Dr. rer. nat. Thomas Tröster
Research Assistant
Stefan Gnaase, M.Sc.

Intruduction

The manufacturing industry can make a significant contribution to the optimization and substitution of existing energy- and resource-intensive processes and process technologies based on the savings. One of the prominent challenges in the forming of stainless steel is the avoidance of cold welding on the so-called bending mandrel holders (also known as bending molds), which can have a negative impact on the service life of the tool, process reliability and results.
The existing process routes for tools optimized for this application offer a high savings potential from an ecological point of view due to the high energy and resource consumption. In addition to the machining of the tool, in the current process it is vacuum-hardened, tempered several times, fine-machined again, polished and then coated. By developing a more efficient production route for these tools, the project aims to minimize the use of energy and resources. The aim was to replace the PVD coatings previously required to avoid cold welding by using alternative materials and the additive manufacturing technique of laser metal deposition (LMD). Energy-intensive processing steps such as vacuum hardening and multiple heat treatments of the tool as necessary preparation for the application of a coating were thus eliminated and the CO2 footprint of the process reduced.

Aim

The primary aim of the project was to develop and demonstrate processes and technologies for the manufacture of tools for stainless steel pipe forming and then to validate them by testing them on functional samples. The aim was to increase efficiency in production while at the same time reducing costs and lowering operating costs by extending replacement cycles. This is achieved by eliminating the energy-intensive vacuum hardening and physical vapor deposition (PVD) processes and by using additive manufacturing as a production technology

Results

The research project began by investigating the causes of failure in the pipe bending process (see Figure 1). To this end, measure-

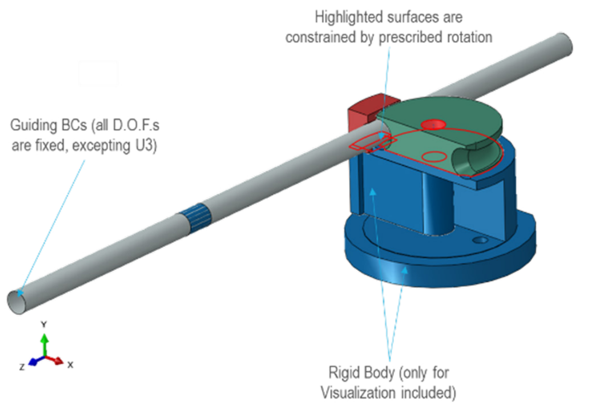

FIGURE 1 CAD forming simulation

FIGURE 2 MACHINED FORMING TOOL

ment methods were developed to record the forces and stresses acting on the component and tool. A process simulation identified the zones of inhomogeneous loads in order to optimize the placement of the measuring instruments. It could be seen that the stress patterns determined in the simulation corresponded to the failure pattern of a real coated bending tool. The zones in which the compressive stress distributions are greatest according to the simulation are also those in which the coating on the component has failed. The coating failure occurs primarily in the feed area of the tool. One reason for this could be the tube expansion during the bending operation, which is limited by the counterholder and thus leads to both increased compressive stress and shear force due to the curvature of the tube.

Investigations of the tool coating after forcing damage corresponding to around 200,000 bending operations provided further insights. The use of sensor technology revealed deviations such as increased force or temperature as signs of impending tool failure.

Based on the initial results, standard tests were developed to simulate the load cases on a laboratory scale. A pin-on-disk test rig was set up to simulate a simplified load case and to compare and characterize the materials used. Fixed, unhardened stainless steel balls (Ø 10 mm) were pressed onto the coated test specimens with a defined test force of 10 N. The test distance that the ball dragged on the test specimen was 1,000 m. The removed volume of the respective balls was then measured and calculated using micrographs.

With the help of the test bench and the knowledge gained, comprehensive material research was carried out to identify suitable material substitutes. Materials with a similar composition such as TiCN coatings as well as ceramic materials and cobalt and nickel-based alloys were considered. Processability by laser metal deposition (LMD) is an important criterion. After the material selection of Stellite 6, Stellite 21 and 1.4301, the development of functional samples began.

Parameter studies determined the LMD process parameters in order to produce dense components. Various geometries were produced and analyzed for this purpose. Based on these results, the respective production parameter with the lowest wear volume was selected for each material in order to produce a demonstrator. For this purpose, the base material was coated close to the contour using the LMD process in the bending radius and then machined to achieve the final contour (see Figure 2). The functional samples were then tested on a laboratory basis. Finally, the most promising functional samples were tested in a practical environment at the project partner's premises.

INTERFACE INTERACTION OF ADDITIVELY MANUFACTURED, PVD-COATED COMPOSITE SYSTEMS - CORRELATION OF SURFACE HARDENING, RESIDUAL STRESSES, ROUGHNESS AND FATIGUE STRENGTH

Although additive manufacturing offers a high degree of freedom for component design and opens possibilities for rapid prototyping, it comes with the downsides of residual porosity and high surface roughness. This raises serious concerns about incorporating such components into practical applications. In this project, surface modification with the aid of thermal spray coatings is explored for iron-based alloys built using laser powder bed fusion (LPBF).

PROJECT OVERVIEW

DURATION

01/2024-01/2026

PARTNER

- Paderborn University (LWK)
- TU Dortmund (LWT)

FUNDED BY

DFG – Deutsche Forschungsgesellschaft
DFG – German Research Foundation

RESEACHER

Research Leader
Prof. Dr.-Ing. habil. Mirko Schaper (LWK)
Prof. Dr.-Ing. Dipl.-Wirt.-Ing. Wolfgang Tillmann (LWT)
Research Assistant
Dr.-Ing. K.-P. Hoyer (LWK)
Vinay Kunnathully Sathees Kumar, M.Sc. (LWK)
Nelson Filipe Lopes Dias, M.Sc. (LWT)

Motivation

Iron-based alloys, specifically steels produced by conventional processing routes, are widely used in day-to-day life. Amongst these, the applications where dynamic loading and stresses are involved come with the most stringent material specifications. This limits the applicability of steels produced by LPBF owing mainly to residual porosity and surface roughness, which are detrimental to their fatigue properties. Hence, surface modification with the aid of appropriate coatings can be employed to qualify such materials for the intended applications.

To explore this possibility, two steels, namely the corrosion-resistant stainless steel 316L and high strength steel 36NiCrMo16, have been chosen for coating with hard nitrides. Additionally, the fatigue properties of such composite structures have not yet been studied in detail.

Approach

The project broadly involves the study and optimization of physical vapor deposition (PVD) parameters of Cr1-xAlxN (CrAlN for short) hard coatings that yield the best fatigue properties for the aforementioned steels in response to the various surface pre- and post-coating treatments.

Our preliminary work, conducted as part of the first funding phase of this project, shows that the coating of 316L substrates produced using LPBF with CrAlN PVD hard coatings leads to an increase in short-term strength; (Fig.1). The layer growth and the resulting adhesive strength are influenced by the crystalline microstructure and the residual stress state of the laser beam-melted (LBM) substrate surface as a result of the construction process and mechanical pre-treatment processes, although the direct cause-and-effect relationships are unclear.

Furthermore, their effect on the fatigue strength is unclear. Hence, the aim of this research project is to investigate the influence of different edge zone modifications of steel surfaces produced by LPBF, i.e. an adaptation of the mechanical properties (edge zone hardening, residual stress state) and crystalline microstructure by means of mechanical, thermal and thermochemical substrate pretreatments to the load collective, on the nucleation and growth phase of PVD hard coatings and their effect on the fatigue strength of LBM substrate/PVD coating composite systems.

For this purpose, the two steels processed by LBM, the austenitic steel, 316L and the quenched and tempered steel 36NiCrMo16 are subjected to the sub-processes such as polishing, plasma nitriding and stress relief annealing in order to provide property-differentiated surfaces (interfaces). The resulting microstructural and mechanical properties are analyzed using metallographic and radiographic methods as well as mechanical test methods.

In addition to this, the adhesive strength and layer growth of PVD Cr1-xAlXN layer systems with different stoichiometries are investigated as a function of the differently pretreated LBM substrates. The long-term behavior of the LBM substrate/PVD layer composite systems are evaluated by means of fatigue tests (high cycle fatigue). The knowledge gained will be correlated with the results of the microstructure analysis in order to determine the mechanistic processes resulting from mechanical, thermal and thermochemical processing of coated LBM components to increase the fatigue strength.

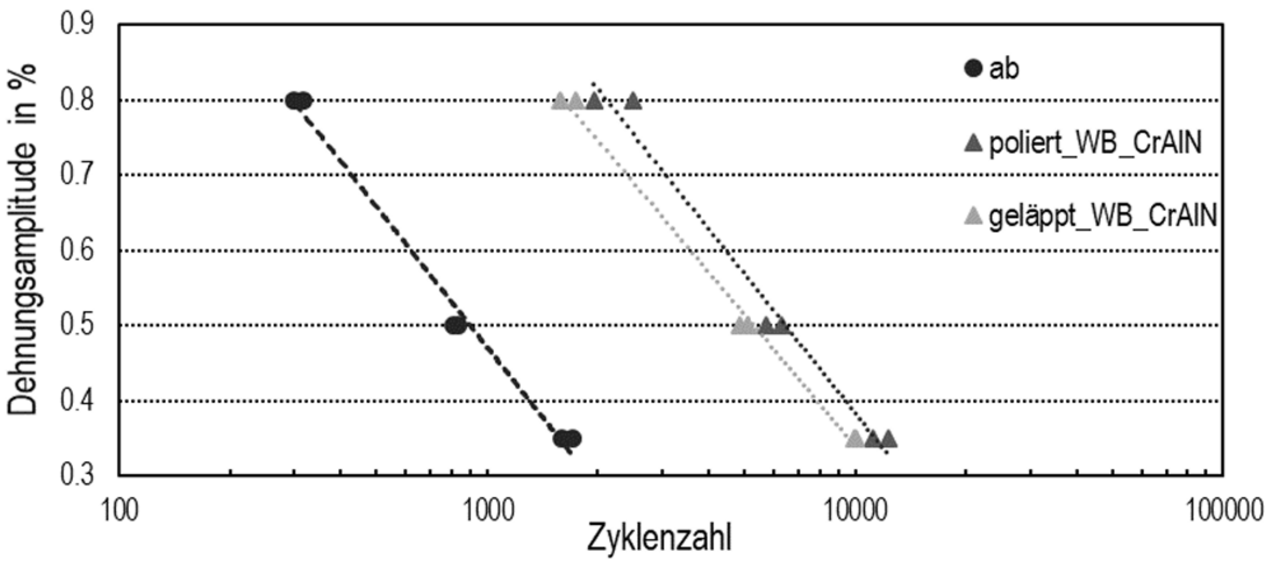

FIGURE 1 Comparison of the elongation curves of additively manufactured substrates made of 316L in the as-built condition and CrAlN coated samples for polished or lapped substrates after heat treatment.

INNOVATIVE LIGHTWEIGHT AND COOLING CONCEPTS FOR ELECTRIC MACHINES THROUGH ADDITIVE MANUFACTURING

High power densities of electrical machines are used in industrial and mobile applications to generate high torques. Despite their high efficiency, these machines generate losses that must be dissipated as heat. Additive manufacturing offers a solution to create complex cooling structures that can increase efficiency. As part of the FVA 882/I research project, innovative lightweight and cooling structures were implemented in a PMSM rotor and housing. An automotive PMSM from WITTENSTEIN was used as a reference motor. The results show a significant improvement in cooling properties and weight reduction while maintaining the electromagnetic properties.

PROJECT OVERVIEW

DURATION

11/2019 – 04/2022

PARTNER

- ASTRO Motorengesellschaft mbH & Co.KG
- Breuckmann GmbH & Co. KG
- Dr. Ing. h. c. F. Porsche AG
- Dunkermotoren GmbH
- OSWALD Elektromotoren GmbH
- STÖBER ANTRIEBSTECHNIK GmbH & Co. KG
- MSF-Vathauer Antriebstechnik GmbH & Co. KG

FUNDED BY

BMWi-Program: Industrial Collective Research (IGF)
AiF - Arbeitsgemeinschaft industrieller Forschungsvereinigungen
FVA – Forschungsvereinigung Antriebstechnik e.V.

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Motivation

High power densities are particularly important in applications where space and weight are limited, such as in mobile devices and vehicles. Despite high efficiency, electrical machines generate losses that must be dissipated through cooling. Conventional manufacturing processes have limitations when it comes to producing complex internal cooling channels. Additive manufacturing offers new ways to produce complex and lightweight structures in a single step. This enables more efficient cooling and a reduction in overall weight, which is of particular interest to the automotive industry.

Aim

The main objective of the project was to optimise cooling and lightweight structures in a PMSM rotor and casing using additive manufacturing. The following specific objectives were achieved

- Design and implement an effective casing cooling system that minimises pressure losses and maximises heat dissipation.
- Reduce the weight of the rotor and casing by using voids and lattice structures without compromising mechanical stability.
- Investigate the electromagnetic properties of the additive manufactured rotor to avoid high eddy current losses.

Proceeding

In the FVA 882/I project, an automotive PMSM from WITTENSTEIN was selected as a comparison motor to evaluate the new structures. The following steps were taken:

Optimisation of the housing cooling:

The existing spiral housing water cooling system was replaced with a system of sinusoidally overlapping individual channels to take advantage of circumferential flow. This structure reduced pressure losses by 75% and simulations showed efficient heat dissipation, even at low pumping speeds.

Weight reduction:

Honeycomb structures were used in the casing and end shields to reduce weight. These structures reduced the total weight of the casing by 45% and the rotor by 33%. At the same time, the mass moment of inertia was reduced by 13%. The use of cavities and lattice structures helped to reduce weight without compromising structural integrity.

Electromagnetic optimisation:

Slots have been made in the rotor surface to reduce eddy currents. The FeSi3 and AlSi10Mg alloys were stress-relieved to increase strength. The shape of the cooling channels between the magnets was determined to avoid negative effects on the electromagnetic properties. Various geometric possibilities made possible by additive manufacturing were integrated into the rotor.

Comparison and test:

The reference machine from WITTENSTEIN and the additively manufactured functional model were compared on an engine test bench. Measurements showed that the functional model induced around 15% less voltage than predicted. However, the improved cooling properties of the additively manufactured housing cooling were clearly demonstrated, while the effectiveness of the rotor cooling could not be fully proven due to an increased magnet temperature.

Results

Additive manufacturing enabled the production of highly complex cooling and lightweight structures that could not have been achieved conventionally. The optimised casing cooling showed a significant improvement over conventional cooling. Weight savings of 45% for the casing and 33% for the rotor were successfully achieved. Electromagnetic optimisation using slots in the rotor surface significantly reduced eddy current losses. Overall, the project demonstrated that additive manufacturing is a promising approach for improving the power density and efficiency of electrical machines.

Conclusion

The technologies and methods developed in this project demonstrate the potential of additive manufacturing to improve the performance of electrical machines. The new approaches offer significant advantages, particularly in applications with high weight and cooling requirements. Future research should focus on further improving the efficiency of rotor cooling and investigating potential applications in other areas.

FIGURE 1 Additively manufactured permanent magnet synchronous motor (PMSM) with integrated cooling and lightweight structures

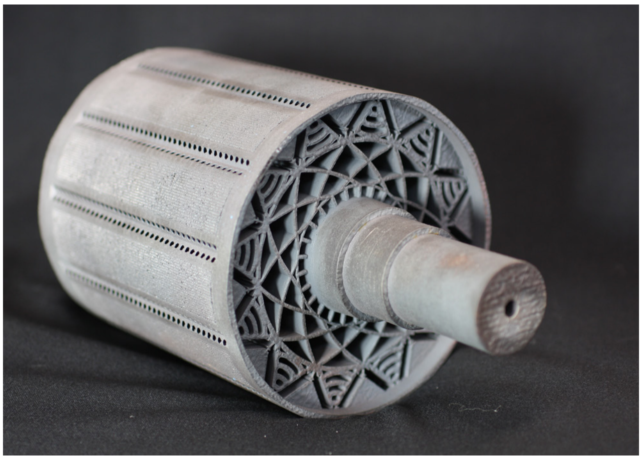

FIGURE 2 Rotor of the functional sample after heat treatment and before post-processing

FUNCTION INTEGRATION IN ADDITIVE-MANUFACTURED DRIVE TECHNOLOGY PARTS - GUIDELINES FOR CONCEPT AND DESIGN

In the transition to a digital and connected industrial production of the future, additive manufacturing offers unique opportunities. The expectations of this group of manufacturing processes are equally high. In order to exploit the diverse potentials, it is necessary to rethink the entire product development process. Special features, such as the possibilities for function integration, must be consistently considered already in the concept and design phase. Within the scope of this project, a catalogue for supporting the conceptual and design tasks associated with function integration by means of additive manufacturing was developed and demonstrated specifically in the field of drive technology using application examples.

PROJECT OVERVIEW

DURATION

08/2021 – 01/2023

PARTNER

- IEM – Fraunhofer Institute for Mechatronic Systems Design

FUNDED BY

FVA – Research Association for Drive Technology

RESEACHER

Research Leader
Prof. Dr.-Ing. Detmar Zimmer

Research Assistant
Sebastian Magerkohl
Thorsten Koers

The process-specific characteristics of additive manufacturing (AM) offer many possibilities and the AM industry has recorded enormous growth rates in recent years. The high degree of design freedom and the cost-effective production of small quantities are only some of the advantages. The technology is now used across all industries for the production of prototypes or tools, but is also increasingly used in the production of series parts. In addition to the possibilities, the new processes are also creating unknown challenges that the users of this technology must consider.
New possibilities require new approaches
In order to use the given potentials, a corresponding development and optimisation process is required, which must be accompanied by a methodical procedure due to the variety of requirements and the complexity of the components. The functional and economic potential of additively manufactured components can only be fully exploited if suitable approaches are developed and applied already in the conception. Process-specific characteristics of additive manufacturing require a rethinking already in the concept phase. Due to the geometric design possibilities of additive manufacturing, complex components can be produced economically and thus enable a higher degree of functional integration. The possibility of implementing several functions in one component and thus saving material and assembly steps offers ecological and economic advantages.

Research objective

The objective was to develop a self-learning document to support the designer in the context of conceptual and design-related challenges. The scope focused on the possibilities of function integration in the application field of drive technology. The consistent use of additive manufacturing still represents a major challenge for many companies. It is particularly difficult for small and medium-sized companies to build up experience in this area, as the barriers to entry are high due to investments. The catalogue with active principles and design guidelines is intended to serve as support for the user in this initial phase, but also beyond.

Results

The result of the project is therefore a self-learning document to support the conceptual and design tasks associated with function integration using additive manufacturing for drive technology. The first section provides a standardised understanding of the basics of additive manufacturing for all users. The second part of the document presents principles and procedures for function integration. The third section presents application examples to visualise the process model with demonstrative objects. Finally, the results were implemented in a self-learning document to accompany the project.

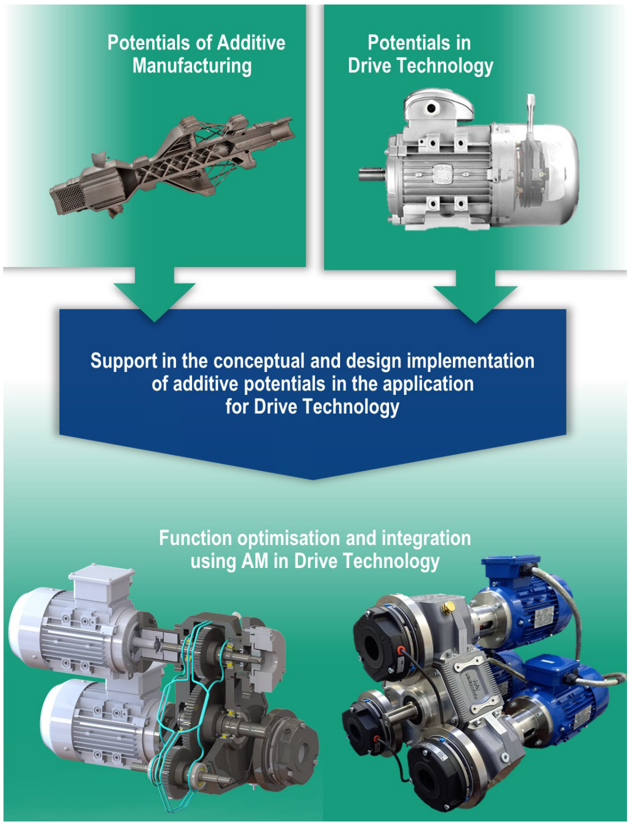

FIGURE 1 Project objective: Use potentials to optimise and integrate functions

MULTIMATERIAL DESIGN USING 3D PRINTING

Additive manufacturing (AM) has the economic potential to complement conventional manufacturing processes, especially in the production of complex, multi-material (MM) components. Still, multi-material combinations from conventional processes are not transferable to AM, due to residual stresses, cracks or thermal expansion rates of the different materials. Furthermore, geometric shape and position tolerances, as well as recycling strategies for powder waste, post-processed waste and the component itself are not yet defined. Based on the 3D printing processes PBF-LB and DED, this project aims at the concurrent engineering of designing processable multi-material optimized alloys, development of design concepts for multi-material structures with specific simulations for load cases and topology optimizations, and an extensive process adaption.

PROJECT OVERVIEW

DURATION

01/2016 – 01/2019

PARTNER

- Nikon SLM Solutions AG (GER)
- Fraunhofer IGCV (GER)
- Univerität der Aegäis (GRC)
- f3nice (ITA), Exponential Technologies (LVA),
- QuesTek Europe AB (SWE)
- AVL List GmbH (AUT)
- SAFRAN Additive Manufacturing Campus (FRA)
- CEA (FRA)
- Amires (CZE)
- CSEM (SUI)
- Skyrora LTD (SCO)

FUNDED BY

European Heakth and Digital Executive Agency (HADEA)

RESEACHER

Research Leader
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Prof. Dr. Mirko Schaper
Research Assistant
Dennis Lehnert
Sven Gründer

Aim

The project proposed addresses the multi-material additive manufacturing to enable unprecedented design freedom for highly complex components with functionally graded properties. Overall, concurrent engineering will be conducted within this project in which multi-materials, AM process modifications, component design, and recyclability will be developed parallel. Thus, a mechanistic project structure is created by applying system engineering starting with the computational material design, over machine optimizations, novel process parameter concepts to AM tailored multi-material component design and recycling. Regarding the multi-material manufacturing via 3D printing, the consortium members will process the AM multi-material combinations INC718, CuCrZr, Cu, 316L, FeSi2.9 & AlSi10Mg.

Procedure

This project will use computationally designed multi-material components using a lean system design approach with science-based models and designs tailored for the interface region to consider thermal stresses using Direct Energy Deposition (DED) and Laser Powder Bed Fusion (PBF-LB). Consequently, novel laser scan strategies will be developed to eliminate undesired cracking in both processes. In PBF-LB, the powder separation and scan strategies must be improved and an adapted and enhanced powder recoater and suction unit must be designed for limiting unintended cross-contaminations, defect formation and thermal stresses at the transition layer. The computationally designed multi-material prototypes will be gas-atomized, and then 3D printed utilizing novel scan strategies. The circular material cycle is investigated to achieve a sustainable manufacturing route integrating life-cycle-cost analyses. The microstructural and mechanical performance is tested in detail of the following material combinations: Ti64-INC718, Al-alloy-Cu-alloy, and Fe (non-magnetic)-Fe (magnetic). Conclusively, a concurrent engineering approach is conducted in which material engineering, multi-material 3D printing, component design, and sustainability are inherently connected to developing lighthouse components for the automotive aeronautics and aerospace industry.

Outlook

MADE-3D aims to impact the entire process chain of 3D printed multi-material components:

- Generic computational material-design concepts, which can be transferred to other MM combinations.
- L-PBF & DED technologies are improved to disrupt 3D printing applications.
- Novel information on design guidelines to exploit the advantages of MM processing leading to numerous product improvements.
- Sustainability addressing energy efficiency, cost, and recyclability to industrialise MM components.

The project offers substantial benefits by revolutionising component weight reduction. Lighter components lead to energy efficiency, reduced emissions, and improved performance in various sectors like aerospace, aeronautic & automotive. This innovation enhances EU's competitiveness, fosters technological leadership, and promotes sustainability, aligning with its goals for a greener future.

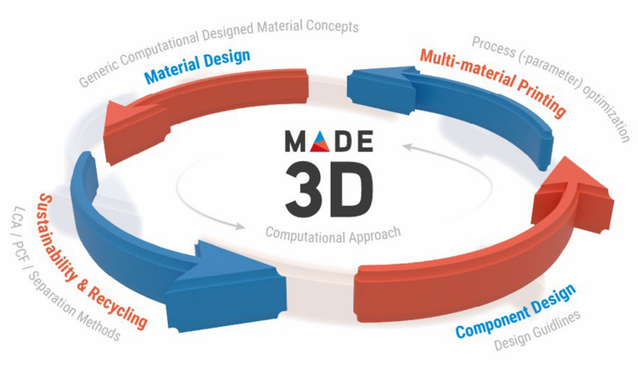

FIGURE 1 Validation of performance parameter

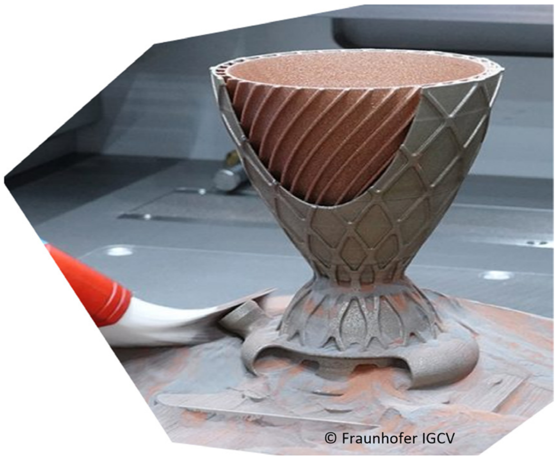

FIGURE 2 Distrotion measurement with CT analysis of the component

DEFINED APPLICATION OF LUBRICANT TROUGH ADDITIVELY MANUFACTURED FORMING TOOLS

The project's objective is to create a modular tool system that incorporates additively fabricated structures with specific permeability for inherent lubrication during the deep drawing process. This tool concept leverages the inherent benefits of processing powdered tool steels through laser beam melting in a powder bed. The resulting tool inserts, distinguished by a unique structural design featuring a defined micro hollow chamber or micro channel structure, facilitate an innovative lubrication approach in the deep drawing process. The goal is to regulate the supply of lubricant during the forming process at a specific time and location, using a minimal quantity of lubricant. This reimagined approach aims to enhance efficiency and precision in the deep drawing process.

PROJECT OVERVIEW

DURATION

03/2023-03/2025

PARTNER

- Forming and Machining Technology (LUF)
- Materials Science (LWK)

FUNDED BY

Aif
IGF Fosta

RESEACHER

Research Leader
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Prof. Dr.-Ing. habil. Mirko Schaper
Research Assistant
Robert Fleischer, M.Sc.
Ermir Cakici, M.Sc.

Objectives

The aim of the project is to develop a modular tool system with additively manufactured, defined permeable structures for intrinsic lubrication in the deep drawing process. The tool concept is based on the processing of powdered tool steels by means of powder bed-based laser beam melting using the process-inherent advantages. The tool inserts generated in this way with a special structural design, which is characterized by a defined micro hollow chamber or micro channel structure, enables an innovative lubrication concept in the deep drawing process with the aim of controlling the lubricant supply during the forming process in a defined time and place with a minimum amount of lubricant. The design and control should improve the sequence and result of the forming process, making the use of additively processable tool steels significantly more attractive and enabling sustainable forming processes. In order to achieve this, the process window for laser beam melting needs to be adapted so that the steel powder can be additively processed into tool components that contain locally adjustable permeable structures with regard to the lubricant application and the resulting tribological properties. In addition to the manufacturability, a tool system and an example deep-drawing process are to be developed in order to demonstrate the performance of intrinsic lubrication as an extension to the current process limits.

Finally, the results of the research project will be used to develop guidelines for the use of additively manufactured lubricant-permeable structures in order to extend the process limits of the forming process with complex steel components. The benefit for SMEs is expected to be that the possibility of such a modular tool system allows the ecological manufacturability of complex steel components.

Approach

Six sub-goals (milestones) are defined to achieve the research objective:

Sub-goal 1: Micro-crack-free additive processing of tool steels

- Robust and reproducible processing of tool steels using LPBF (≥ 99.9 % relative density).

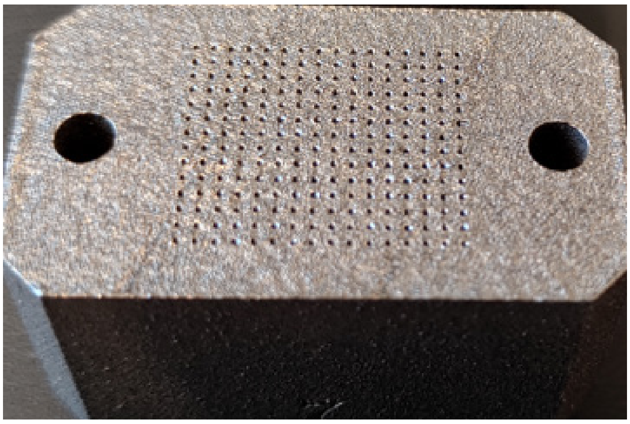

FIGURE 1 Modular tool component with fine permeable structures in a defined section

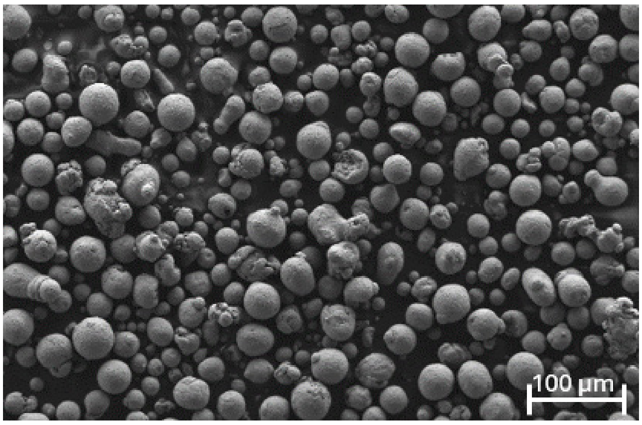

FIGURE 2 SEM image of utilized tool steel metal powder for morphological analysis

- Basic knowledge of processing, the formation of defects and the adjusted microstructure
- Milestone 1: Fundamental understanding of the microstructure and any defects in the processed materials.

Sub-goal 2: Manufacturability of delicate tool (tool) structures
- Production of filigree, defined permeable structures / corresponding surfaces in sheet metal forming tools.
- Milestone 2: Production of intrinsically lubricated tool components using LPBF.

Sub-goal 3: Functionality testing
- Knowledge of the mechanical loads on the tool structures from sub-goal 1 to ensure that the tool inserts are suitable for the process. Proof of lubricant-permeable functionality and fulfillment of surface quality requirements.
- Milestone 3: Proof of the mechanical and process-related suitability of the lubricant-permeable structures for sheet metal forming processes.

Sub-goal 4: Tribological principles
- Qualification of the active and passive lubricant supply for the deep-drawing process, the lubricant-permeable tool inserts and the establishment of a guideline for the design of the meso- and macroscopic structures of the lubricant pockets. Derive statements on the change in friction behavior and wear of the tool.
- Milestone 4: Basic knowledge of the tribological behavior of intrinsically (minimally) lubricated friction pairings.

Sub-goal 5: Fundamentals of deep drawing of components made of high-strength steel materials using tools produced by LPBF with intrinsic lubrication functionality
- To demonstrate the possibilities for controlling deep drawing processes using intrinsic minimum quantity lubrication concepts in conjunction with corresponding surface structures. Correlation of the effect and interaction of process, tool, material and auxiliary material parameters with the sequence and result of deep-drawing processes using high-strength steel materials.
- Proof of functionality through the production of functional sample workpieces and a practical demonstrator.
- Milestone 5: Successful application of the acquired process knowledge through the production of a demonstrator (tool and workpiece (scaled axle carrier)) made of high-strength steel.

Sub-goal 6: Design instructions for the user
- Derivation of guidelines regarding the processing and application of additively manufactured defined permeable tool inserts with information on economic design / layout for deep drawing.
- Milestone 6: Design guidelines for process and tool production successfully completed.

POLYLINE - INTEGRATED PRODUCTION LINE FOR POLYMER-BASED AM APPLICATIONSSTAINLESS STEEL TUBE PROCESSING

The POLYLINE project brings together 15 industrial and research partners from Germany to develop a next-generation digitized production line. This line will be used to produce plastic components for the automotive industry. The aim is to supplement established production techniques (e.g. machining, casting, etc.) with additive manufacturing (AM) high performance line production systems.

PROJECT OVERVIEW

DURATION

02/2020-01/2023

PARTNER

- BMW Group – Additive Manufacturing Center
- EOS GmbH Electro Optical Systems
- Grenzebach Maschinenbau GmbH
- DyeMansion GmbH
- Krumm-tec
- 3YOURMIND GmbH
- Additive Marking GmbH
- Bernd Olschner GmbH
- Optris GmbH
- Fraunhofer IGCV
- Fraunhofer IML
- Technische Universität Dortmund
- Universität Augsburg
- Universität Duisburg Essen
- Universität Paderborn

FUNDED BY

BMBF

RESEACHER

Research Leader
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Research Assistant
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Klaas Tuschen, M. Sc.

POLYLINE
Integrierte Linienanwendung von polymerbasierten AM-Technologien

Project Objectives

The primary goal of the POLYLINE project is to advance polymer-based laser-sintering (LS) additive manufacturing (AM) into an automated and efficient production process (see Figure 1). The project aims to elevate AM technology to a level where it can compete with established manufacturing processes like machining and casting in high-performance production systems. This development will enable more flexible production, with parts being manufactured directly in Germany, demonstrated through examples of series parts from the automotive industry.

Motivation

Currently, the integration of additive manufacturing processes into conventional production lines is limited, both vertically and horizontally. This is due to several factors, including AM-specific production steps (such as the batch process) and the generally low level of automation in machining and transport processes. These challenges result in discrete production intervals and a high degree of manual effort. Additionally, the digital data chain across the horizontal process chain is often discontinuous at various interfaces, leading to a lack of transparency, increased error susceptibility, and limited monitoring throughout the processes. These issues make it difficult to integrate AM into existing production control systems, thereby restricting the potential of additive manufacturing in series production and assembly lines.

Procedure

To achieve the project's objectives, the project focuses on achieving breakthroughs in both digital and physical systems. This includes recording and documenting all key values and quality criteria (such as identification, history, and measured values) from the CAD model to the finished component.

The individual production sub-processes—from process preparation to the laser-sintering process, cooling and unpacking, as well as cleaning and post-processing of the parts—will be automated and integrated into the planned production line. For the first time, all stages of an LS production chain will be fully interconnected.

Project Information

This research project is part of the “Line Integration of Additive Manufacturing Processes” program by the Federal Ministry of Education and Research (BMBF). It is funded by the BMBF with €10.7 million and is supported by the VDI Technology Center (VDI-TZ GmbH) as the project management organization.

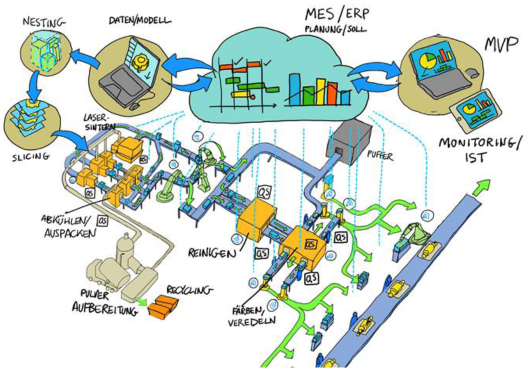

FIGURE 1 © G. Katsimitsoulias, Fraunhofer IML

INTELLIGENT-CONTROLLED AM PROCESS CHAIN USING SIMULATIVE AND EXPERIMENTALLY DETERMINED COMPONENT, MATERIAL AND PROCESS DATA (READDI)

The automotive industry is a key industry in Germany and one of the country's largest employers. Innovative, flexible and versatile production methods are required in order to withstand international competition and meet increasing customer demands. In particular, there is great interest in lightweight, low-vibration parts with a high degree of functional integration for electric mobility. Additive manufacturing can make a significant contribution to the realisation of such requirements. This project will implement a prototype of additive serial production for the automotive industry.

PROJECT OVERVIEW

DURATION

10/20219 – 12/2023

PARTNER

- Daimler AG
- DMG Mori GmbH
- EDAG Engineering GmbH
- FAU Erlangen-Nürnberg (Institute of Photonic Technologies)
- Heraeus Nobelight GmbH
- Indutherm Gießtechnologie GmbH
- INTES GmbH
- Karlsruhe Institute of Technology (Institute of Production Science)
- Paderborn University (Chair of Design and Drive Technology)
- Protiq GmbH
- QASS GmbH
- Robert Bosch GmbH
- Rosswag GmbH
- Simufact GmbH
- USU Software AG

FUNDED BY

BMBF

RESEACHER

Research Leader
Prof. Dr.-Ing. Detmar Zimmer
Dr.-Ing. Vera Denzer
Research Assistant
Tobias Lieneke; M.Sc.

Motivation and aim

One of the aims of this project is to realise a prototypical line integration with a view to the implementation of series production of additive manufactured parts in the automotive industry. Appropriate in-line and in-process measurement technologies will provide feedback from the individual process steps. To this end, all parts of the process chain, including part design, powder, the LPBF process itself and post-process, will be connected and vertical and horizontal data integration will be achieved.

Scope of the project

Additive manufacturing has advanced significantly in recent years, opening new possibilities for product development and component manufacturing. However, challenges in quality and functionality remain, prompting research into several key areas. This project focused on three main design topics: damping with additive-manufactured particle dampers, developing design guidelines for support structures, and investigating geometric accuracy in Powder Bed Fusion - Laser Beam/Metal (PBF-LB/M). The project aimed to develop comprehensive methods to optimize additively manufactured components by considering design recommendations, active principles, and geometric deviations. The innovation lay in creating solutions to assist designers in component design, particularly in investigating vibration damping functions to enhance functional integration and density, thereby adding value to component manufacture. Quantitative experimental and simulation studies were conducted to compare the performance of additively manufactured components with conventional ones early in the design process, aiming to optimize component design, functionality, and necessary tolerances for a robust manufacturing process. This involved intensive analyses of geometry and process parxxameters impacting component quality. The innovations were documented in digital catalogs of active principles, design guidelines, and tolerance values, and integrated into software tools. In part design for additive manufacturing, the concept and design phases can be digitized for line integration. Additive structures significantly improve vibration dampening through high functional integration and density, quantified by experimental investigations to enhance part performance.

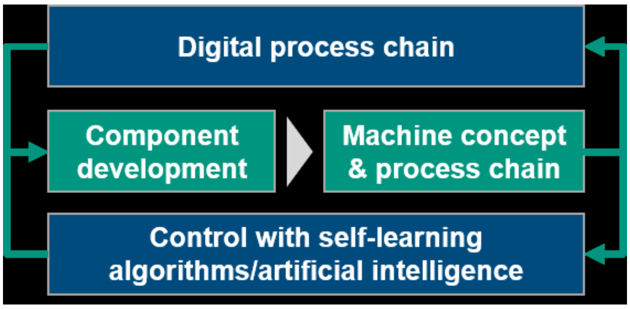

FIGURE 1 Concept of process chain

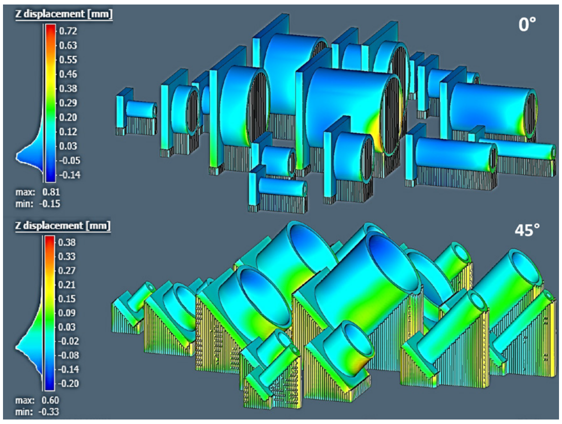

FIGURE 2 Simulation results for cylinders in different orientations including support material in PBF-LB/M

Comparing additively and conventionally manufactured parts early in the design process allows for the derivation of design guidelines for particle impact damping. Additionally, design guidelines for manufacturing-oriented support design were digitized in design catalogs. Post-processing involves experimentally developing geometric deviations and evaluating results using machine learning methods. Recommendations for designing parts suitable for measurement were also formulated. The aim was to optimize part design based on function and required tolerances, enabling a robust process chain. Feedback from the end of the process chain can be used to iteratively improve parts or process parameters. Experimental results on particle impact damping, manufacturing support design, and geometric deviations were transformed into digital operating principles, design guidelines, and tolerance catalogs, integrated into software tools within the project. Utilizing artificial intelligence and machine learning aids in creating a universally applicable digital process chain, complementing the actual process chain.

Results by Paderborn University

The additive manufacturing research conducted within the sub-project has resulted in important advances in the damping of particle dampers, the development of design guidelines for support structures and the investigation of geometry accuracy. These findings help to overcome the challenges associated with the quality and performance of additively manufactured components and open up new opportunities for the application of additive manufacturing technology in various industries. Further research and development are needed to realise the full potential of this technology and drive its integration into series production, including in other industries.

Damping structures

The damping of additively manufactured components using powder cavities integrates damping properties directly into structural components, improving functionality without extra costs. Project results show promising damping properties, using a performance approach to determine the loss factor. A specially developed test rig measures velocity and force, and damping is evaluated via dissipation factor maps. Design guidelines were derived, and the potential of the particle attenuator was demonstrated with a maximum loss factor of $\eta = 1.27$.

Support structures

Solid support structures in PBF-LB/M affect component quality and process efficiency. A method was developed to create production-oriented design guidelines for support structures, improving quality and efficiency. These guidelines are based on quality criteria and involve producing test specimens and standardising procedures for investigating support structure parameters. Future research should explore more support structures, integrating results into a database for comprehensive process understanding.

Geometrical accuracy

Additive manufacturing often results in insufficient geometric accuracy, a critical issue for industrial use. A method was developed to analyse geometric deviations, including application-oriented test specimens and innovative measurement methods. The results provide insights into causes of shape deviations, improving simulation models for predicting these deviations. Significant influences include installation space position, orientation, and nominal dimensions. Future research should investigate geometric deviations further and optimise simulation models, focusing on process parameters like laser power and hatch distance to improve process quality and reduce production costs.

REFLAM-LS: DEVELOPMENT OF RECYCLEABLE AND FLAME-RETARDANT MATERIALS FOR LASER-SINTERING

Laser-sintering is one of the most popular polymer 3D printing technologies for industrial applications. However, the number of suitable materials is still severely limited, meaning that not all customer requirements can be met. One example of these often-conflicting requirements is the flame retardancy of polymer laser-sintered materials, which is required for aerospace, medical, electronics and many other industries. Currently, flame-retardant laser-sintering powder materials are commercially available, but two major problems prevent their economic use in industry. Either these powders contain halogenated flame-retardant additives, or they cannot be recycled. This results in very high material costs that cannot be justified from a sustainability perspective.

PROJECT OVERVIEW

DURATION

05/2024 – 04/2027

PARTNER

- Launhardt GmbH
- Weidmüller Interface GmbH & Co. KG
- Siemens Healthineers AG

FUNDED BY

EFRE/JTF-Program NRW 2021-2027

RESEACHER

Research Leader
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Research Assistant
Fabian Neitzel

Motivation and Aim

The demand for flame-retardant parts produced with additive manufacturing technologies is growing rapidly, especially in the mobility and E/E industries. Although some flame-retardant polyamide 12 powder materials for laser-sintering are currently commercially available, two main problems prevent their sustainable and economical use. First, many materials use halogenated flame retardants (FR), especially brominated flame retardants. While these can be combined with many plastics and are relatively inexpensive, they are persistent in the environment and bioaccumulative. In addition, some of these flame retardants produce corrosive and highly toxic by-products or combustion gases in the event of a fire. With the implementation of European directives such as REACh, RoHS and WEEE, many OEMs have committed to phasing out halogenated products from their portfolios. As a result, these products are no longer available for laser-sintered parts.

The second issue is the lack of recyclability of powders containing halogen-free flame retardants. With currently available powder materials, such as PA2210 FR from Electro Optical Systems or DuraForm FR1200 from 3D Systems, the manufacturers completely preclude process recycling of the unexposed powder after a production run. Due to the aging of the polyamide or flame-retardant additive, the manufacturer can no longer guarantee the specified fire-retardant properties of the aged powder. This lack of recyclability fundamentally prevents ecological and economical use. Since polyamide 12 consists mainly of carbon and hydrogen atoms, and the chemical industry still obtains most of its carbon requirements to produce these polymers from fossil sources, the high reject rates cannot be justified in terms of resource efficiency and sustainability.
Therefore, the ReFlaM-LS research project aims to develop the first halogen-free powder material with flame-retardant properties for the laser-sintering process, which allows process recirculation and thus recycling of the high proportion of excess powder after each production iteration.

Scope of the Project

A recycling-optimized polyamide 12 powder will be used for the polymer matrix in this project. Recycling-optimized means that the post-condensation and thus the aging of the material during processing in the laser-sintering process is significantly reduced. The recycling-optimized polyamide 12 as a base material thus combines a high potential in terms of recyclability with a high degree of market acceptance and versatility. The flame-retardant effect of the material is achieved by using halogen-free flame retardants such as melamine cyanurate or aluminum diethyl phosphinate. These have sufficient temperature stability and hydrolysis resistance to withstand the process conditions of laser-sintering. The basic feasibility has already been demonstrated in preliminary studies.

FIGURE 1 UL94 Vertical Flammability Test

RESOURCE AND ENERGY EFFICIENCY BY INCREASING THE BUILD-UP RATE IN THE LASER BEAM MELTING PROCESS BY OPTIMIZING THE LASER FOCUS

The nickel-based alloy Inconel 718 poses a great challenge to conventional machining due to its high strain hardening and toughness. Here, the LPBF process offers an alternative with potential savings if sufficiently high productivity can be achieved. Based on the parameter study carried out, starting from 60 µm parameters for the manufacturing of components, exposure parameters could be developed to realize manufacturing with 120 µm and 150 µm layer thickness, with almost the same geometric accuracy. For this purpose, the parameters of laser power, focus diameter, hatch distance and scan speed were varied. The negative defocusing of the laser showed a positive effect on the density of the parts, realizing densities ≥ 99.9 %, with high dimensional stability, good mechanical properties and a reduced manufacturing time of up to 61 %.

PROJECT OVERVIEW

DURATION

04/2022-09/2022

PARTNER

FUNDED BY

Ministerium für Wirtschaft, Industrie, Klimaschutz und Energie des Landes Nordrhein-Westfalen

RESEACHER

Research Leader
Prof. Dr. rer. nat. Thomas Tröster
Research Assistant
Christian Bödger, M.Eng.

Introduction

Additive manufacturing, particularly Laser Powder Bed Fusion (LPBF), offers substantial potential for lightweight construction, providing benefits such as design freedom, reduced material waste, and lower tool wear. However, LPBF's productivity is lower compared to conventional manufacturing methods. This research builds on previous studies that increased productivity by enlarging the layer thickness from 60 µm to 180 µm. The current study extends these findings by widening the laser focus to expose a larger powder bed area per scan vector, potentially saving up to 50% of exposure time.

Experimental Details and Methodology

The experiments were conducted using an SLM 280 2.0 machine equipped with a 700 W ytterbium fiber laser. The Inconel 718 powder used in the experiments was spherical, with particle sizes ranging from 10-45 µm. Various parameters, such as laser power, scan speed, and hatch distance, were tested to determine their impact on the build rate and sample density. A Central Composite Design (CCD) type Design of Experiments (DoE) strategy was employed to systematically vary these parameters at layer thicknesses of 120 µm, 150 µm, and 180 µm. Initial tests kept the laser focus constant at 113 µm, producing cubic specimens to measure density and geometric accuracy.

Results and Discussion

One of the key findings was that negative defocusing of the laser, which involves moving the focus point below the powder bed surface, had a positive impact on part density. This technique resulted in relative densities of 99.94% or higher. The improvement in density is due to the divergent beam path during negative defocusing, which resembles heat conduction welding and avoids keyhole defects and gas porosity common in positive defocusing.
By adjusting process parameters such as laser power, focus diameter, hatch distance, and scan speed, the study achieved high densities with substantial geometric accuracy. This approach also led to a significant reduction in manufacturing time, thereby improving productivity. When testing different layer thicknesses, the

research found that mechanical properties were comparable to the standard 60 µm thickness at 120 µm and 150 µm. However, at 180 µm, mechanical properties such as tensile strength and elongation at break were reduced.

Tensile tests and Charpy impact tests were conducted to evaluate the mechanical properties of the produced samples. The results indicated that increasing the layer thickness to 120 µm resulted in mechanical properties similar to those obtained with the standard 60 µm thickness. The 150 µm thickness also showed acceptable mechanical properties, while the 180 µm thickness exhibited reduced performance, particularly in terms of tensile strength and elongation at break.

The successful application of negative defocusing indicates a potential pathway to enhance the LPBF process's productivity while maintaining the desired material properties. These findings are particularly significant for industries such as aerospace, where high-performance materials like Inconel 718 are crucial. The research highlights the importance of fine-tuning process parameters to balance productivity and quality.

In conclusion, by optimizing process parameters, particularly through negative defocusing and adjusting the laser focus diameter, the study achieved a significant increase in productivity for the LPBF process using Inconel 718. The findings suggest that the optimized parameters can maintain high geometric accuracy and mechanical properties while substantially reducing manufacturing time. This research provides a foundation for further improvements in additive manufacturing productivity for high-performance alloys.

Future research should focus on refining these parameters further and exploring their application to other high-performance materials. Additionally, investigating the long-term performance and durability of parts produced with optimized LPBF settings will be crucial for broader industrial adoption. Moreover, an in-depth understanding of the interaction between various parameters and their combined effect on the LPBF process could lead to further enhancements in efficiency and quality. Advanced modeling techniques and real-time monitoring systems could also play a vital role in optimizing and controlling the manufacturing process, ensuring consistent and reliable production outcomes.

The significance of this study extends beyond immediate productivity gains. By improving the LPBF process for Inconel 718, industries can benefit from reduced production costs, faster turnaround times, and the ability to create complex geometries that were previously unattainable. This progress in LPBF technology also aligns with the increasing demand for sustainable manufacturing practices. Reduced material waste and energy consumption are key benefits of additive manufacturing, and enhancing the LPBF process further amplifies these advantages.

Another important aspect of this research is its potential impact on other high-performance materials beyond Inconel 718. The methodologies and findings can be applied to other nickel-based superalloys, titanium alloys, and even certain steel grades. This cross-material applicability enhances the value of the research, paving the way for broader industrial adoption of optimized LPBF processes.

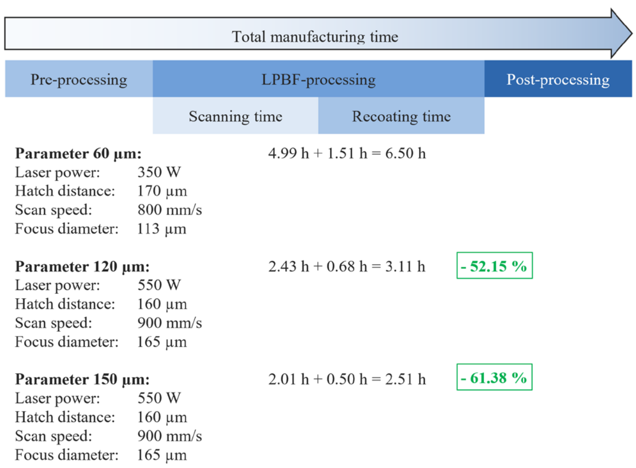

FIGURE 1 LPBF manufacturing time for different layer thicknesses

INCREASING ENERGY AND RESOURCE EFFICIENCY IN THE SLM PROCESS THROUGH PROCESS-OPTIMIZED ADJUSTMENT OF POWDER FRACTIONS (SERAP)

Selective Laser Melting (SLM) has established itself as one of the most widely used additive manufacturing processes in recent years. However, the technical potential of the process has not yet been fully exploited, opening up further research opportunities. The focus of this project is on improving material yield while simultaneously increasing component densities. In the future, this could save energy, as the need for remelting of rejected powder during recycling and the associated high energy consumption would be reduced.

PROJECT OVERVIEW

DURATION

10/2020-09/2022

PARTNER

- Chair of automotive lightweight design (LiA); Rosswag GmbH

FUNDED BY

Deutsche Bundesstiftung Umwelt (DBU)

RESEACHER

Research Leader
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By testing multimodal powders, a strategy is demonstrated to increase material utilization by up to 25%. Previously unused powder fractions are made usable through additional processing steps, contributing to a significant increase in energy and resource efficiency in the manufacturing process. By reducing the amount of powder that needs to be melted, more than 60,000 tons of CO2 can be saved based on the projected powder consumption.
The aim of the project is to improve component densities and yield during powder production by optimizing the powder fractions used in the SLM process. To this end, bi- and trimodal powder configurations with broader grain size fractions compared to the industry standard are employed. The use of multimodal powder results in a theoretically higher packing density in the process, leading to a denser powder bed. Consequently, the project will examine whether denser components can also be produced in this way. Additionally, the utilization of a wider particle size range can improve powder yield by reducing waste during powder production.

To place the research results in an economic context, the potential energy savings of the project will be determined through a Life Cycle Assessment (LCA), analysing the various processes of powder production and SLM. The focus will then shift to closer examination of the powder in the SLM process. Specifically, bi- and trimodal powders made of steel 1.4404 will be used in the process, and their effects on powder bed density and component porosity will be investigated. Using a custom-developed coating test rig, parameter studies on the developed powder configurations will be conducted for varying layer thicknesses, aiming for the maximum possible powder bed density. The use of broader powder particle classes than those typically used in practice (15-63 µm) will also be studied. Based on the research findings, components will be produced using the different powder configurations and standard powder, and the impact of powder configuration on porosity and mechanical properties will be evaluated.

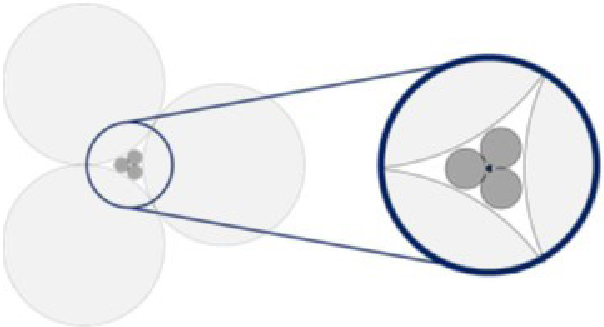

FIGURE 1 Particle size ratio in multimodal mixtures

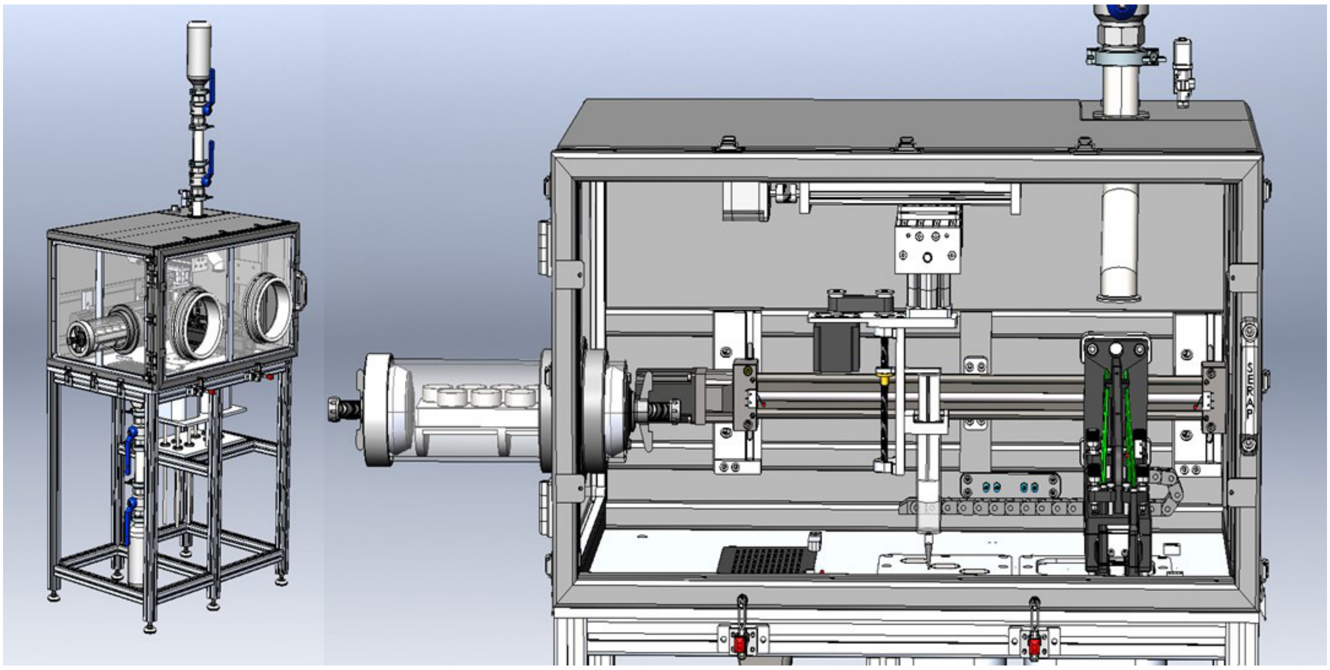

FIGURE 2 Developed coating chamber for the investigation of coating parameters

SIMULATION OF THE SHRINKAGE BEHAVIOUR IN FUSED DEPOSITION MODELING

The Fused Deposition Modeling (FDM) process is one of the most common additive manufacturing processes. Due to the cooling of the material after the deposition of the thermoplastic strand, shrinkage occurs. The degree of the occurring shrinkage depends on certain process parameters as well as on the geometric properties of the components. As the influences of these process parameters and geometric properties are not yet sufficiently known, this project investigated the effects on the shrinkage by the use of simulations of the ongoing processes inside the FDM machine.

PROJECT OVERVIEW

DURATION

12/2019 – 11/2022

PARTNER

FUNDED BY

Deutsche Forschungsgemeinschaft (DFG)

RESEACHER

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Thorsten Koers

DFG Deutsche Forschungsgemeinschaft
German Research Foundation

Summary

Additive manufacturing is a manufacturing process and is characterized by the layer-by-layer generation of components. The layer-by-layer principle enables almost unlimited accessibility to every area of the component to be manufactured during the manufacturing process. This results in new potentials with regard to the design of complex component structures that cannot be produced economically by conventional methods such as machining. The Fused Deposition Modeling (FDM) process is a widely used additive manufacturing process. Here, a thermoplastic polymer filament serves as the raw material. The filament is fed into the so-called FDM-head by a feeder unit, which is located in the heated build chamber, where it is plasticized in a heated nozzle. A plasticized plastic strand is discharged from the nozzle, forced by the following material being pushed into the heated nozzle. In the system used in the project, a “Fortus 400mc large” from Stratasys, the strand is deposited in the respective layer in a defined manner by the movement of the nozzle in the XY-plane. For this purpose, first, the contour and then the filling of the cross-sectional area of the respective layer of the component is applied. The build platform is then lowered by one layer thickness and the deposition process begins for the subsequent layer.

The successive build-up of the component from individual, plasticized polymer strands results in complex cooling processes. These cooling processes result in anisotropic shrinkage of the final component. In previous investigations, KNOOP showed that the linear shrinkage factors established in practice only apply to specific nominal length ranges for the test specimens investigated. Until now, components have been adjusted in an iterative process of repeated manufacturing and measuring to achieve better dimensional accuracy. Due to the long process times, this procedure is not economical. From this, the need for research was derived to develop a possibility to apply different shrinkage factors to different areas of the component already in the CAD-file. Within the scope of the project, the approach envisaged in the application was initially pursued. In the course of the investigations, however, the approach considered proved to be unsuitable. Instead of the proposed cooling simulation, modeling (DOE) of the shrinkage

behavior of raster lines and the geometry-specific volumetric shrinkage of components was resorted to in the further course of the project. This model is applied locally by a software developed within this project according to the situation and depending on the process parameters to be used in the subsequent manufacturing process. The results show that with the developed methodology, the dimensional accuracy of simple geometries can be improved beyond the results obtained by applying linear scaling factors.

Validation

In order to determine the general transferability of the adaptive scaling factors of the developed software, in addition simple curved test specimens with different diameters were manufactured and the dimensional and shape deviations in the XY plane were measured. The dimensional deviations are small at the local layer level. The formation of a concave shape of the cylindrical surfaces results in an increased scatter of measured values globally. By extended modelling of the adaptive scaling the concave shape in the Z direction can be eliminated. For simple curved test specimens, constant measured values are achieved in the strand direction.

The transferability of the results, which were determined using basic test specimens (cuboids, cylinders), were tested on a complex demonstrator (Figure 2). For validation purposes, this was manufactured without and with the self-developed software and then analysed by measurement on 20 different local and global non-curved and curved component geometries. These measurement results confirmed the preliminary tests on basic test specimens.

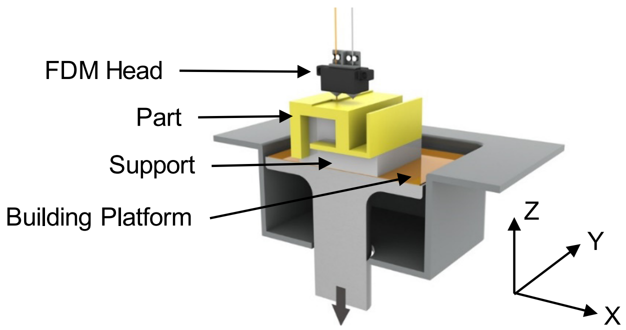

FIGURE 1 Schematic structure of an FDM-system

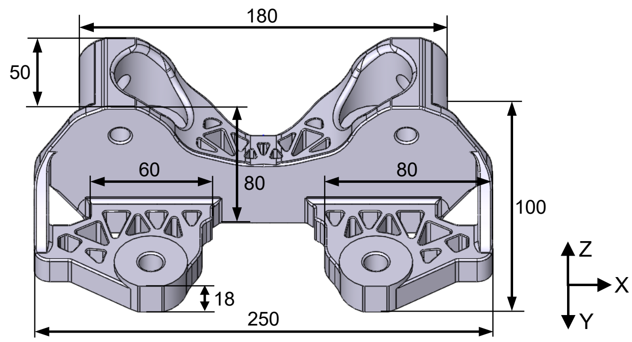

FIGURE 2 Visualisation of the demonstrator used to validate the determined local scaling factors

SIMULATION AND MODEL VALIDATION FOR DEVIATION ANALYSIS OF AM ROTORS

The aim of the project is to analyse deviations between nominal and actual dimensions of additively manufactured rotors and their magnetic properties. It aims to identify the causes of the discrepancies between FEM simulations and empirical measurements and to develop design measures for critical areas in the additive manufacturing of rotors. The results should prevent future manufacturing and simulation errors and improve the efficiency and accuracy of additive manufacturing of electrical machines.

PROJECT OVERVIEW

DURATION

07/2024 – 10/2024

PARTNER

- WITTENSTEIN AG
- ZF Friedrichshafen AG
- hofer AG
- Lenze SE
- Falk Heilfort, Dr. Ing. h.c. F. Porsche AG

FUNDED BY

FVA

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Motivation

The FVA 882/I research project showed that the induced voltage of the functional model differed significantly from the simulation results. This deviation can be attributed to various factors such as leakage fluxes, saturation effects and material properties. Detailed investigation is required to understand and minimise these differences. While additive manufacturing offers great benefits, it also presents challenges that need to be addressed. By identifying and analysing these challenges, future projects can benefit from improved processes and more accurate simulations.

Aim

The project pursues the following main objectives:

- Comparison of the nominal and actual dimensions of the rotor geometry, including leakage gap, air gap and cooling channels.
- Comparison of the nominal and actual magnetisation curves of the soft and hard magnetic materials used.
- Analysing the reasons for the deviations between FEM simulations and empirical measurement results from the ILuKadd3D project.
- Development of design solutions for critical areas in the additive manufacturing of rotors for electrical machines.

Proceeding

To achieve the aims, the project is divided into several phases:

<u>Measurement and documentation:</u>
One of the rotors produced in the project is cut open, ground and measured in the relevant areas. Deviations between target and actual sizes are recorded and documented.

<u>Reproduction and adjustment:</u>
Test specimens are reproduced to check and verify the deviations found. These deviations are minimised by adjusting the geometry and process parameters.

<u>Simulations:</u>
2D and 3D FEM simulations are performed using the updated parameters and geometries. These simulations should provide information on how the various factors affect the performance and magnetic properties of the rotors.

<u>Design actions:</u>
Based on the results of the measurements and simulations, design recommendations for the rotors will be developed. These measures will optimise additive manufacturing and ensure that critical areas are correctly designed.

<u>Expected results:</u>
The project expects the following results:

<u>Rotor geometry comparison:</u>
A detailed comparison of the target and actual dimensions of the rotor geometry is carried out to identify deviations and analyse their causes.

<u>Magnetisation curves:</u>
The target and actual magnetisation curves of the materials used are compared to understand deviations and their causes.

<u>Analysis of deviations:</u>
A comprehensive analysis of the reasons for the deviations between simulations and empirical measurements is carried out. This includes factors such as leakage flux, saturation effects and material properties.

<u>Design advice:</u>
Specific design measures will be developed to improve the additive manufacturing of rotors. These measures will support future projects and optimise the manufacturing and simulation of electrical machines.

Conclusion

The proposed project aims to minimise the discrepancies between simulation and reality in the additive manufacturing of rotors. The knowledge gained will help to improve the efficiency and accuracy of additive manufacturing and avoid future errors in manufacturing and simulation. This will not only improve the performance of electrical machines, but also promote the use of additive manufacturing in industry.

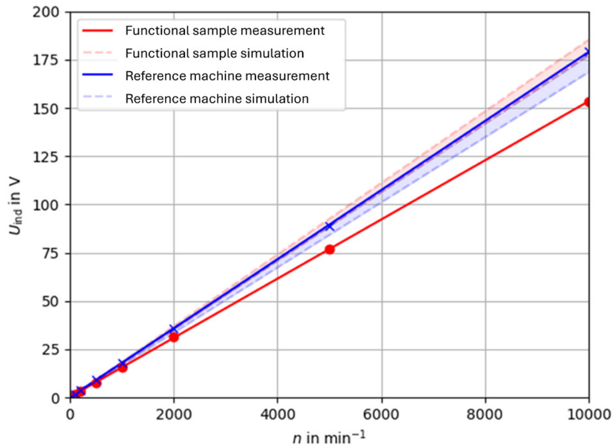

FIGURE 1 Induced voltage of functional model and reference machine

INOCULATION OF ALUMINIUM POWDERS FOR ADDITIVE MANUFACTURING GUIDED BY DIFFERENTIAL FAST SCANNING CALORIMETRY

To process hard to weld materials like high-strength aluminum alloys using laser beam melting (LBM) is one current challenge in additive manufacturing. The implementation of solutions in this field of research provides a considerable potential for lightweight applications, especially for mobility and transportation systems. Within the Special Priority Program (SPP) 2122, promoted by the German Research Foundation (DFG), the Chair of Materials Science (LWK) with the Direct Manufacturing Research Center (DMRC) and the Competence Center °CALOR as part of Rostock University have joint their resources to perform this project on a high level of in-depth science.

PROJECT OVERVIEW

DURATION

2021-2024

PARTNER

- Chair of Materials Science (LWK) of Paderborn University
- Competence Center °CALOR and Chair of Materials Science (LWT), both Rostock University

FUNDED BY

Deutsche Forschungsgemeinschaft (DFG)

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Research Assistant
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DFG Deutsche Forschungsgemeinschaft
German Research Foundation

Objectives

The project aims to develop new powders for PBF-LB/M of high-strength aluminium alloys that prevent hot cracks. This will be achieved by designing nanoparticle (NP) inoculated powders. NPs act as nuclei during rapid solidification, creating a fine-grained microstructure with finely distributed melt. Volume inoculation of NPs in powder particles is proposed to be more effective than surface inoculation due to direct contact with the melt. Preliminary work with TiC and AlN NPs in EN AW-7075 powder supports this. Differential Fast Scanning Calorimetry (DFSC) will guide the design, analyzing rapid solidification of single powder particles. In the first funding period, DFSC solidification onset temperatures were linked with crack-free PBF-LB/M components. Isothermal DFSC will now be applied to study solidification finish. The correlation between solidification behavior and PBF-LB/M across different alloys and NPs will be refined, and NP influence on phase transformations during cooling and heat treatment will be investigated.

Approach

Ball milling is employed to explore the impact of nanoparticle (NP) on the nucleation efficiency during solidification. This method allows for the use of existing powders, producing both small batches for Differential Fast Scanning Calorimetry (DFSC) and accumulating batches for Powder Bed Fusion-Laser Beam Melting (PBF-LB/M). Additionally, it enables the combination of various base materials and grain refiners, and the inclusion of NP mixtures. The investigation will focus on titanium carbide, (TiC) with an NP size of 40 nm and quantities up to several mass percentages will be examined, aligning with previous findings and SPP 2122 guidelines.
The powder modification will ensure potential nuclei are within the powder particles' volume. Initially, NP addition to 7075 powder via ball milling creates a pre-modified powder with an excess of NPs. This powder is then compacted into wire, fed into a 7075 melt, and cast into rods, followed by atomization. Preliminary work with TiC NPs demonstrated the effectiveness of this approach. The modified powders will be characterized using laser diffraction, X-ray fluorescence spectroscopy (XRF) combined with an analysis of additive manufactured products regarding inductively coupled

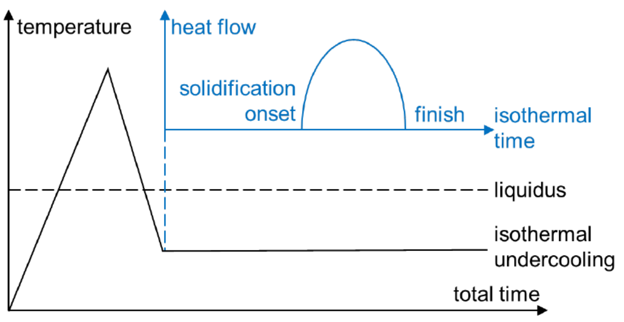

FIGURE 1 Schematic temperature/time course of isothermal solidification experiments in DFSC

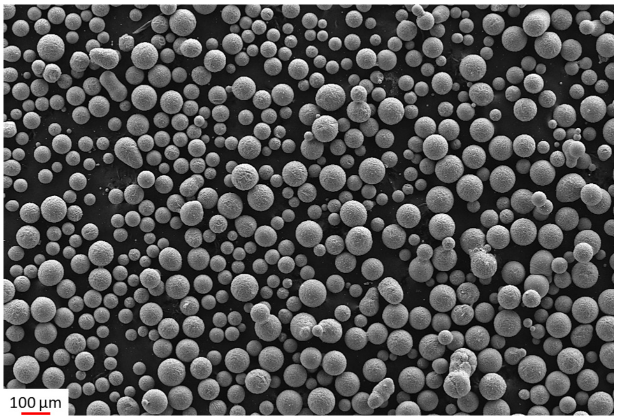

FIGURE 2 SEM-SE of modified EN AW-Al7075 ultrasonic atomized powder

plasma-optical emission spectroscopy (ICP-OES) and transmission electron microscopy (TEM).
DFSC will systematically analyze rapid solidification of powder particles, correlating with PBF-LB/M results. Single particles as well as bulk specimens will be prepared for microstructure analysis, extending to scanning electron microscopy (SEM) and electron backscatter diffraction (EBSD). This comprehensive approach will establish a robust correlation between solidification behavior and PBF-LB/M performance. Mechanical properties will be assessed through hardness and tensile tests in both as-built and heat-treated conditions, considering the impact of NPs on solid-state transformations.

Outlook

After successful demonstration of surface inoculation of AlZnMgCu1.5, further similar materials are to be modified to reduce defects which ocure at high heat input.
In addition, an expansion of the materials portfolio, both nanomaterials and alloys for lightweight design, is planned. Essential factors to implement this kind of material modification for industrial use are the safty handling with nanoparticles and inoculated powder such as adding as small quantities as possible of nanomaterial to reach the largest possible effect in grain refinement.
Once the processability of the inoculated material by laser beam melting is demonstrated, the next target setting is the transmission of the results to other additive processes, if feasible.

THERMODYNAMICALLY SUPPORTED MATERIAL MODIFICATION OF THE HEAT-TREATABLE STEEL 42CRMO4 FOR MICROCRACK-FREE ADDITIVE MANUFACTURING

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PROJECT OVERVIEW

DURATION

03/2023 – 09/2025

PARTNER

- Materials Science (LWK)
- Steel Institute (IEHK, RWTH Aachen)

FUNDED BY

Aif
IGF Fosta

RESEACHER

Research Leader
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Research Assistant
Robert Fleischer, M.Sc.
Vaibhav Vyas, M.Sc. (IEHK)

Introduction

The use of low-alloy, microcrack-free heat-treatable steels in additive manufacturing would allow the production of near-net-shape components for applications with the highest strength and toughness requirements. The economic perspective can be divided into two main segments: Prototype construction & small series components. With the development of an application-adapted, economically processable low-alloy heat-treatable steel through increased build-up rates in the LBM process, the SMEs involved in the PbA gain a significant competitive advantage.

Regarding the production of prototypes, there is the potential to significantly reduce the costs and development time of new powertrain components by being able to additively manufacture iterations of prototype components without the prior production of costly sand-casting molds or forging tools. Conventional functional models can also be generated profitably using LBM. In this context, it is important that the chemical composition of the material is modified as little as possible. This makes it possible to ensure hardenability during the subsequent heat treatment, e.g. through martensitic transformation and/or precipitation processes. In this way, a simple substitution of the process-material combination with mechanical properties that are as comparable as possible can be achieved. Consequently, approval of the AM-adapted 42CrMo4 should be possible without lengthy testing. Therefore, the motivation for adapting the material is initially mainly for use in prototype construction. In addition to the acceptance of the designers and users, a transferability of the component characteristics can thus be derived.
Taking into perspective small series, highly stressed components with bionic structures and additional functions can be produced by developing a modified heat-treatable steel. These components have great potential to significantly improve the performance of entire assemblies, for example through topology optimization.

Project Aim

The following two working hypotheses are formulated as part of this research project:

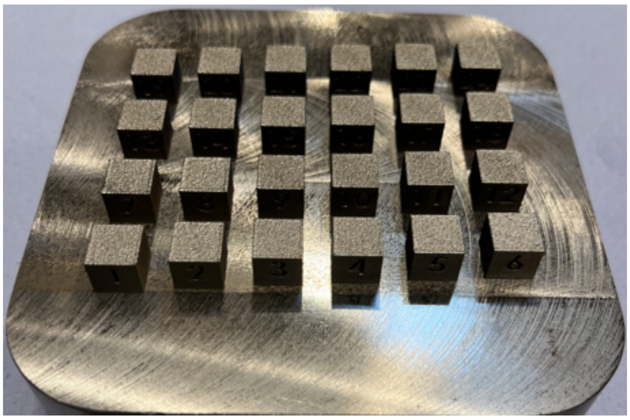

FIGURE 1 Cubical specimen for process development

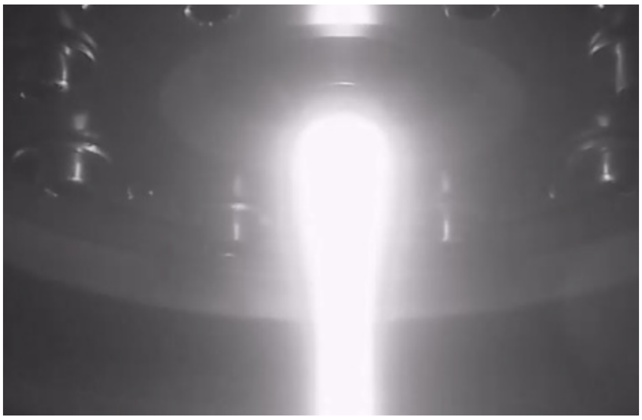

FIGURE 2 VIGA-ATOMIZATION: POWDER PRODUCTION OF DESIGNED MATERIAL

Superordinate working hypothesis:

- The LBM-compliant material modification of the heat-treatable steel 42CrMo4 enables microcrack-free processing when using a substrate plate heating of maximum 200 °C.
- Working hypothesis 1:
- Microcracks during LBM processing can be avoided by a finer grain size in combination with reduced element segregation during solidification, lowering of the martensite temperature and an adapted melt pool geometry.
- Research objective 1:
- Microcrack-free processing of the modified quenched and tempered steel using commercially available LBM systems. Essentially, crack-free production is to be achieved through a finer microstructure, a reduction in element segregation and a lowering of the martensite start temperature. Among other things, fine, high-melting titanium nitrides are to be introduced during gas atomization for this purpose
- Working hypothesis 2:
- After LBM processing, fine, high-melting precipitates (20 nm to 100 nm) are present in the material. Accordingly, austenite grain growth should be inhibited during the subsequent heat treatment. When the heat treatment of the modified 42CrMo4 is adapted, both the microstructure and mechanical properties are comparable to those of the forged material.
- Research objective 2:
- Thermodynamic-kinetic simulations of phase stability and precipitation processes as a basis for the adapted heat treatment (temperature and duration of austenitizing and tempering).

Procedure

The development of heat-treatable steel for additive manufacturing (AM) involves crafting an AM-compatible 42CrMo4 steel through a detailed System-Design Chart, focusing on adjusting carbon content and evaluating alloys like manganese, silicon, and titanium to enhance mechanical properties and AM processing and manifesting the theoretical approach by atomization and characterization of the material. Major goals are to narrow the solidification range, induce finer grain structures, lower martensite start temperatures below 200°C, reduce low-melting phases, and stabilize the weld pool. Thermodynamic simulations streamline experimentation, optimizing chemical compositions to achieve targeted martensitic temperatures with reduced segregation. Additives like aluminum and titanium are introduced to increase melt pool surface tension, reducing weld spatter. Microscopic and diffractometric analyses reveal the microstructure, while mechanical characteristics are benchmarked against traditional steels through tests such as tensile strength and hardness. Comprehensive analyses, including light and electron microscopy as well as X-ray diffraction, are used to obtain detailed information on the microstructural characteristics. Mechanical properties are assessed by comparing tensile tests, hardness measurements and notched bar impact tests with conventionally produced heat-treatable steels.

EDUCATION

CONTENT

EDUCATIONAL PROGRAMME

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Studentlab3d – student laboratory 88

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DMRC – AM LESSONS

Education is one of the most important factors for the development of additive manufacturing towards an industrial established and production capable manufacturing technology. With this motivation, the DMRC is active in many teaching and training measures in terms of additive manufacturing.

Thereby, different task groups are addressed: students, teachers/trainers as well as technology beginners and experts from the industry. In terms of academic teaching, the Direct Manufacturing Research Center steadily strives to implement additive manufacturing contents in the lessons at the Paderborn University.

An important milestone was achieved few years ago by setting up an elective module "Additive Manufacturing" within the master's degree course in mechanical engineering. The elective module consists of the compulsory lecture "Additive Manufacturing" and of at least two other selectable courses.

In average, over 170 students takek part in the compulsory lecture "Additive Manufacturing" every year and learn fundamental knowledge about additive manufacturing.

Since 2017 the lecture consist of two different parts and is read over 2 semesters. This knowledge of cause comprises information about all relevant additive manufacturing processes as well as information regarding a proper product development for additive manufacturing, economics, and applications.

In addition, for the selectable courses, students could chose two of eight selectable courses. While, the compulsory lecture "Additive Manufacturing 1/2" deals with additive manufacturing completely, each of the eight selectable courses handled additive manufacturing partially – with at least 20% of its content.

Furthermore every year around 100 stundents write their thesises with a tas related to the additive manufacturing process chain.

DMRC – SEMINARS FOR INDUSTRY

Besides the scholar teaching, the DMRC is active in industrial education activities as well. Several seminars have been performed together with industrial partners.

DGM seminar

Introduction into additive manufacturing in cooperation with University of Kassel the DMRC performed a three-day seminar at the Paderborn University to provide basic knowledge about additive manufacturing. The seminar comprises both, theoretical knowledge together with particle exercises in order to transfer a comprehensive under- standing of the technology. Both, theoretical and practical information were transferred for metal- powder, plastic-powder and plastic- lament based technologies.

DGM seminar - advanced

The advanced training takes place annually and is aimed primarily at metal and polymer scientists, engineers, design engineers and technicians, who are already have an insight into the various additive manufacturing processes. The three most important additive manufacturing processes are presented within the framework of the advanced training: for plastics „fused deposition modeling“ and „selective laser sintering“ and for metals „selective laser beam melting“. The topics addressed range from powder qualification, the performance of parameter studies and application examples, and covers the entire process chain of additive production of polymers and metals. Based on the knowledge that the participants have already acquired in industrial practice or through introductory training, detailed and practical information on all relevant process steps (e.g. topology optimization) are provided and explained in detail.

Additive Manufacturing Specialist VDI

In 2017, the DMRC and VDI Wissensforum GmbH, the training provider of the Association of German Engineers (VDI) have agreed to collaborate in a practice-oriented qualification course developed by VDI WF together with experts from the additive manufacturing industry.

Participants will complete the course with a recognized VDI certificate. First courses have started in 2018. Within the seminar series the DMRC will educate in the area “Design for additive Manufacturing” and “Additive Manufacturing Processes - Polymer”.

Design for additive manufacturing seminars

The DMRC owns profound knowledge about design for additive manufacturing. Such knowledge is mainly desired by the industry to support the product development and product design process. In order to transfer this knowledge the DMRC performed several seminars on design for additive manufacturing with different industry partners. These seminars contained information about the advantages and disadvantages of additive manufacturing regarding product design as well as how to concept and design a part that shall be manufactured with additive manufacturing.

Potential finding and enabling seminars

Many companies currently are in the exposed position to decide whether they should use additive manufacturing in their business or not. However, the required knowledge basis to make such decision is often not fully given; potentials and risks are hardy known and difficult to detect. For such reason and in order to support companies with required information, the DMRC performed potential finding and enabling seminars together with industry partners. Together with experts from various disciplines, workshops have been performed in order to identify promising parts for a beneficial additive manufacturing and the belonging business cases.

STUDENTLAB3D – STUDENT LABORATORY

Student Lab3D

The StudentLab3D at the University of Paderborn is a facility designed to enhance students and employees learning experiences in the field of additive manufacturing and 3D-scanning. The labor opened in 2014 and is especially dedicated to students and employees of the University of Paderborn. The labor provides access to two AM-Processes (Fused-Filament-Fabrication and the Photopolymerization) and has three different types of AM-Machines. Next to the possibility for students to realize own ideas or parts, 3D-scanning is also possible and free to use. The StudentLab3D offers many workshops to further improve students and employee's knowledge in the field of additive manufacturing processes, computer aided design and 3D-scanning.

PROJECT OVERVIEW

PARTNER

Paderborn University

RESEACHER

Research Leader
Prof. Dr.-Ing. Hans-Joachim Schmid)

Research Assistant
Maximilian Salm, M.Sc.
Fabian Neitzel, M.Sc.

https://dmrc.uni-paderborn.de/de/inhalt/lehre/studentlab3d/

StudentLab3D at the Paderborn University

Start of the project

The project was funded by the Paderborn University in 2014. The Direct Manufacturing Research Center won the "Award for Innovation and Quality in Teaching 2014" in result of establishing and organizing the StudentLab3D. With the financial support, three FFF-machines and a 3D-scanner were purchased. Over time, the equipment was extended more and more. Nowaways, the StudentLab3D has over 10 AM-machines.

Teaching and workshops

All students and the staff of the University of Paderborn are invited to visit, and use use the StudentLab3D. While providing a 3D printing and 3D scanning service, the StudentLab3D offers many different workshops. The three basic workshops cover the major procedures that are used in 3D printing technologies, the basics of 3D scanning technologies and the basics of computer aided design (CAD). The StudentLab3D also provides workshops for experienced users going into detail in topics like the FFF-process. Additionally, the teaching staff of all faculties of the Paderborn University is invited to implement 3D printing into their lessons and lectures. Among the integration in the engineering faculty and the master module additive manufacturing, the StudentLab3D cooperates with other faculties. For example, 3D printed sculptures are designed in a cooperation with the art faculty and scaled mannequins of reallife students for tailoring purposes are manufactured in a cooperation with the textile and fashion faculty.

UPBRACING TEAM

Thanks to the cooperation with the DMRC, the UPB Racing Team has once again been able to manufacture many components, some of them essential, using the SLM process.

Thanks to the SLM process, we can design our components to withstand stress and use design and simulation to create shapes that would not be possible using other manufacturing processes. Through analysis using a topology optimisation programme, we were able to identify components with high potential for weight reduction.

These were, for example, our wishbone links to the chassis. Because our wishbone design means that the forces acting on the links are very different, we were able to design and manufacture each individual link to match the load.

The new PX424E race car contains more additive manufactured components than previous years' race cars. This gave the team members the opportunity to apply and develop their theoretical knowledge of additive design. They also had the opportunity to learn the practical aspects of using the SLM machine, such as preparing and finishing the machine and removing supports from components.

CHAIRS AND INSTITUTES

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DATA MANAGEMENT IN MECHANICAL ENGINEERING

INTRODUCTION

The research group DMB investigates innovative approaches to data driven processes. The knowledge gained is applied in the design and planning of products.

Bridging the Gap between Science and Industry
In collaborative research projects, the DMB bridges the gap between science, industry, and end-users. This is highlighted by close connections with manufacturing and service companies, including small and medium-sized enterprises as well as major enterprises. The focus on the needs and goals of all stakeholders facilitates the practical application of research results. The IT-based collection, processing, and targeted provision of data are studied with an emphasis on applicable aspects. In this regard, business process management methods and semantic technologies have a high priority in the orientation of the research.

Project Scope and Goals
The projects at the DMB cover a broad spectrum of relevant topics in the field of design and planning. Specific goals include knowledge management, the integration of expert knowledge into product and process models, the identification and utilization of hidden knowledge, the development of applicable assessment tools for ecological and economical sustainability, as well as integration of data driven optimization processes in complex industrial environments.

Data Driven Resource Management and Quality Control
The scientific scope is further expanded through industrial research projects in additive manufacturing. A key aspect of these projects is the development and implementation of advanced data driven resource management and quality control systems. By leveraging robust research data management practices, DMB ensures that large datasets generated during the additive manufacturing process are systematically collected, processed, and analysed. This approach not only enhances the precision and efficiency of manufacturing workflows but also contributes to the continuous improvement of product quality. The integration of research data management with additive manufacturing allows for real-time monitoring, optimization of material usage, and predictive maintenance, ultimately leading to more sustainable and reliable production processes.

The expertise gained from completed and ongoing research projects forms the foundation for DMB's ideas, systems, and technologies related to planning, coordination, training, decision-making, and integration of gained knowledge into the educational environment university.

Currently, 7 research assistants and up to ten student assistants work at DMB, contributing knowledge from the fields of engineering, economics, and computer science.

RESEARCH INFRASTRUCTURE

Hardware:
- Meltio – Wire Laser Metal 3D Printing
- BigRep Studio
- BigRep ONE
- UltiMaker Factor 4
- UltiMaker S5. – Air Manager
- UltiMaker S5 – Metal Kit
- UltiMaker 3 – Dual Extruder
- Prusa XL
- Prusa MKi3

Software:
- Geomagic Freeform incl. 3D Systems
- MSC Apex Generative Design
- Synera

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INSTITUTE OF APPLIED MECHANICS

FAM

»Additive Manufacturing is the key for the development and optimization of individual products.«

Prof. Dr.- Ing. Gunter Kullmer

INTRODUCTION

The FAM conducts application-oriented and basic research and development in the area of applied mechanics. The motivation essentially arises from the areas of structural mechanics, biomechanics and computer simulation and may be divided into three main research fields.

“Strength optimized and rupture safe design of components” deals with the dimensioning and optimization of components and structures with respect to the practically oriented advances of the FEM standard software and its efficient use in various applications. In this relation the applied tools are stress and deformation analyses as well as notch stress tests and fracture mechanical tests including fatigue crack growth experiments. The propagation behavior of fatigue cracks in many cases determines the life time of the components and technical structures. To predict the crack growth behavior and to prevent damage, various crack growth simulation programs were created and are in use at the institute. The area “Biomechanical analysis of the human musculoskeletal system” covers the simulation of courses of movement up to the development of intelligent healing aids.

The aims are the evaluation of injury risks and the avoiding of resulting injuries. In order to provide an optimal rehabilitation process, medical devices are frequently required to be individually fitted to the patient’s physical condition. So, additive manufacturing grows to become an attractive approach in medical engineering, e. g. for orthoses, implants and prostheses. The third area of research “Optimization and new development of products in cooperation with industrial partners” deals with the solving of specific problems which occur in practice by implementing the above mentioned core competences.

ADDITIONAL EQUIPMENT OF THE CHAIR

- Two servohydraulic test machines (100kN)
- Two electrodynamic test machines (10kN) + climate chamber (-100°C – 200°C)
- Crack length measurement systems (current potential drop method)
- Digital image correlation system
- Digital light microscope (Keyence VHX)
- Computer systems and work stations for FEM-simulations

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CHAIR OF FLUID PROCESS ENGINEERING (FVT)

»Additive manufacturing offer great potential to intensify heat and mass transfer applications and thus increase their efficiency.«

Prof. Dr.-Ing. Julia Riese

INTRODUCTION

- Heat recovery and process intensification play a major role in the transformation of industrial processes towards the reduction of energy intensity and thus operational costs. In the Fluid Process Engineering group we apply scale-bridging methods to identify suitable technical solutions. These solutions are determined by means of theoretical and experimental work focusing on heat and mass transfer applications.
- AM techniques offer great possibilities to intensify single phenomena like heat and mass transfer as well as the design of intensified unit operations and equipment. Therefore, a detailed understanding of the underlying phenomena is crucial and can be achieved by applying different modeling methods. For single phenomena Computational Fluid Dynamics (CFD) is a powerful tool as velocity, temperature, pressure and concentration in continuous phases can be calculated with a very high level of detail. This enables the optimization of fluid flow fields or temperature profiles in complex geometries. Additionally, the degrees of freedom for complex geometries offered by AM techniques open up new design opportunities.
- The development and investigation of those geometries by means of CFD simulation is accompanied by other modelling, simulation and optimization techniques as well as by experimental work to validate theoretical results.
- Current research in the area of AM focusses on the investigation of fluid dynamics and heat transfer on rough, additively manufactured surfaces. Major challenges here include the characterization of surface roughness on micro-structured surfaces and the corresponding selective adjustment of printing parameters to intensify heat transfer without increasing pressure drops. Application areas are for example the cooling of electronic devices.

Additionally, we work on the following topics that offer potential synergies with AM methods:

- Investigation of micro and secondary structures for heat and mass transfer applications by means of CFD simulations
- Electrification of complex structures by functionalized materials
- Design optimization of chemical reactors with intensified heat dissipation exemplified by the development of Power-to-Gas plants
- Development of high-temperature heat storage system based on phase change materials
- Development of modular heat exchanger systems for the integration in industrial heat pumps

ADDITIONAL EQUIPMENT OF THE CHAIR

Hardware

- Pilot plant for absorption and desorption
- Pilot plant for condensation in pillow-plate heat exchangers
- Pilot plant for high-temperature heat storage using phase change material
- Experimental set-up for investigation of heat exchangers
- Experimental set-up for hydrodynamic investigation of complex structures with multiphase flows

Software

- Abaqus
- ANSYS Fluent
- AspenONE®
- LabVIEW
- Matlab
- OpenFOAM
- Python
- STAR-CCM+

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HEINZ NIXDORF INSTITUTE – PRODUCT CREATION

HEINZ NIXDORF INSTITUT
UNIVERSITÄT PADERBORN

»In order to innovate and thus ensure long-term corporate success, it is essential for companies to think outside the box. Product engineering plays a central role in the innovation process«

Univ.-Prof. Dr.-Ing. Iris Gräßler

INTRODUCTION

We consider Additive Manufacturing as a key technology in digitalized, sustainable Product Creation. Therefore, we apply a holistic research approach spanning research along the entire product lifecycle, from strategic product planning through engineering and production into product life and Circular Economy.

Strategic Planning and Innovation Management

Synergies in entrepreneurial competences, the product range and customer structures are optimally exploited when the business policy is aligned with a holistic entrepreneurial vision. The aim of our research work in the field of strategic planning is to enable users to independently derive future scenarios. Digital business models are developed on this basis, considering both material core products and services. Scenario-Technique is one of the tools we use and evolve to evaluate market and technology developments. Artificial Intelligence and mathematical description also reduce the sources of error resulting from heuristics.

Model Based (Systems) Engineering

Systems Engineering support the effective and efficient engineering of products. We want to inspire the end customer with a product innovation, so application scenarios must be used to find out how the product will be used, the prevailing boundary conditions and the profile of the target buyer group. In our research, we provide tools for the functional and production-related realization of complex overall technical systems. We link the various specialist disciplines with methodological engineering approaches such as the V-model for mechatronic and cyber-physical systems and systems engineering. Our holistic approach towards AM includes the use of system models as the engineering backbone for manufacturing and in entire Product Lifecycle Management.

Production Management and Realisation

Production management is undergoing considerable change, particularly in terms of Industry 4.0 as well as, prospectively, Catena-X and Manufacturing-X. Considering AM as part of production systems, we are helping to shape this change towards sustainable, networked and automated production. We optimise the interface between production and engineering by expanding engineering methods and implementing tools for digital production system planning and automated production planning and control. In doing so, we manage to increase the flexibility of production systems through the application of intelligent algorithms without any loss of production.

Digital and Virtual Engineering

We assume that end-to-end IT support of the full product creation process even information circularity in PLM is essential in future Product Creation, especially for exploiting potentials of AM technologies. The focus is therefore on research into the applicability and application concepts for information technologies. System models, for instance, are used to enable interdisciplinary engineering and, consequently, semantic integration of product data along the product life cycle. Virtual and Augmented Reality, as further examples, serve as tools for designing and planning the modern, complex products of tomorrow.

ADDITIONAL EQUIPMENT OF THE CHAIR

Smart Automation Laboratory
- Production System with decentralized scheduling
- 5-axis machining centre, milling and turning machine
- Robotics (5-axis industrial robot, collaborative robot)
- Self-organizing logistics and transport system
- Small-size 3D printers

Smart Innovation Laboratory
- Interactive Tables and Displays
- Head mounted displays, treadmills and data gloves
- Lean Production infrastructure
- 3D scanner for Hybrid Prototyping

Software Tools
- Computer Aided Engineering/CAx (NX, SolidWorks, Matlab, ...)
- System Modelling (Cameo, MagicDraw, ...)
- Data Management (Teamcenter, DOORS, …)

Equipment for Digitalization (incl. VR/AR devices)
- VR equipment (Meta Quest 3, HTC Vive, Oculus Quest)
- AR equipment (Magic Leap, Microsoft HoloLens 2)

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DESIGN AND DRIVE TECHNOLOGY

Chair of Design and Drive Technology

» The resource-saving production of compact, functionally integrated components is a key advantage of additive manufacturing. Furthermore, these technologies enable the processing of materials that cannot be used conventionally but generate a functionally relevant advantage. This opens up the possibility of completely reinventing old components and assemblies. «

Prof. Dr.- Ing Balázs Magyar

INTRODUCTION

The Chair of Design and Drive Technology is headed by Prof Magyar. He completed his doctorate in 2012 at the Technical University of Kaiserslautern, where he held the junior professorship for tribology at the Chair of Machine Elements, Gears, and Transmissions from 2013 to 2018. In 2018, he moved to industry, where he took over as Head of the Lubricants and Tribology Department at the Corporate Research and Development of ZF Friedrichshafen AG. In the winter semester of 2022/23, he accepted an appointment at the University of Paderborn and took over as Head of the Chair of Design and Drive Technology.

The work of the chair focuses on theoretical and experimental investigations in the fields of

- Electromechanical drives
- Additive manufacturing from a design perspective.

Key aspects in the field of electromechanical drives are

- Reducing the resources required to operate drive systems and their components.
- Modularity in the context of intelligent variant management

In the area of additive manufacturing, the objectives are to

- Systematic development of rules for production-oriented design, including post-processing aspects
- Design for tolerances
- Integrate additional functions such as damping or cooling
- Adapting design methodology to take account of the design freedoms offered by additive manufacturing
- Optimization of powertrain components based on additive manufacturing

ADDITIONAL EQUIPMENT OF THE CHAIR

Equipment (test rigs)

- high-speed friction
- multi-motor drive system
- torsion vibration
- wear resistance of profiled shaft joints with sliding seat
- condition monitoring of rolling bearings
- bearing damage
- damping
- heat transfer
- Laser beam melting maschine – SLM 280HL 1.0 (DMRC)
- Sieving station – Assonic KSM500 (DMRC)
- Vacuum cleaner with wet separator – Delfin MTL3535 (DMRC)
- Heat treatment furnace – Nabertherm LH120/14 (DMRC)
- Blasting unit – Joke mikromat 50 eco
- Hand grinder – Joke ENESKAmicro 600
- National instruments (NI) compactRIO system

Software

- Altair Simlab/Hyperworks
- Ansys Workbench
- Matlab
- Solid Works
- Nikon Camio
- Nikon Focus
- Dymola

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KUNSTSTOFFTECHNIK PADERBORN

» Additive manufacturing is excellent for individual parts and small batches to save the high injection molding tool costs. Therefore, we are working on the continuous improvement of the fused layer modeling processes. «

Prof. Dr.-Ing. Volker Schöppner

INTRODUCTION

The KTP (German: Kunststofftechnik Paderborn) stands for forty years of successful research and development of manufacturing processes in the field of polymers and rubbers. This results in a qualified training in the theoretical and practical field of polymer engineering as well as in an intensive cooperation with national and international industrial companies. International congresses and conferences are regularly participated by the KTP staff.

The two professorships of the KTP ensure a broad range of knowledge transfer:

- Polymer Engineering, Prof. Dr.-Ing. Elmar Moritzer
- Polymer Processing, Prof. Dr.-Ing. Volker Schöppner

The research at the KTP is about different kinds of polymers, which become more and more significant in the field of mechanical engineering and displace traditional materials in their application fields. To adapt the processing performances optimally to the technical requirements, the KTP has developed application-oriented simulation tools for all fields of polymer processing. These software tools help to find solutions of problems quickly and make it possible to achieve a high process transparency.

The research focuses have a special concentration on the transformation of process models into tools to simulate polymer processing procedures. Due to the experimental verification of the models and the simulation tools as well as in return the use of simulation tools to improve the processes, an interplay between theory, experiment and modeling / simulation in terms of a continuous improving process exists. To realize this, real processes in the laboratory- and production measure are of the same importance as the theoretical and simulation-based analysis of the processes and the necessary IT- equipment and competence. Hence, the KTP emphasizes a good laboratory equipment.

In the field of additive manufacturing, the research of the KTP focuses on the continuous development of processes with regard to material development, mechanical and geometrical properties, surface quality and process optimization. The research takes place in the fields of:

- Fused Deposition (FDM) or Fused Layer Modeling (FDM)
- Arburg Plastic Freeforming (APF)
- Fused Granular Fabrication (FGF)
- Digital Light Processing (DLP)

ADDITIONAL EQUIPMENT OF THE CHAIR

Simulation Programs

- REX (Computer-Aided Extruder Design);
- PSI (Injection Molding Simulation);
- SIGMA (Simulation of Co-Rotating Twin-Screw Machines);
- PAM (Polymer Material Database)

Equipment

- Zwick Roell: Universal Testing Machine 1446 (10 kN)
- Zwick Roell: Universal Testing Machine 1474 (50 kN)
- Twice Zwick Roell: Universal Testing Machine ProLine Z010 (10 kN, climatic chamber with elastic modulus)
- Instron: Elektrodynamic Testing Machine ElectroPuls E10000 (7 kN)
- Reichert Jung: Thin Cutting Device (Polycut)
- Keyence: Digital Microscope (VHX-600)
- Keyence: Confocal Laser Microscope (VK-9710)
- Streurs: Grinding and Polishing Device (Tegral/Force-5)
- GE: Computer Tomography CT (Phoenix nanotom s)
- Mettler Toledo: Thermoanalytical Testing Device TGA/DSC (1 Star-System + TMA/SDTA 841)
- High pressure capillary rheometer: Göttfert RHEOGRAPH 50
- PVT measuring device (or melt density measuring device): Capillary rheometer PVT 500 (Göttfert)

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AUTOMOTIVE LIGHTWEIGHT CONSTRUCTION

www.Leichtbau-im-Automobil.de

» Die intensive Forschung im Bereich der additiven Fertigung ermöglicht ein immer besseres Verständnis der komplexen Verfahren. Damit können Verfahrensgrenzen hinausgeschoben und insbesondere die Herstellungsprozesse signifikant beschleunigt werden. Die damit einhergehenden Kostenreduktionen eröffnen zukünftig immer breitere Anwendungsfelder «

Prof. Dr. Thomas Tröster

INTRODUCTION

Research Activities

Due to exhaustible raw materials and demands on climate protection, the reduction of vehicle masses in order to reduce fuel consumption is of critical importance. Therefore, main focus of the group "Automotive Lightweight Construction" is on innovative solutions for the automotive industry and related others in terms of materials, processes and applications. As the economic ef ciency is a critical issue for most industries, the cost structures of different process-routes are also taken into account in order to develop innovative components and applications, featuring high performances as well as balanced cost-to-weight ratios. For example, load-bearing components made of ultra-high-strength steel processed by the press-hardening technique could be mentioned here.

Another important research field pursued by this chair is the development of load adapted parts. Within these parts, the material properties in different sections of a component are adjusted depending on specific product-requirements, e.g. the mechanical loading. Thus, low or high strengths as well as brittle or ductile areas can be locally tailored by an appropriate selection of the applied process-route. Techniques used in this area are for example the inductive heating, whereby the evolution of the microstructure as well as physical properties can be modified within a short period of time.

Equipment

The chair provides different possibilities for studying material as well as component properties. This covers a wide range of static, cyclic and dynamic tests as well as microstructural studies. In addition to 3 axle tests with static and cyclic forces up to 80 kN, cupping tests with temperatures up to 800 °C can also be performed. To exploit the potential of lightweight construction, the chair can perform additive manufacturing possibilities of PBF-LB with the DMG MORI LT12 and LT30 in addition to the LMD technoogy with the DMG MORI LT65 3D. Crash tests can be performed with impact velocities of up to 25 m/s and impact energies up to 31 kJ, whereby this test facility can be equipped with an a high speed 3D camera system in order to analyze, for example, local strain distributions. Furthermore, the group of Automotive Lightweight Constructions has licenses of the major CAD and simulation tools, such as Solid- Works, Abaqus, LS-Dyna and Hyperworks.

ADDITIONAL EQUIPMENT OF THE CHAIR

Software

- Matlab and IBM SPSS Statistics
- SolidWorks
- Abaqus
- Hyperworks
- LS-DYNA
- MATFEM
- ARAMIS GOM
- GRANTA CES selector

Hardware

- Tensile testing machines (dynamic, static, high/low temperature)
- Drop weight tester 150kg-500kg
- Clamping plate for multiaxial loadings
- Component crash-test facility (bending, compression, high-speed testing)
- Cupping test (Nakajima, Bulge)
- High Speed tensile test equipment – Zwick HTM8020

- 3D Optical measurement for elongation- and deformation analysis (Aramis GOM)
- Optical inspection technology
- Thermal testing technology (induction heating 60kW, resistance heating 756 kW, annealing oven, thermography camera)
- Metallography (wet cutting machine, automatic polishing machine, microscopy)
- Resin-transfer-moulding system for epoxy- and PU-resin
- Hardness measurement machine

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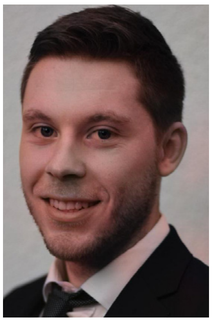

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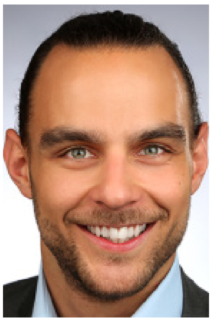

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CHAIR OF MATERIALS SCIENCE

» Additive manufacturing will experience a significant breakthrough, if different materials can be processed to a single hybrid component. «

Prof. Dr.-Ing. habil Mirko Schaper

INTRODUCTION

The scientific focus of the Chair of Materials Science (Lehrstuhl für Werkstoffkunde, LWK) is on investigating the relationship between production and manufacturing processes, the ensuing microstructure of the components produced, and the technical properties that result from this interaction. Subsequently, the correlations are analysed and described with (numerical) models. The overall goal is the reduction of process chains to save time, space, costs and energy whilst improving the material's properties at lower use of materials. Due to the fact, that most researches are based on industrial processes, steel and aluminium are of particular interest. Current research topics, in addition to the production of monolithic aluminium strips, include issues concerning the adaption of new, high strength alloys for the twin-roll casting process by affecting the process parameters to achieve a grain refinement and to avoid micro-segregations. In addition, the production of hybrid strips, for example steel-aluminium-compounds, are addressed. Regarding additive manufacturing, investigations on multi material combinations with the focus on lightweight construction and function integrated parts for applications in aviation, aerospace and automotive are conducted.

To enable the fabrication of these multi-material parts, the materials are modified by computational design to improve the bonding. To validate these modifications, specimens are 3D printed with modified alloys via Powder Bed Fusion-Laser Beam (PBF-LB) using optimized process parameters. Furthermore, soft-magnetic materials are a prominent research issue at the LWK, another step closer towards more electromobility. The aim is, to develop a soft-magnetic material with superior (electro-)mechanical and magnetic properties, due to a high silicon or cobalt content, as well as low specific densities for lightweight constructions. Of course, the processing and modification of conventional steel, like drawn steel, tool steel or duplex steel, and high-strength aluminium alloys, are further research topics in the field of additive manufacturing, with the aim to implement the advantages of the laser melting process to develop materials with superior properties. Our work here is driven by experimental investigation, and ranges from foundational research in previously unexplored areas to practical industrial applications; our research encompasses almost every type of metallic material.

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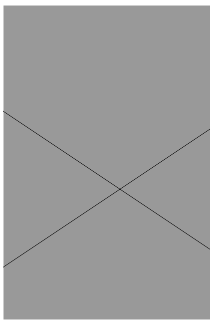

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Alloy development;
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ADDITIONAL EQUIPMENT OF THE CHAIR

- CCD based optical emission spectrometer (Tasman Q4, Bruker)
- Confocal Laser Scanning Microscope (LEXT OLS3100, Olympus)
- Digital Image Correlation
- Digital Microscope (VHX 5000, Keyence)
- Ferritscope (FMP30, Fischer)
- Fully Automated Hardness Tester (KB 30 FA)
- Furnaces (N300, N41/N13 & Top 16/R, Nabertherm)
- Instrumented Pendulum Hammer (CEAST 9050, Impactor)
- Laser (MD X1520C, Keyence)
- Macro-Hardness Testing Machine (Frankoskop, Frank)
- Magnetic Powder Testing Kit (easy K, GAZ Prüftechnik)
- Mechanical Testing Machine (Electro Force 3550, Bose)
- Micro-Computertomograph (Skyscan 1275, Bruker)
- Miniature Load Frame
- MiniCell System (Ibendorf)
- Optical / Stereo Microscopes (Axiophot, Zeiss & Olympus)
- Pendulum Impact Tester (PW 30-E, Otto Wolpert-Werke GmbH)
- Potentiostat (MLAb 100, Bank Electronik)
- Precision Cutting Machines
- Rolling Mill
- Scanning Electron Microscopes (Ultra Plus, Zeiss & XL 40 ESEM TMP, Phillips (now Quanta 600, FEI))
- Servo-hydraulic Testing Systems (810, Landmark & table top system, MTS)
- Small-Load Hardness Tester (Micromet, Bühler)
- Thermal Camera (VarioCamhr head HiRes384, InfraTec)
- Transmission Electron Microscope (CM200, Philips & JEM-ARM200F, JEOL)
- Twin-roll Strip Casting Process
- Ultrasound Tester Sonotec ST10
- X-ray Diffractometer (X'Pert, Philips (now PANalytical GmbH))

PARTICLE TECHNOLOGY GROUP

» In Laser Sintering a detailed understanding of particle properties and particulate interface characteristics is decisive for processability as well as final part properties. «

Prof. Dr.-Ing. Hans-Joachim Schmid

INTRODUCTION

Particle technology is a specialization in process engineering. We investigate the properties and further the production, conditioning and manipulation of particulate systems as well as their characterization. Such particulate systems may consist either of solid, liquid (i.e. droplets) or even gaseous (i.e. bubbles) particles in a matrix which might be either gaseous or liquid. These systems show a complex behavior, sometimes called the 'fourth state of aggregation'. Principally, if particles become smaller and smaller particle-particle interactions become dominant for the behavior of such systems. The Particle Technology Group is involved in fundamental and applied research in the field of particle technology. We have a strong focus on understanding the behavior of particulate systems and to learn how to produce a requested particulate property in a final product. Therefore, doing fundamental, publicly funded research is considered to be equally important as cooperations with companies on very specific projects, to develop solutions in the field of particle technology. The Particle Technology Chair performs research and offers expertise in the following fields:

Powder Production Methods for Laser Sintering

- Cryogenic milling
- Mechanical particle rounding
- Particles from Gas Saturated Solutions
- Filament Extension Atomization

Development and Qualification of new Materials for Laser Sintering

- Filled Materials
- Flame Retardant Materials

LS-Porces Optimizations

- process monitoring and qualification
- Parameter development

Aerosols

- Aerosol particle formation
- Exhaust gas filtration

Rheology of Suspensions

Characterization of particles and dispersed systems

ADDITIONAL EQUIPMENT OF THE CHAIR

Particle size analysis

- Photon Cross Correlation Spectroscopy PCCS - Sympatec Nanophox
- Acoustic Spectrometer - Dispersion Technology DT 1200
- Light Scattering Spectrometer – Palas Welas 3000
- X-Ray Disc Centrifuge - Brookhaven Instruments BI-XDC
- Dynamic image analysis – QICPIC Sympatec
- Sieve analysis
- Sedimentation Balance
- Scanning Mobility Particle Sizer (SMPS) - TSI
- Goniometer (Combined Static-Dynamic Light Scattering)
- Modular particle size and shape analyser QICPIC

Rheometry

- Pressure - Driven Capillary Rheometer Rosand Rh-7
- Viscometer - Ubbelohde
- Rotational Rheometer - Anton Paar MCR501
- Torque Rheometer - Rheodrive 7
- Melt Flow Tester - Zwick Mflow

Powder Rheometry

- Revolution Powder Analyzer – PS Porzesstechnik
- Ring Shear Tester - Shulze

Crushing

- Cutting Mill - Retsch SM2000
- Stone Mill - Fritsch Pulverisette
- Stirring Ball Mill - Netzsch LabSta
- Cryogenic mill – 100 UPZ Hosokawa

Other

- Multi-Process-Machine – MPU 50 ATP Hosokawa

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TECHNICAL AND MACROMOLECULAR CHEMISTRY (TMC)

INTRODUCTION

The chair is divided into the research areas
- Adhesion and Corrosion Science
- Sustainable Interfacial Engineering of Advanced Materials and Composites
- Surface and Thin Film Engineering
- Advanced Surface and Interface Spectroscopy
- Nanobiomaterials

Structures, forces, and reactions at interfaces are of paramount importance to the diverse functions of modern materials and biomaterials. The Chair of Technical and Macromolecular Chemistry develops new approaches in the areas of in-situ and operando analysis of interfacial processes and measurement of molecular forces at interfaces.
In addition, new surface modification and thin-film deposition processes which lead to functional and durable surfaces and interfaces are developed at the TMC. Examples of sustainable surface and thin film processes are plasma enhanced chemical vapor deposition or electrodeposition.
Research in the field of biomaterials and nanobiomaterials focuses on issues of biocompatibility, corrosion, protein adsorption and nanostructuring by means of supramolecular self-organisation.
The basic and mostly interdisciplinary work is integrated in various DFG programs. In addition, the chair cooperates on a national and international level with various leading industrial partners in the fields of chemicals, steel, automotive, electroplating and polymers.
In addition to public funded research projects, the Laboratory for Material and Corrosion Analysis (MCA) is available for direct cooperation between industry and professors. The aim is to provide the project partners with as comprehensive information as possible.
In the field of teaching, lectures are offered for the faculties of mechanical engineering and natural sciences in the fields of technical chemistry, materials science, electrochemistry, interfacial chemistry, surface analysis and biomaterials.

Recent research highlights of the research groups:
Within the research group “Adhesion and Corrosion Science” the additively manufactured Fe-based alloys were analyzed within regard to the corrosion processes in physiological electrolytes. In-situ electrochemical FTIR-spectroscopy was successfully applied to the analysis of polymeric fouling processes on nanostructured surfaces.
The “Nanobiomaterials” group achieved the hierarchical self-assembly of DNA origami nanostructures into ordered lattices on technologically relevant silicon oxide surfaces, which is crucial for their application as masks in molecular lithography. The group also identified fundamental design parameters that can be used to control DNA origami stability under various denaturing and degrading conditions.

The “Advanced Surface and Interface Spectroscopy group” is focused in the development of novel operando approaches to investigate the interaction of dielectric materials with reactive gases by ambient pressure photoelectron spectroscopy.

The group “Surface and Thin Film Engineering” deals with the deposition and analysis of thin films for the improvement of barrier properties of packaging materials used for food and pharmaceutic products. Beside other techniques, plasma-enhanced chemical vapor deposition can be used to control the chemical composition and microstructure to tune the barrier properties.

At the Laboratory for Materials and Corrosion Analysis (MCA) complex materials as used in technical applications and their corresponding degradation processes are studied.
We offer our partners:
- Analysis of metal surfaces
- Corrosion analysis of metals, polymers and composites
- Analysis of interfacial degradation processes and corrosion products

EQUIPMENT OF THE CHAIR

- X-ray photon spectroscopy and Auger electron spectroscopy
- Infrared spectroscopy (FT-IRRAS, PM-IRRAS, ATR, DRIFTS) and AFM-IR
- UV-Vis spectroscopy
- Raman microscopy
- Ellipsometry of thin films
- Optical emission spectroscopy (ICP-OES)
- Electrochemical analysis
- Electrochemical quartz crystal micromachining (QCM)
- Scanning Kelvin probe (SKP)
- Atomic Force Microscopy
- Thin-film technologies (PVD, CVD, PE-CVD, dip-coating, spin-coating, spray-coating, self-assembly, electrodeposition)
- Adhesion measurements (peel test, contact angle measurements, contact force measurements)

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PUBLICATIONS

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BOOKS AND JOURNALS

2023

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Klippstein, S.H., Heiny, F., Pashikanti, N., Gessler, M., Schmid, H.-J. (2022): Powder Spread Process Monitoring in Polymer Laser Sintering and its Influences on Part Properties. In: JOM - The Journal of The Minerals, Metals & Materials Society (TMS) 74 (2022) 1149–1157.

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2021

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2019

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