DMRC

DIRECT MANUFACTURING RESEARCH CENTER

RESEARCH
INNOVATION
EDUCATION

Annual Report **2018/19**

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The University for the Information Society

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Coordination and Design
Dr. Christian-Friedrich Lindemann

Texts
DMRC staff and members

FOREWORD

Dear Members and Friends of the Direct Manufacturing Research Center,

this is the tenth year for the DMRC in performing research to „develop Additive Manufacturing towards an industrial established production process". Looking back to the beginnings, we started with three additive manufacturing machines and a core group of five industry members and a lot of motivation and passion. We are proud of the development the DMRC has taken in the past years. Nowadays we have over 15 professional production systems, 26 industry partners working together with researchers from three out of the five faculties of the Paderborn University.

Looking back to 2018, our highlight was the start of the „iAM-NRWmaterials" project of the Paderborn University. Innovative and application-adapted materials for Additive Manufacturing are in the focus of the research. The project is funded by the state of North Rhine-Westphalia and the European Union (5.34 mio €). The project is a milestone in the history of the Additive Manufacturing research at the Paderborn University. Once implemented, the researchers will be able to produce their own base materials in Fused Deposition Modeling, Laser Sintering and Selective Laser Melting. In addition, the topic of Hybrid Lightweight Design in general has become a focus topic at the Paderborn University. Within this profiling area, the Institute for Lightweight and Hybrid Design (ILH) has moved next to the DMRC with a new building. The cooperation between both institutes offers further research possibilities and completes the AM process chain, especially with sophisticated post processing facilities.

- Besides many exciting developments, here are some highlights we want to share:
- We were able to welcome Assonic, BASF, Hosokawa Alpine, and Voith as new industry members in the DMRC consortium.
- We have now published the 14th PhD theses in the field of additive manufacturing. Seven of them were published since 2018.
- In the year of 2019 we will spend over 6 Million € for research in additive manufacturing.
- We are planning an anniversary conference on the future of AM. Come and join us 26/27th September 2019.

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

SCIENTIFIC DIRECTOR

Prof. Dr.-Ing. Hans-Joachim Schmid

MANAGING DIRECTOR

Dr.-Ing. Christian-Friedrich Lindemann

DMRC — DIRECT MANUFACTURING RESEARCH CENTER

RESEARCH
INNOVATION
EDUCATION

DMRC-PARTNERS 2019

AKG · assonic · Baker Hughes · BASF · bigrep · Boeing · Centroplast · Eisenhuth · EOS · Evonik · Heraeus · H&H · Hosokawa Alpine · John Deere · JP Industrieanlagen · Klaeger · Krause DiMaTec · Mettler Toledo · Porsche · Protiq · Rembe · Siemens · SLM Solutions · SAC FS Stükerjürgen · Tørwegge · voestalpine · Voith

ANNIVERSARY CONFERENCE

Shaping the Future of Additive Manufacturing

10 YEARS

RESEARCH
INNOVATION
EDUCATION

Registration & further information

www.10-years-dmrc.com

10 YEARS INDUSTRIALIZATION OF ADDITIVE MANUFACTURING

26.09 - 27.09.2019
Paderborn University

The DMRC will celebrate its 10th anniversary this year. Do not miss the opportunity to be part of this special application oriented networking event!

Main Topics

- Presentations from science & industry
- Collaborative approaches for the industralization of AM
- AM as driver for the local and european economy - from SME to large companies
- Industrialization & Quality Assurance - AM for serial production
- Progress in AM standardization and working groups
- AM - Solutions for the mobility sector
- ...

What to experience

- Panel discussions in every session - discuss and connect with the experts
- Keynote speeches from Boeing and Porsche
- Further speeches from Baker Hughes, Siemens, TÜV-Süd, Mobility goes Additive, Heraeus, VDMA, BDLI, ...
- Experience additive manufacturing live at the tour through the university - from base material to part production, post-processing and testing facilities
- Network and connect with the experts in Additive Manufacturing, ...

Guided Lab Tour - Networking - Evening Event with DJ (till late)

Direct Manufacturing Research Center (DMRC) » Mersinweg 3 » 33100 Paderborn » Tel: (0)5251/ 60-5415 » info@dmrc.uni-paderborn.de

CONTENT

ABOUT THE DMRC

CONTENT

MOTIVATION AND AIM

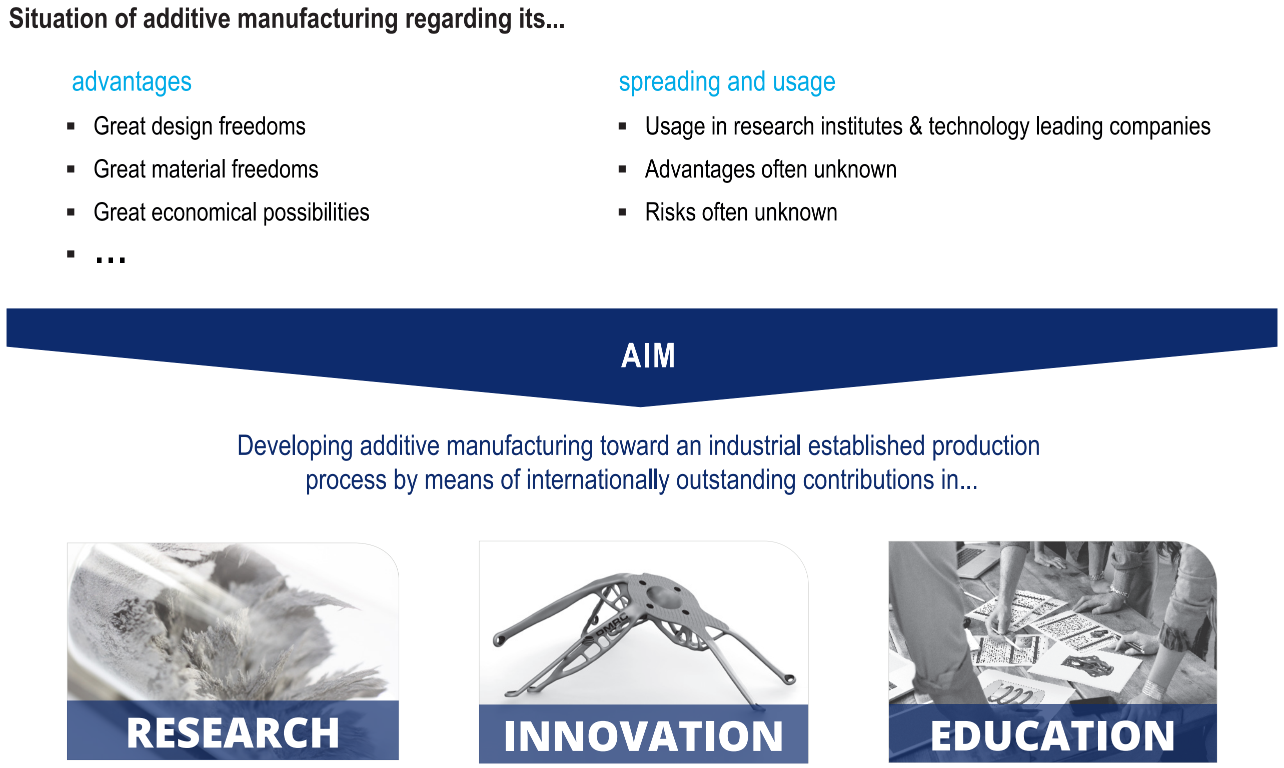
Additive Manufacturing processes create parts in layers and without using formative tools. In many indstries this technology may have a highliy disruptive character. This manufacturing technology offers many benefits like:

- 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. Unknown material combinations are possible in the future.
- 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 has the aim to develop additive manufacturing towards an industrial established production process.



STRUCTURE OF THE DMRC

The aim of the DMRC implies that the additive manufacturing technology needs to be handled comprehensively. This goes along with the fact that several very different disciplines need to be covered: material science, particle technology, process understanding, mechanics, applications, design, software support, business and so on. In addition, the research and development focus will change over time from one discipline to another.
These were two clearly defined goals that the structure of the DMRC wanted to to meet:

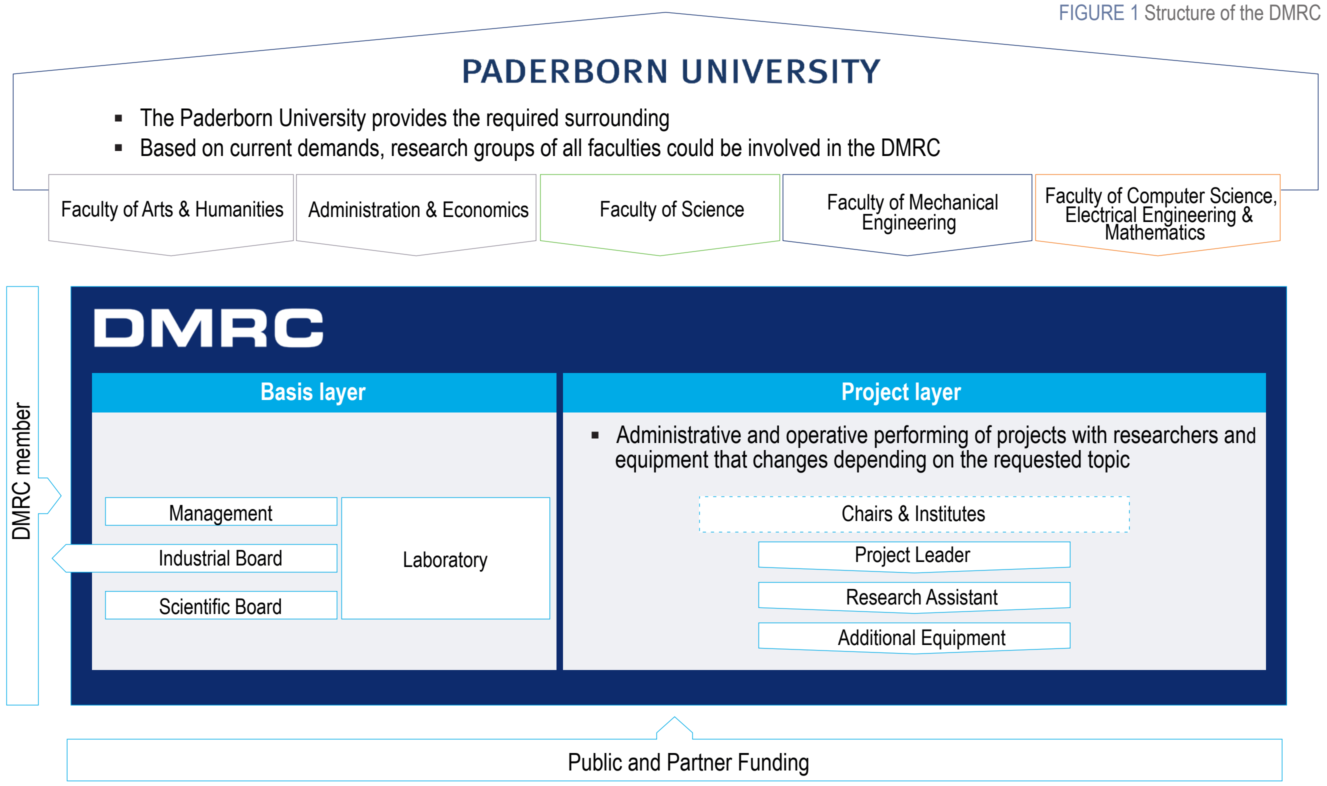
- The DMRC structure must be interdisciplinary
- The DMRC structure must be flexible

In order to fulfill these requirements, the DMRC is structured in different layers:
Basic Layer: This layer contains the management of the DMRC, the industrial and the scientific board as well as the laboratory. The DMRC Basic Layer has the task to steer the DMRC and to create an appropriate surrounding to perform research and innovation.

Project Layer: Within this layer, projects are performed. Therefore, each project consist of the project leadersfrom both , the industry and scientific board, the research assistants and, additional equipment from the university. Project tasks and budgets are defined in the DMRC Basic Layer.

Paderborn University: The surrounding and the third layer for the DMRC forms the Paderborn University with its five faculties. Located in this surrounding, the DMRC can invite experts from Arts and Humanities, Business Administration and Economics, Natural Science, Mechanical Engineering, Computer Science, Electrical Engineering and Mathematics to join the DMRC and work on projects. The additive manufacturing acitivities at the Paderborn University are coordinated by the Paderborn Institute for Additive Manufacturing (PIAF).

FIGURE 1 Structure of the DMRC



STANDARDIZATION COMMITTEES

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 - Geregelter Elektroantrieb and FVA AK Additive Manufacturing. It aims at uncover new application potentials of Additive Manufacturing in the field of drive train applications. FVA AKGEA is focused on applications regarding controlled electric drives.

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 is a working group consiting of the key stakeholders of the german aerospace industry. THE DMRC actively takes part in teh working 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 grous education and materials.

WORKING GROUPS

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

DVM
Deutscher Verbandes für Materialforschung u. Prüfung e.V.
- Committee: Additive Manufacturing

DVS
Deutscher Verband für Schweißen und verwandte Verfahren
- Committee: Additive Manufacturing process

FVA
Forschungvereinigung Antriebstechnik e.V.
- Committee: Additive Manufacturing in drive train applications

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

VDI FA 105.1
Verein Deutscher Ingenieure
- Committee: Additive Manufacturing - Plastic

VDI FA 105.2
Verein Deutscher Ingenieure
- Committee: Additive Manufacturing - Metals

VDI FA 105.3
Verein Deutscher Ingenieure
- Committee: Design for Additive Manufacturing

VDI FA 105.5
Verein Deutscher Ingenieure
- Committee: Legal aspects of Additive Manufacturing

VDI FA 105.6
Verein Deutscher Ingenieure
- Committee: Safety aspects of Additive Manufacturing

VDMA
Verband Deutscher Maschinen- und Anlagenbau
- Working group: Additive Manufacturing - Automotion

INVOLVED CHAIRS AND INSTITUTES

FACULTY OF MECHANICAL ENGINEERING

Automotive Lightweight Construction

Prof. Dr. rer. nat.
Thomas Tröster
Head of Chair

Chair of Material Science

Prof. Dr.-Ing. habil.
Mirko Schaper
Head of Chair

Chair of Fluid Process Engineering

Prof. Dr.-Ing.
Eugeny Kenig
Head of Chair

Computer Application in Design an Planing

Univ.-Prof. Dr.-Ing.
Rainer Koch
Head of Chair

Design and Drive Technology

Prof. Dr.-Ing.
Detmar Zimmer
Head of Chair

Heinz Nixdorf Institute

Univ.-Prof. Dr.-Ing.
Iris Gräßler
Head of Chair - Product Creation

Institute of Applied Mechanics

Prof. Dr.-Ing. habil.
Gunter Kullmer
Head of Chair

Institute of Applied Mechanics

Prof. Dr.-Ing. habil.
Hans Albert Richard
Head of Chair

Particle Technology Group

Prof. Dr.-Ing.
Hans-Joachim Schmid
Head of Chair

Kunststofftechnik Paderborn

Prof. Dr.-Ing.
Elmar Moritzer
Head of Chair

Kunststofftechnik Paderborn

Prof. Dr.-Ing.
Volker Schöppner
Head of Chair

FACULTY OF SCIENCE

Technical and Macro Molecular Chemestry

Prof. Dr.-Ing.
Guido Grundmeier
Head of Chair

FACULTY OF COMPUTER SCIENCE

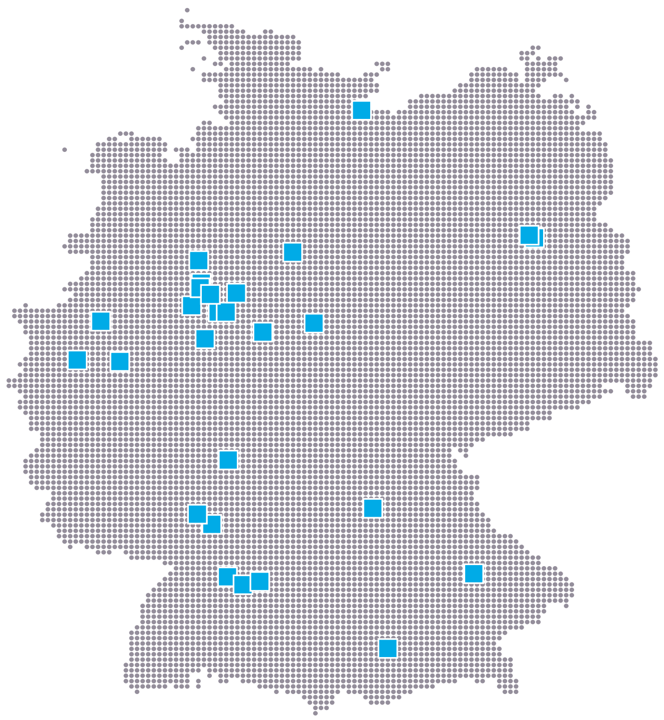
Chair of Database and Information Systems

Prof. Dr.
Gregor Engels
Head of Chair

PARTNERS 2018/2019

INTERNATIONAL

NATIONAL



Being part of a network often provides benefits and possibilities that cannot be obtained individually. Therefore – besides fundamental and applied re-search – the DMRC provides an excellent network. At its core, this network is formed by a research community that is comprised of 27 industrial partners in 2017 from all disciplines along the value chain of Additive Manufacturing. This network allows our industry partners to benefit from both the commonly researched knowledge and the collaboration within the DMRC stakeholder network. Performing pre-competitive research, being preferred partner in publicly funded projects or exchanging knowledge about cutting-edge research findings and innovations are just a fewpoints our partners benefit from.

USA

Baker Hughes, a GE company

Boeing

DENMARK

Danfoss

SWISS

Mettler Toledo

GERMANY

AKG

assonic

BASF

bigrep

Centroplast

Eisenhuth

EOS e-Manufacturing Solutions

Evonik Industries

H&H

Heraeus

Hosokawa Alpine

John Deere

JP Industrieanlagen

Klaeger

Krause DiMaTec

Porsche

Protiq

Remba

SAC FS Stükerjürgen

Siemens

SLM Solutions

Torwegge

voestalpine

Voith

LABORATORY

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. In order to fulfil this task, the DMRC provides in total six industrial relevant manufacturing machines from four different technology 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 increased.

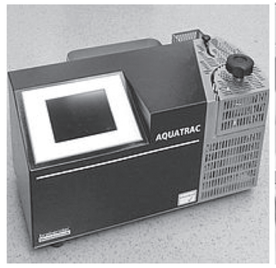
In 2017 the DMRC has e.g. invested into test rigs to investigate further aspects of the future electro mobility, into an optical scanning head for the coordinate measurement machine, and further equipment for the preparation of our test specimens. In the DMRC – Laboratory we always strive to provide latest research results on state of the art machines.

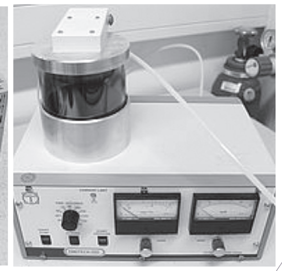
And, in case the DMRC equipment is still not sufficient for a specific task or request, the DMRC can utilise all equipment, which is available at the chairs that work together in the DMRC. This chair equipment comprises a very wide field of different testing machines, microscopes, test rigs and even computer tomography. Summarizing this, the total accessible equipment opens up 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 tables listed on the next pages. The additional equipment of the chair is listed in the section “Chairs and Institutes”.

EQUIPMENT

MOISTURE MEASUREMENT
AQUATRAC

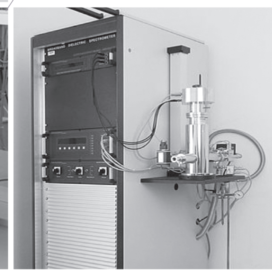




SPUTTER COATER
SC7620

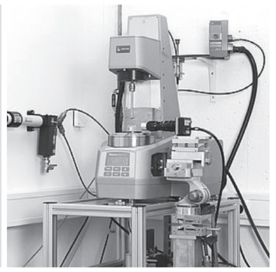
EXTRUSION PLASTOMETER
MFLOW

PHYSICAL AND CHEMICAL ANALYSIS



DIELETRIC
SPRECTROMETER

PRECISION BALANCE



RHEOMETER
PHYSICA MCR 501

HOMMEL ETAMIC
T80000

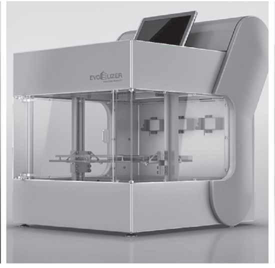
GEOMETRICAL ANALYSIS

NIKON ALTERA 8.7.6

FUSED DEPOSITION MODELING

FORTUS 400 MC

EVOLIZER



GEWO SYSTEME

FREEFORMER

LOW PRESSURE DRYER 30

LASER SINTERING

SINTERIT LISA

EOISINT P395

EOISINT P396

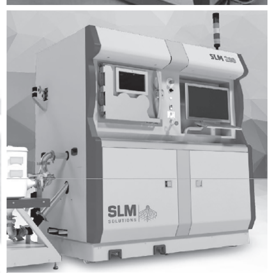
LASER MELTING

SLM 250 HL

SLM 280 HL

SLM 280 1.0

VACUUM DRYING (SELF-CONSTRUCTION)



SLM 280 2.0

OPTICAL ANALYSIS

PARTICAL SIZE ANALYSER MASTERSIZER 2000

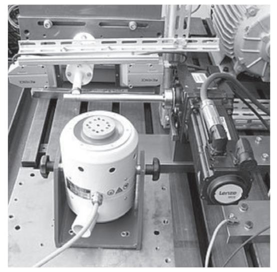
THERMAL IMAGING

3D MEASURING MACRO-SCOPE

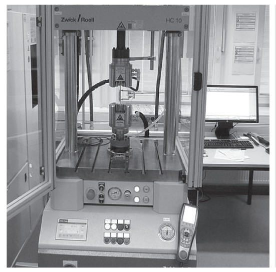
3D SCANNING

SCANNING ELECTRON MICROSCOPE (SEM)

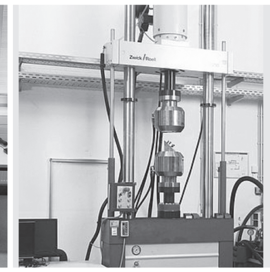
MECHANICAL ANALYSIS



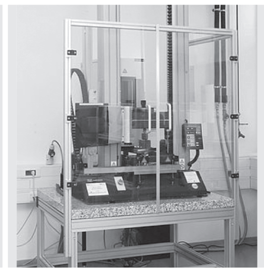
TEST RIG FOR BENDING VIBRATIONS



ZWICK HC 10



ZWICK HB 250



INSTRON 5569

DIRECT MANUFACTURING RESEARCH CENTER (DMRC)

> We aim to develop Additive Manufacturing as an industrial established production process.
> We create outstanding results in Research, Innovation and Education.
>
> Dr.- Ing. Christian-Friedrich Lindemann

INTRODUCTION

Field of research

As an university-based institute the research runs in our genes. Due to its interdisciplinary structure and the large number of involved chairs and professors the Direct Manufacturing Research Center (DMRC) can handle projects in many different research and application fields. Our activities and competences range from basic to application oriented research projects

Research leads to innovation

With our roots in basic research we are an industry driven and therefore application oriented research centre. We strive to develop innovative solutions and products together with and for our industry partners. Our interdisciplinary competence and the test equipment from 12 different chairs helps us to develop complex solutions and products. We want our partners to "direct manufacture" their final innovative products. In the upcoming years, e.g. we want to be able to print a complete electric engine including new materials. Furthermore, we are developing biodegradable materials for medical applications.

Education at the DMRC

Education is one of the most important factors for the establishment of additive manufacturing as a production capable manufacturing technology. We integrate our latest results from research and innovation activities in our education programs and update them regularly. The DMRC is active in many teaching and training measures in terms of additive manufacturing. The provided knowledge reaches from fundamental trainings to very deep and profound seminars. The spectrum of the addressed users reaches from academia (students to teachers) and industry (trainers to experts).

ADDITIONAL EQUIPMENT OF THE DMRC

Laser Sintering

- EOSINT P395
- EOSINT P396
- Sinterit LISA

Fused Deposition Modeling

- FORTUS 400 mc
- Freeformer
- EVOLIZER
- GEWO Systeme
- Low Pressure Dryer 30

Laser Melting

- SLM 260HL
- SLM 280HL
- SLM 280 1.0
- SLM 280 2.0
- Vacuum drying (self-construction)

Optical Analysis

- 3d measuring macroscope
- Electron Mikroscope
- 3D scanning kolibriMulti
- Particle size analyser Mastersizer 2000
- Thermal imaging camera P600, FLIR

Geometrical Analysis

- Nikon Altera 8.7.6
- Hommel Etamic T8000

Physical and chemical Analysis

- Moisture measurement AQUATRAC
- Precision balance
- Dielectric spectrometer
- Rheometer Physica MCR 501
- Extrusion plastometer Mflow
- Sputter Coater SC7620

Mechanical Analysis

- Instro 5569
- Zwick HC 10
- Zwick HB 250
- Test rig for bending vibration

STAFF

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START-UPS

The success of the German economy largely depends on its future employees. Thus, three new start-ups were founded by former DMRC scientists. "AMendate GmbH" focuses on making future products lighter and more bionic, while "Additive Marking - Produktionsintegrierte Kennzeichnung GbR" 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. Like the DMRC itself, the goal of all these startups is the industrial implementation of this technology.

AMendate is developing a fully automatic topology optimisation soft- ware for Additive Manufacturing. This technology considers the rules of design for Additive Manufactu- ring and greatly simplifies the opti- misation process. Developed from the user's perspective, this software meets all engineering requirements. High resolution guarantees detailed structures, and stress optimisation creates bionically shaped geometries with an even distribution of stresses. An automatic, intelligent smoothing algorithm efficiently transfers the result into geometries that can be printed directly. With the automatic retransition into CAD-models the need becomes redundant to further process the resulting product using ad- ditional, special software. AMendate gives design engineers an error-free, printable component that meets every requirement, all in super-quick time.

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 assu red 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 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. As a highlight, the company will exhibit its solution for safe, contamination-free and traceable powder handling at the Formnext Trade Fair. A container system developed especially for Additive Manufactu- ring, with leak-free valves, makes it possible to store and handle the powders used in the process, keeping them away from oxygen and moisture, and using RFID tags to guarantee clear traceability. It is also developing air-conditioned, mobile manufacturing cells as part of a collaborative arrangement with a manufacturer for industrial const- ruction purposes. In addition to providing the ideal conditions for in- stalling AM plant technology, gas sensors and an air purification system will also achieve a substantial improvement in industrial safety.

RESEARCH

CONTENT

ADDITIVE MANUFACTURING OF MEDIUM CARBON STEELS AND A COCR-ALLOY

Since a decade, selective laser melting (SLM) has gained significant attention from academia and industry. This powder-bed based technology enables the manufacturing of highly complex and filigree parts in a near-net-shape manner with a relative density of approximately 99.9 %. However, the material spectrum available for SLM has to be extended in order to further industrialize the process. In particular, martensitic steels, with a medium carbon content of approximately 0.5 ma.-%, represent a class which has rarely been addressed so far.So far, almost all research has addressed austenitic-, precipitation hardenable stainless-, maraging-, and martensitic steels.

PROJECT OVERVIEW

DURATION

01/2018 - 12/2018

PARTNER

Industrial Consortium of DMRC

FUNDED BY

Industrial Consortium of DMRC

RESEARCHER

Research leader
Prof. Dr.-Ing. habil. Mirko Schaper (LWK)

Research assistant
Florian Hengsbach, M.Sc. (LWK)
Dominik Ahlers, M.Sc. (LiA)

DMRC DIRECT MANUFACTURING RESEARCH CENTER — RESEARCH INNOVATION EDUCATION

Objective

The aim of this research project is to process and characterize hard to weld materials. Since a martensitic transformation, which usually occurs during cooling, is accompanied by a volume increase of approx. 2 % - 4 %, hot cracking may prevail. In order to avoid hot cracking the fabrication temperature was increased from 200 °C to 400 °C.
The martensitic steel H13 (1.2344) is widely known for the additive manufacturing of components, primarily tools[1]. Despite this, medium carbon steel obtains a limited hot hardness, which is of utmost importance during molding or hot forming operations. Thus, another martensitic steel is required for the SLM process, which satisfies this expectation. In this project, W360 Isobloc has been chosen to investigate the microstructure and mechanical properties. This high molybdenum-chromium-vanadium tool steel is suited for applications in which highest toughness and hot hardness is needed, i.e., in cold work, hot work, and plastics tools.
One further medium carbon steel group, which has rarely been investigated, can be identified as quenched and tempered (QT) steel. These steels exhibit high toughness accompanied by high strength. Thus, QT steels are employed in machinery and structures in which an increased yield strength and an abrasion resistance is demanded, e.g., as gears, cutting edges, or camshafts. Within this project, the quenched and tempered steel 1.6773 was processed and analysed in terms of processability, microstructure and mechanical properties.
The third material processed within this project was the CoCr-alloy Stellite 6. Generally, stellite materials possess superior tribological and corrosion properties under aggressive conditions. Both steels, the martensitic steel W360 and the QT steel 1.6773, possess medium carbon contents of approximately 0.5 wt.%, which has not successfully been processed at larger diameters, e.g., >50 mm. Evolving high residual stresses lead to numerous liquidation cracks as well as solidification cracks during SLM fabrication. A promising approach to avoid the undesired cracks is the modification of the scan-strategy in combination with the variation of the build platform temperature up to 400 °C.
Until now, these materials are processed by casting methods or powder metallurgy [2]. Nonetheless, based on the processing technologies available, the geometrical freedom is restricted, and the machining is extremely challenging.

Approach

By employing an infrared-heating system (Figure 2), which was set-up in cooperation with the company Heraeus, it was possible to build dense parts with the addressed materials. Based on the homogeneous temperature distribution in the build chamber the tempertaure gradients have been minimized, resulting in less (hot) cracking and reduced pores. For 1.6773 (QT steel) dense specimens were built at a temperature of 200 °C in the build chamber. Regarding W360 a high hardness (> 635 HV) could be achieved for this hot tool working steel when heating the chamber to 450 °C. In this case the standard parameter set for 316L has been utilized. Finally, it was proven, that Stellite 6 is processible with selective laser melting using the infrared-heating system at a tempertaure of 530 °C (Figure 3).

Outlook

For these material groups corrosion tests have to be conducted in elctrolytes, which suit the applications and further investigations concerning the fatigue behavior are planned.

[1] Holzweissig MJ, Taube A, Brenne F, Schaper M, Niendorf T. Microstructural Characterization and Mechanical Performance of Hot Work Tool Steel Processed by Selective Laser Melting. Metall and Materi Trans B 2015; 46 (2):545-9.
[2] Yadroitsev I, Sumrov I, Selective laser melting technology: from the single laser melted track stability to 3D parts of complex shape, Physics Procedia 2010, 5, 551-60.

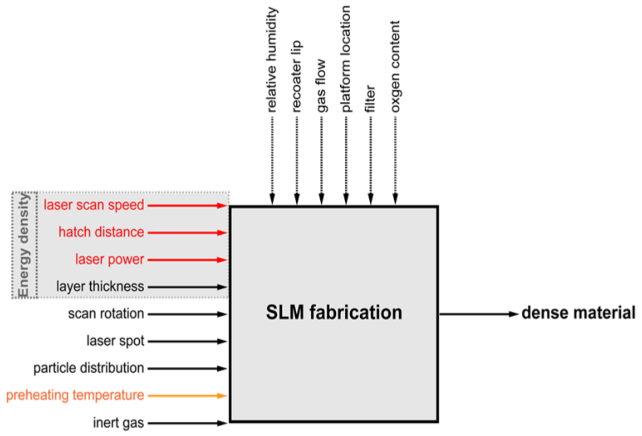

FIGURE 1 Influencing process parameters for selective laser melting

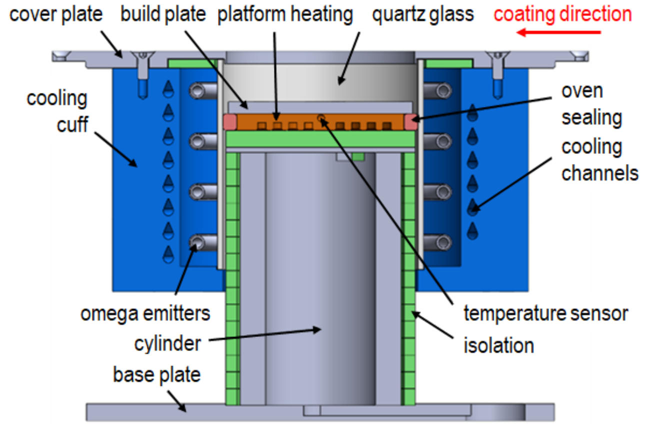

FIGURE 2 Prototype of the developed infrared-heating system

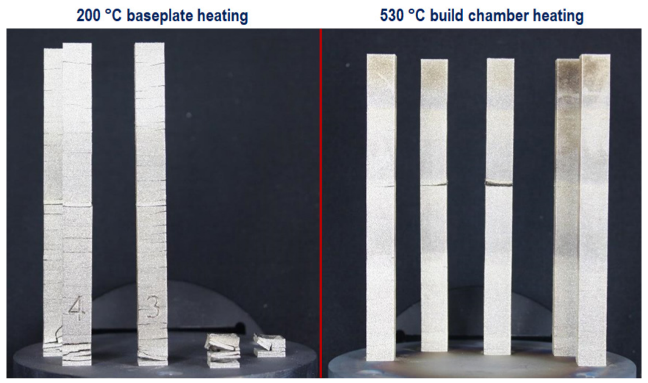

FIGURE 3 Comparison of the influence of a platform heating and a build chamber heating with the example of Stellite 6

FUSED DEPOSITION MODELING WITH METAL POWDER FILLED FILAMENTS

Metallic components can be produced with the additve manufacturing processes Laser Melting (e.g. SLM) or Electron Beam Melting (EBM). Another possibility for the production of metallic AM parts is the use of the FDM process based on polymer filaments filled with metal powder. In accordance to the conventional MIM (Metal Injection Molding) process, the finished parts (green parts) are removed of polymer in post-treatment steps (brown part). After this the metal particles are sintered (final part). This project should give a brief overview of this process.

PROJECT OVERVIEW

DURATION
04/2019 - 06/2019

PARTNER
Industrial Consortium of DMRC

FUNDED BY
Industrial Consortium of DMRC

RESEARCHER
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Research assistent
Christian Schumacher, M. Sc.

DMRC DIRECT MANUFACTURING RESEARCH CENTER RESEARCH INNOVATION EDUCATION

Motivation

According to the current state of the art, metallic components can be produced with Laser Melting (e.g. SLM) or Electron Beam Melting (EBM). Due to the high design freedom in the area of additive manufacturing, these processes are increasingly used for complex parts, small series or individualized products. A disadvantage of the Laser Melting process are the high investment costs for the machines that are equipped with one or more high-power lasers (> 300.000 €). In addition, high costs are incurred for peripheral equipment that is necessary for production: Sieving station, vacuum cleaner, blasting station and other post-processing machines.

Another possibility for the production of metallic AM parts is the use of the FDM process based on polymer filaments filled with metal powder. In accordance to the conventional MIM (Metal Injection Molding) process, the finished parts (green parts) are removed of polymer in post-treatment steps (brown part) and the metal particles are sintered (final part). A major challenge in Metal-FDM is the large shrinkage of 15 to 20% in every direction in space due to debinding and sintering. This shrinkage must be taken into account when designing parts for this process.

Since the filament contains a polymer that is filled with metal particles, it can be processed with conventional FDM machines that are available on the market. Possible areas of application could be the manufacturing of parts with internal structures that do not require external accessibility. Furthermore, the Metal-FDM process can be used to produce multi-material parts or parts with otherwise incompatible materials, e.g. regarding the SLM- or EBM-process. Another major advantage of the FDM process is that material is only used for the actual part and no entire build chamber has to be filled.

Furthermore the process is expected to allow utilizing material systems that are developed and used in today's MIM industry. Therefore the production of raw material is already established at an industrial scale which shows the potential to reduce material cost for these AM process chains due to the large production amounts coming from MIM.

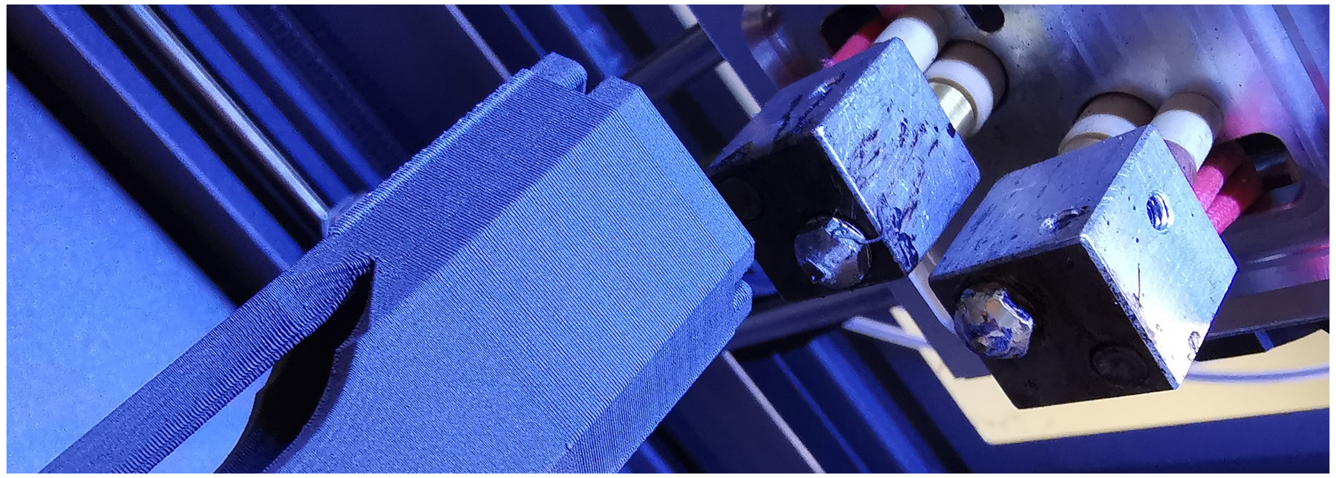

FIGURE 1 FDM part out of a metal powder filled polymer

Aim

The aim of this project is to generate know-how for Metal-FDM as a further AM process in the DMRC and thus also for the industrial partners. A material from BASF will be used for a mechanical characterization. The mechanical characterization should allow a comparison with the established SLM process.

Proceeding

First suitable process parameters have to be defined for the provided material. These include, for example, process temperatures as well as flow and feed velocities. After suitable process parameters have been found, the toolpath parameters (layer height, raster width, raster angle, fill density, etc.) are defined for the project.

The parameter set is defined using simple test specimens (e.g. density cubes) so that the effects of the different parameters on density and shrinkage in the three directions of space according to the part orientation can be determined.

After a parameter set is found the mechanical properties are investigated. FDM parts might have a very high porosity of > 10 %. The porosity might significantly influences the properties of metallic parts. Therefore, elementary FDM-typical process parameters (like toolpath parameters) are varied to determine the influence on static strength values (e.g. tensile strength and elongation at break).

Furthermore, the FDM-typical anisotropy for this material will be investigated. Therefore, in addition to the flat orientation (in the XY-plane), the orientation along the Z-axis is examined, as well.

Additionally, a comparison is made with mechanical characteristics that have been produced with conventional or other AM processes (Laser Melting). This enables to evaluate the performance of the material and the process. Finally an exemplary use case for Metal-FDM shall be identified and presented in this work package. A possible application shall be revealed where the SLM process may be uneconomical due to the high investment costs or the complex in-house post processing. Basic design limitations for SLM, FDM and the post-FDM sintering process may also be considered.

CHANGES OF STAINLESS STEEL POWDER

In many applications, which can be produced by AM, stainless steel (1.4404) is the most commonly used steel, because it has a well-balanced property profile. For serial production, deep knowledge on the robustness of part properties against variation of powder characteristics is required. The characteristics of the powder material, next to process parameters as well as hard- and software, are important key factors. During the use phase of powder, effects like washing out of fine fractions and the pick-up of nitrogen change the powder characteristics. Therefore, the powder properties permanently change during the manufacturing process. The scope of this project is to investigate the influences of relevant changes of powder characteristics on the material as well as on the part properties.

PROJECT OVERVIEW

DURATION

01/2018 – 12/2018

PARTNER

Industrial Consortium of DMRC

FUNDED BY

Industrial Consortium of DMRC

RESEARCHER

Research leader
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Research assistent
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DMRC DIRECT MANUFACTURING RESEARCH CENTER – RESEARCH INNOVATION EDUCATION

Objectives

The first important step in influencing the powder properties is to create different particle size distributions (PSD) of the stainless steel powder. This is done through systematic manipulation by sieving different size distributions. The second important influencing factor is the possible uptake of nitrogen of the powder during the manufacturing process. The influence of nitrogen on the powder characteristics will be investigated by aging the powder under nitrogen atmosphere at a defined temperature and time. After influencing the powder properties, the next step includes the manufacturing of the test specimen with the aim of studying the impact of different PSDs on mechanical part properties. The specimen production is carried out by using the selective laser melting manufacturing process. The specimen are tested only in one material condition (as built). The last step includes the experimental investigations to determine mechanical and fracture mechanical properties.

Procedur

The project aim is the investigation of the powder material with its specific influencing factors during the use-phase. Of particular interest thereby is the lot to lot variation of the powder quality inside specified ranges. Because of that, it is necessary to investigate how a shift of the median value x50 affects the material properties. The approach is to shift the median value, through a sieving process, as near as possible to the range limits of the particle size range. The specified particle size range of the standard powder is between 10 µm – 45 µm with an average particle size of d(0.5) = 29µm. The first generated size d istribution is in the range between 25 – 45µm with an median value of d(0.5) = 35µm (upper limit). The second generated size distribution is in the range between 15 – 35µm with an median value of d(0.5) = 24µm (lower limit). The artificial aging process takes place inside a climate chamber under nitrogen atmosphere condition. In this regard a temperature of 200°C is provided, because this temperature is generally present during the building process, when using platform heating. At intervals of about 12 hours, small samples of powder are taken over a period of about one week. The sample of powder which is removed is immediately sealed under vacuum in a glass tube. Based on this, the nitrogen content of the stainless steel powder were determined through thermal extraction with a carrier gas. For a complete powder characterization different test procedures are necessary. In particular, three different material tests are carried out. For all three types of experiments it is necessary to manufacture test specimen. All specimens were built on the SLM 280HL under a nitrogen inert gas atmosphere. For the manipulated powder a smaller building platform is used because it need less powder. Finally, tensile and fatigue tests are carried out to determine the tensile and fatigue strength. Furthermore crack propagation experiments are executed in order to establish crack propagation curves for all different powder states.

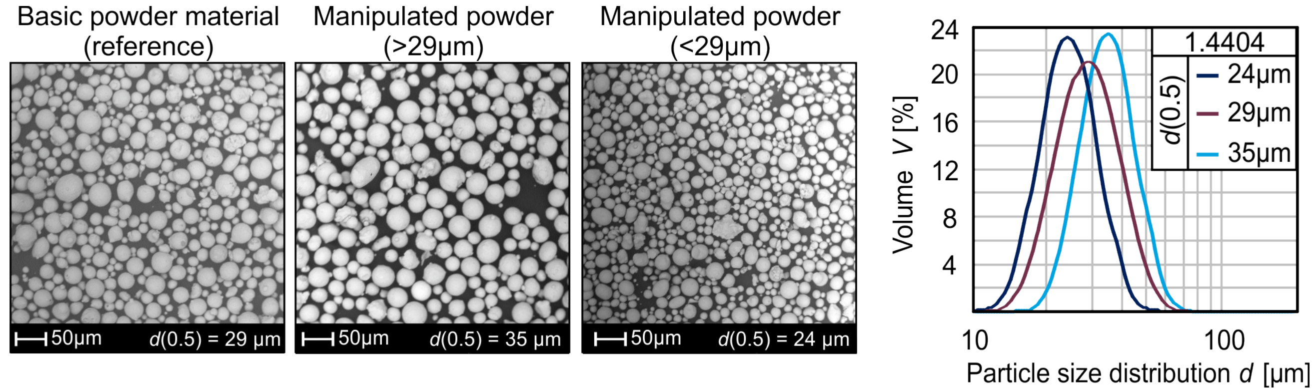

FIGURE 1 SEM-images and PSD of the investigated powder types

Results

The reference nitrogen content at the beginning of the aging process is 0.085 %. The results of the aging process show an insignificant increase of the nitrogen content of the powder even after long aging time. So it can be concluded, that the selected aging temperature of 200°C does not lead to an increase of the nitrogen content. The next step was to investigate if there is a difference between the nitrogen content of the powder and the nitrogen content of the manufactured specimen. In this regard we measured the nitrogen content of two different specimens from two different previous building jobs. The analysis shows a nitrogen content 0.08 % for both specimens and thus it lies in a similar range with respect to the aged powder material. So in summary it can be concluded, that there is apparently no change in the nitrogen content of the powder as well as of the manufactured parts through the building process.

Tensile and fatigue tests

The tensile tests have shown that manipulating the powder particle size distribution has a measurable but not significant effect on the tensile strength, with an increase of 18MPa for a grainsize smaller than 31µm and an increase of 31MPa for a grainsize bigger than 31µm. Furthermore, the elongation at break increased by 11% respectively 18%. Furthermore the results show, that there is no significant influence due to the size of the building platform. The results of the fatigue life tests correlate with these observations, where the small / large fractioned powder conditions withstood an on average 20MPa higher stress level. No significant change can be observed in the slope of the logarithmical regression lines for the finite life graphs.

Fatigue crack growth experiments

With regard to the fracture mechanical analysis, the results for the tests with the three different particle size distributions show, that for the examined powders the crack propagation curves have almost the same curve progression, especially in the threshold area and in the middle region. Only in the fracture toughness region some slight differences are observable. The best fracture mechanical results are achieved with the small frationed particle sizes in which we have a slight improvement in the threshold value. But in summary it can be said, that there is obviously no significant influence on the crack propagation curve or the threshold value when using different particle size distributions. Also, identical results were obtained by using different building platform sizes.

Outlook

Further investigations could be conducted with different material characteristics as the influence of different heat treatments, building direction or the powder humidity. In this way the material can be fully characterize for the additive manufacturing process.

CONCEPT AND CASE STUDIES

To enable the use of AM in broad industrial practice, specific tools are required. Function-orientated active principles are a proven tool in the design process to find solutions. Within the project corresponding active principles are developed, especially for AM, and verified on demonstrators and applications. The potential of a function-orientated AM-design is illustrated and examined on industrial applications. In 2017, the focus was on the topics "heat transfer"and "structural optimization". The project framework was continued 2018 with the topics "Magnetic Flux Guidance" and "Structural Damping". For 2019, the project will focus on "Embedded Sensors" to implement certain sensors within components that are manufactured by using the Laser Beam Melting process (LBM).

PROJECT OVERVIEW

DURATION
CaCS 2017 / 2018 / 2019
(one year each)

PARTNER
Industrial Consortium of DMRC

FUNDED BY
Industrial Consortium of DMRC

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Research assistent
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Michael Haase, M.Sc.

DMRC – DIRECT MANUFACTURING RESEARCH CENTER – RESEARCH INNOVATION EDUCATION

Objective

Additive Manufacturing (AM) is a technology that provides a high level of design freedom. The full potential of AM can only be used if possibilities and challenges of the technology are known and taken into account. In this context, information on the expected changes in performance data due to a suitable AM-design is important.
The idea of the project is to deduce active principles for defined topics using the advantages of AM. To show the practical application, active principles are used to develop generic case studies that are relevant to the industry. For this purpose, suitable design drafts are developed according to VDI 2221 and analyzed with regard to achievable performance enhancement to compare the AM-design with conventionally manufactured components.
As a long term objective, the idea of "Concept and Case Studies" shall be applied to different topics:

- heat transfer (2017)
- structural optimization (2017)
- magnetic flux guidance (2018)
- structural damping (2018)
- embedded sensors (2019)

The results show potentials of additive manufacturing for the respective topic and can be used to inspire design engineers and to emphasize the technical benefits by using AM.

Procedure

The procedure in each year is divided into three phases (Figure 1). The first phase is a general research on the subjects. The investigation does not focus exclusively on the application of AM, but on the thematic objective itself. This approach allows a systematic and comprehensive examination of the topics in general. In addition to the identification of already existing concepts, new approaches can be detected by using the AM-specific possibilities.
The general research approach merges into the second phase, the identification of suitable active principles. In the process already known and new approaches are considered. In some cases simulations were performed to estimate the influence on performance data. With a focus on the application in the design process, a clear and uniform form of presentation was important. Accordingly, all active principles were recorded in a uniform table form which contains a graphic illustration, descriptions of practical relevance, application examples and their quantitative impact on the performance development. The tables are presented in a catalogue which contains the active principles as well as application examples.
In the concept phase of the design process, promising concepts must be selected, which are to be examined in greater detail. To support the decision in this early phase, experience is helpful. In order to make that available for the corresponding subject area, industrial demonstrator components are optimized using a design for AM (Figure 2). These components can be used to verify and demonstrate the applicability of the active principles for each topic. In 2017 the topics were heat transfer (2 & 4), structural optimization (5) and combinations of both topics (1 & 3). Due to the generic approach and the use of function-orientated active principles, the application of the results is not limited to the demonstrators. The active principles allow a broad applicability and can be used in further components.

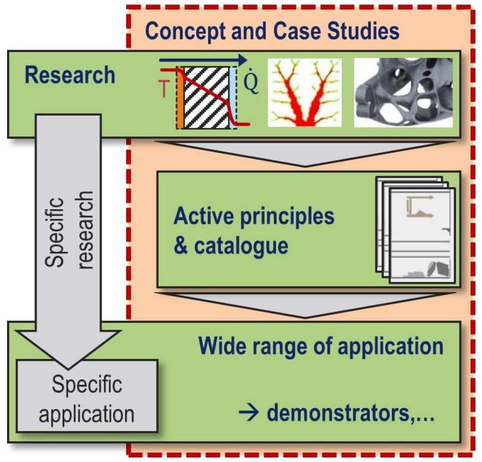

FIGURE 1 Project concept and process phases

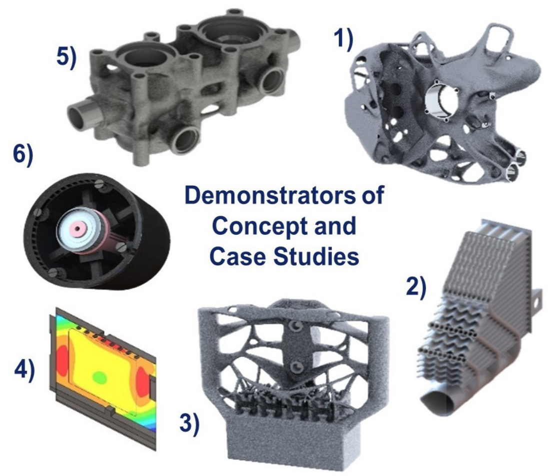

FIGURE 2 Selection of demonstrators developed in CaCS

Results in 2018

In the field of magnetic flux guidance, it could be shown that the three-dimensional freedom of design of additive manufacturing could be used specifically to generate a preferred magnetic direction. For this purpose, corresponding specimens were manufactured from an iron-silicon alloy on an SLM machine. Although the specimens showed that solid structures have the best conduction properties, the targeted introduction of air gaps allows a clear preferred direction. In this context, the constructive implementation of three-dimensional magnetic flux paths in components would be possible. As a demonstrator (Figure 2), a valve (6) was designed whose rotary motion is caused by the use of the preferred magnetic direction. The principle of actuation is similar to a compass that aligns itself in a magnetic field.
An influence could be identified on the structural damping with lattice structures. Experimental tests have shown that the damping properties of the lattice structures can be influenced. However, computer-aided simulation and optimization currently fail at the limits of the software systems, which are only able to map damping in fine lattice structures to a limited extent. The results show the potential to integrate lattice structures into components in a targeted manner and thus to enable the damping properties also in the context of lightweight construction requirements.

Results in 2019

The research topic for 2019 is „embedded sensors". In this context, the integration of the sensors during the manufacturing process in an SLM system will be investigated. The aim is to identify active principles and design guidelines with which it should be possible to integrate sensors into components manufactured using the SLM process. Particularly problematic are the powder removal and the process-related temperatures during the manufacturing process. The general guidelines should take these aspects into account and make the implementation of such sensor solutions easier in the future.

DMDR 3.0 – UPDATED AND EXTENDED DMRC DESIGN RULE CATALOG

Design rules for additive manufacturing (AM) processes are important for the acceptance of these technologies and are required by the industry. Furthermore, design rules are necessary to provide and teach the design freedoms of AM to users of these technologies as well as to students. The project "DMDR 3.0 – Updated and Extended DMRC Design Rule Catalog" is aimed at extending the exisiting DMRC Design rule catalog by further processes, materials, manufacturing machines and parameter settings

PROJECT OVERVIEW

DURATION

01/2019 – 12/2019

PARTNER

- Baker Hughes Oilfield Operations, Inc.
- BASF New Business GmbH
- Evonik Resource Efficiency GmbH
- John Deere GmbH & Co. KG
- Porsche AG
- Siemens AG
- SLM Solutions Group AG
- The Boeing Company

FUNDED BY

Industrial Consortium of DMRC

RESEARCHER

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Johannes Tominski, M.Sc.

DMRC DIRECT MANUFACTURING RESEARCH CENTER RESEARCH INNOVATION EDUCATION

Objectives

The project "Direct Manufacturing Design Rules" (DMDR 1.0 and 2.0) is aimed at developing design rules for additive manufacturing processes and to make them accessible to a broad spectrum of users ranging from the scientific community and the industry to students.
To reach this goal, standard elements were defined in the DMDR 1.0 project in 2008. These are geometrical elements which are frequently used in the design of technical products. Based on these elements, a process-independent method for the development of design rules was set up. Using this method, design rules were developed for laser sintering, laser melting and fused deposition modeling processes. Different machines, materials and process parameters were used at the DMRC for this purpose. The derived design guidelines depend on these three influencing variables. For this reason, the developed design rules are only applicable to the described boundary conditions of cases which were considered in the DMDR 1.0 and 2.0 projects.
The scope of the developed design guidelines can be extended by considering changed boundary conditions. This is the objective of the research project "Direct Manufacturing Design Rules 3.0".
Using the method provided by the DMDR 1.0 project, it shall be checked whether the developed design rules can also be applied to different procedures. Different materials, manufacturing machines and parameter settings will be considered. The scope of validity will be extended by seven new combinations of material, manufacturing machines and parameters. Thus, the DMRC Design Rule Catalog can be can be extended by seven further pillars of the project DMDR 3.0 project (figure 1).

To extend the range of validity, the following work packages are defined:

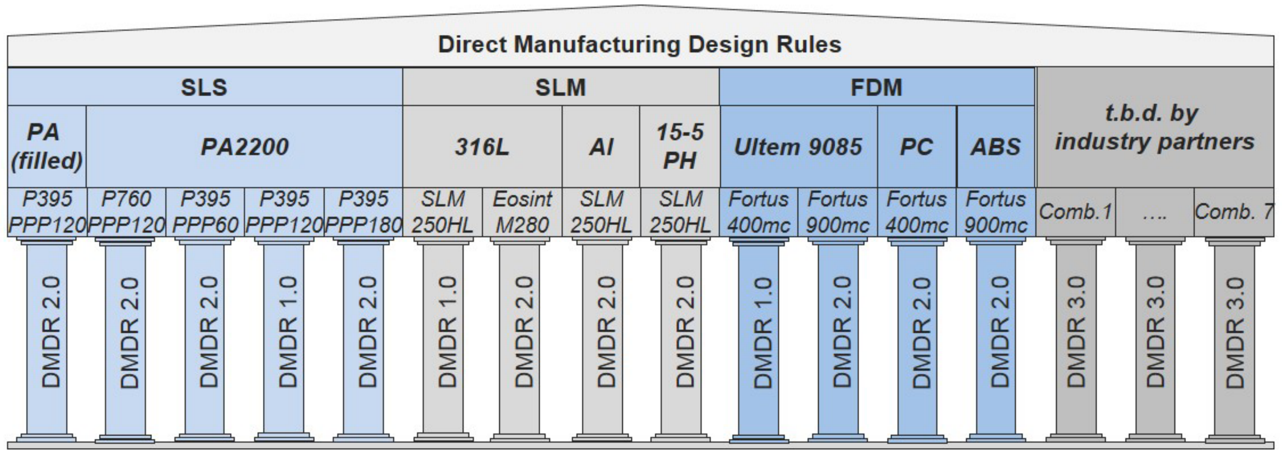

FIGURE 1 Schematic illustration of the validity area of the design rules developed in projects DMDR 1.0 and DMDR 2.0, enhanced by the design rules of project DMDR 3.0

Work package 1: Extension of the range of validity for seven new machine-material-parameter-combinations

The industrial partners select eight preferred combinations, which they frequently use in their companies or intend to use in the future. In order to achieve the highest possible significance of the results and to avoid the pure consideration of metallic materials, the proposals are discussed with the DMRC and decisions are made regarding the eight combinations.
Construction job data provided by the DMRC for the test specimens are first prepared by the industrial partners with regard to the boundary conditions and then produced. A description of the production of the test specimens also provided by the DMRC accompanies this process in order to guarantee the same methodical procedure that was defined in the DMDR 1.0 project, regardless of the boundary conditions.
In order to enable a statistical evaluation and to increase the significance of the results, the test specimens are produced in triplicate and shipped to the DMRC. The DMRC determines the respective measured variables of the test specimens according to the methodical procedure and subsequently evaluates them.

Work package 2: Adaption of the design rule catalog

As part of the second work package, the DMRC design guidelines catalog developed in DMDR 1.0 and 2.0 will be adapted to the results of the DMDR 3.0 project. The results of work package 1 are integrated into the respective design guidelines with a note on the respective combination. This process is accompanied by the analysis whether the respective guideline is relevant for the examined boundary conditions. If necessary, the previous design catalog will also be extended by further design guidelines if a combination requires this.
The result of the project DMDR 3.0 is a design rule catalog with extended validity. With the design guidelines and the specific limit values it is possible to realize a robust component design for a multitude of combinations. The catalog forms a current basis for the handling and training of additive manufacturing.
In addition, components can be optimized for additive manufacturing using the updated and extended design rule catalog. Furthermore, this offers the possibility to reduce time and therefore costs by the conscious approach during the component design.

EFFECT OF DEFECT

Defects such as porosity are more commonly encountered in as-built Additive Manufacturing (AM) parts than in wrought alloys and some defects, such as trapped powder or lack of fusion etc., are unique to the DMLM process. Process-specific defects that can be produced during the generation need to be characterized using destructive and non-destructive evaluation methods, as there are no established standards. Consequently there is a lack of effect-of-defect data for AM parts, which hinders part acceptance. Developing a catalogue of defects commonly encountered in the L-PBF process, and categorizing the critical defect types, sizes and distributions is critical for establishing acceptance criteria.

PROJECT OVERVIEW

DURATION

01/2019 - 01/2020

PARTNER

Industrial Consortium of DMRC

FUNDED BY

Industrial Consortium of DMRC

RESEARCHER

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DMRC RESEARCH INNOVATION EDUCATION
DIRECT MANUFACTURING RESEARCH CENTER

Aim

The aim is to develop a database of typical defects formed during the DMLM process and to study the effect of these defects on the AM part's performance. Based on the effect-of-defect studies, defects can then be classified into critical and allowable categories, which will help establish limits for part acceptance for specific operational conditions as well as develop methods to prevent or reduce the critical defects.

Procedure

Specific material and process parameter combination and operating conditions will be selected to constrain the range and complexity of the problem. Nevertheless there is a need for a strategy that can reproduce specific defects (e.g. pores) in the building process while ideally not creating any other types of defects (cracks) to allow an independent evaluation of the effects on the mechanical properties. The state of the art machines already generate high density parts without severe imperfections and therefore defects like cracks or large voids usually do not occur in standard materials like INC 718, AlSi10Mg or Ti6Al4V. For this reason it is not possible to just build samples with the standard parameters but with intentionally inadequate conditions as wrong parameters, powder humidity or oxygen content to analyse the influence of these conditions on the process.
After developing the procedure to a specific defect, tensile specimen will be produced and analyzed in a CT-scan, so that the reason of failure might be predicted under real conditions. In addition an investigation of the fracture surface (e.g. SEM, light microscopy) will help to determine the cause of failure. As not only the type and size of a defect is important but also the location in the part. In this case, a catalogue will be filled with these information to allow a precise prediction of the negative effects of defects in AM parts in the future. Additionally to the typical tensile tests, a Charpy impact test will be considered, as defects have a major influence on the notch impact strength, especially with brittle materials.
In a first attempt, density cubes will be printed in order to find a method with which the desired types of defects can be specifically generated. If these preliminary tests are satisfactory, tensile specimens will be produced with the parameters and building conditions found. A further examination will introduce the defects locally, in a few layers or a small volume in the tensile specimen, in order to guarantee a defined failure and to be able to consider the distribution as well as the frequency. The printed samples are then examined in the specified manner.
The results of the tensile tests, fracture surface analysis and CT scans will be evaluated together in order to establish a connection to the defects and to achieve a systematic characterization of these. Based on the results, a classification of the defects is then attempted, which classifies them into permissible and inadmissible, taking into account the position, the material, etc. of the defect.

Conclusion

The performance and quality of AM parts is significantly influenced by the material characteristics and process parameters. Characterizing defects and their effect on mechanical performance would help address gaps related to acceptance criteria for AM parts.

Acknowledgements

The DMRC would like to thank the NMI – Natural and Medical Sciences Institute at the University of Tuebingen for taking the pictures of the different pores.

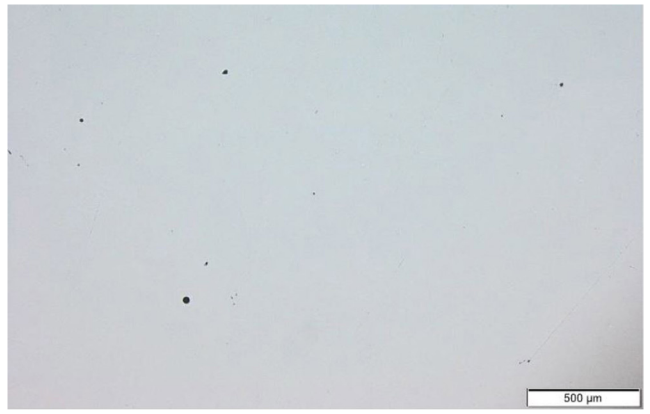

FIGURE 1 Spherical gas porosity

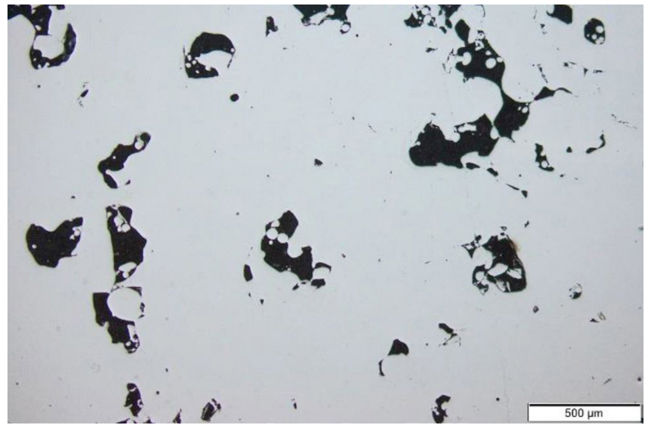

FIGURE 2 Lack of fusion pores

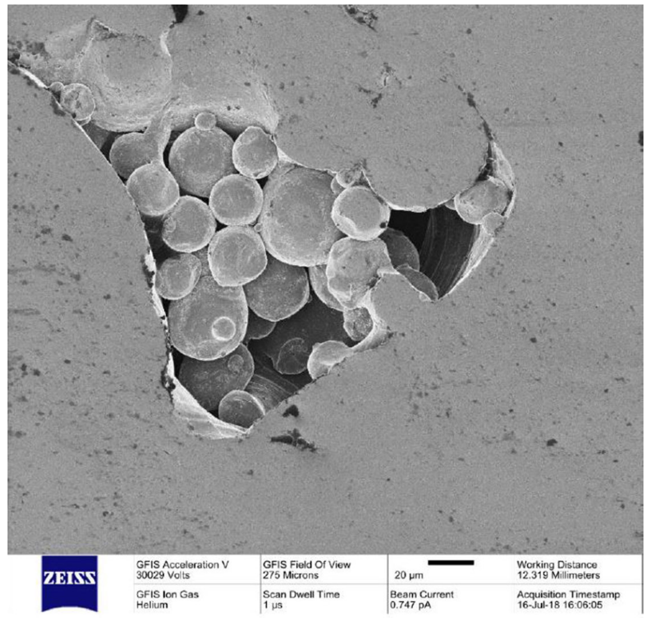

FIGURE 3 Close-up of lack of fusion pore with unmelted powder particles

FOCUS - ACTIVE STRATEGY IMPLEMENTATION AND ADVANCEMENT

The DMRC is one of the most important national and international research institutes for Additive Manufacturing technologies in industrial applications. In this position, the DMRC needs to act as an influencer in the AM community, to focus ambitions towards key research areas and to advance quickly but sound in all of these areas and strengthen strategic decisions of partners. For the maintaining of this position, the DMRC has to follow a strategy being aligned to future developments of AM. The FOCUS project included the screening of the AM society, the validation and adaption of the DMRC strategy of 2013. Additionally, FOCUS supports managing roles by the implementation of methods and tools to operationalize the handling of the DMRC strategy.

PROJECT OVERVIEW

DURATION

12 months

PARTNER

The Boeing Company

FUNDED BY

Industrial Consortium of DMRC

RESEARCHER

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Research assistant
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Christian Oleff, M.Sc.

DMRC DIRECT MANUFACTURING RESEARCH CENTER — RESEARCH INNOVATION EDUCATION

Motivation

Additive Manufacturing (AM) is a technology being influenced by dynamic changes based on technological improvement and research results. These dynamic changes imply the implementation of an adaptable strategy. In the “FOCUS” project the changes of the AM environment (promising industries, research fields, requirements and the research landscape) were investigated and the strategy of 2013 was validated. On the basis of the information the strategy for the DMRC until 2025 was adjusted. For the changing of a passive to an active strategy, methods and tools were implemented to plan and control the strategic approach.

Study update

The studies which were published in the context of the DMRC project “Strategy” are high frequently requested by industries. The content of the studies was generated in 2011 until 2013. To provide a holistic state of the art overview of the AM environment, topics such as promising industries, research fields and the research landscape were investigated and updated. The update of the studies was used as the basis for the alignment of the DMRC strategy. Additionally, the updates offered the opportunity to strengthen the visibility of the DMRC in the AM environment.

Strategy validation

In the “Strategy” project ten strategy variants were identified for the DMRC. The strategic variants differ by the degree of industrial or scientific orientation. Based on the strategic direction of the DMRC the variant “Industrial Research Base” was selected. The “Industrial Research Base” has not a clear focus on research or industrial applications. In FOCUS the strategy variant was validated by different stakeholder groups with several methods. In a strategy meeting with DMRC partners strategy variables being identified in the “Strategy” project were assessed. Additionally, the existing roadmap of the DMRC were proven on the fulfilled strategy aims. A stakeholder map was generated including competitors, potential partners and relevant AM committees. Potentials and risks were identified by using a SWOT analysis in the strategy meeting. Results of the strategy meeting show that the strategy variant is still valid. But there are few strategy variables such as key activities, key resources and development of standards which need to be changed according to the DMRC partners.

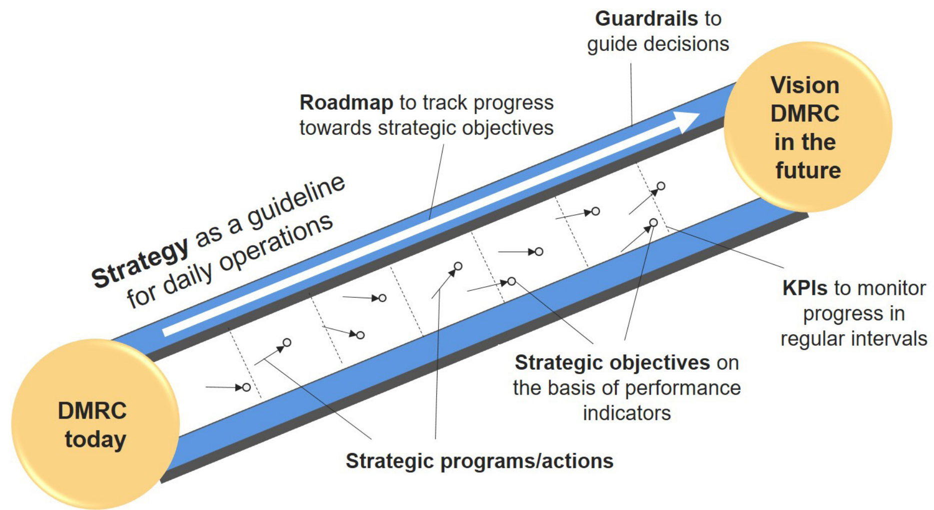

FIGURE 1 DMRC Strategy Setup

Strategy alignment

For the strategy alignment questionnaires and interviews were used as methods. The focus of both, questionnaire and interviews, dealt with aspects being identified as changeable points in the strategy meeting. Additionally, the aims of the DMRC partners in context of AM were identified. The results were used to adapt strategic variables and to identify research fields being relevant for the DMRC in the future. The aims being mentioned by the DMRC partners were clustered in the following points: process characteristics and maturity, materials, business model, AM integration into production, efficiency, application and knowledge/methods/tools.

Operationalization

For the operationalization the Balanced Score Card (BSC) was implemented into the processes of the DMRC. The BSC includes the four perspectives: customers, values and finances, employees and resources and processes. The method provides as a planning and controlling tool for every time period. The DMRC management will use the BSC to structure Standard Key Performance Indicators (KPI) and roadmap aims. Additionally, the DMRC roadmap was adapted and extended until 2025. The list of Standard KPIs and the roadmap 2025 build the basis for the BSC. The DMRC board will implement Standard KPIs and roadmap aims into the BSC for planning the next time period. At the end of the time period, the BSC will be used to prove the fulfillment of the strategic aims. For the usage in operational processes, a management cockpit will be implemented for the DMRC management. It includes diagrams visualizing the development of strategic aims in the context of the BSC perspectives. For the implementation of the strategy, immediate actions were identified.

Conclusion

The strategy of the DMRC was validated in the FOCUS project. The chosen strategic variant “Industrial Research Base” is still valid. Only few strategic variables inside the strategic variants had to be adapted.
Interactions with DMRC partners by questionnaires and interviews were used to identify strategic aims being relevant for the identification of core research fields. These aims were implemented in a list of Standard KPIs and the DMRC roadmap 2025.
For the operationalization of these Standard KPIs and roadmap aims, the BSC was implemented in the processes of the DMRC. For the implementation of the DMRC strategy, immediate actions were identified which have to be fulfilled in the next time period.

PA613 - LS POLYAMIDE FOR HIGH TEMPERATURE APPLICATIONS

The introduction of the selective laser sintering (SLS) process into the market of the direct manufacturing of components demands materials which meet the high requirements of the industry. PA613, a polyamide developed by Evonik to be used in high temperature applications for example in automotive or electronic industry, is tailored to the SLS process. Within the described project parameters to process the new material on an EOS P396 laser sintering system are investigated in correlation to resulting build part properties. This way high quality and reproducible components are targeted and limits of the applicability can be found.

PROJECT OVERVIEW

DURATION

06/2018 - 12/2019

PARTNER

Industrial Consortium of DMRC especially EVONIK and EOS

FUNDED BY

Industrial Consortium of DMRC

RESEARCHER

Research leader
Prof. Dr.-Ing. Hans-Joachim Schmid

Research assistent
Christina Kummert, M. Sc.

DMRC DIRECT MANUFACTURING RESEARCH CENTER RESEARCH INNOVATION EDUCATION

Motivation

The last DMRC Project “LS Polyamide for High Temperature Applications – Processing and Properties of PA613” verified that the new LS material PA613, delivered by Evonik, shows good processability on the regular “low temperature” LS EOS P396 machine and mechanical part properties are about 25 % better than the ones of polyamide 12 build parts. However, beside higher strength, higher temperature resistance is required in advanced applications like electronics or automotive industry. The temperature resistance in addition to other advanced short term material properties will be investigated within this project. As PA613 is not known in conventional manufacturing, it is important to classify the material within the range of engineering plastics to become a new high performance material in industry. For this purpose, more information about part properties have to be generated.

Evaluation of processability and recyclability

First of all, the general processablity of PA613, in terms of powder recoating behavior and process temperatures, has to be evaluated. Furthermore, parameters and machine settings have to be found to manufacture robustly build parts. This should not only be tested for virgin powder material but also for recycling powder. Each new laser sintered material is affected by its own aging effects due to the process conditions. These and their extent has to be tested first. This can be accompanied by an investigation of a suitable mixing ratio to manufacture components with high quality and to reuse as much material as possible which already served as support material in the process.
For this purpose, test specimens with different mixing ratios of virgin and aged powder are built and surfaces as well as mechanical properties, for example, are regarded. Resulting characteristics are not only correlated to the refresh ratios but also to the MVR (Melt Volume flow-Rate)

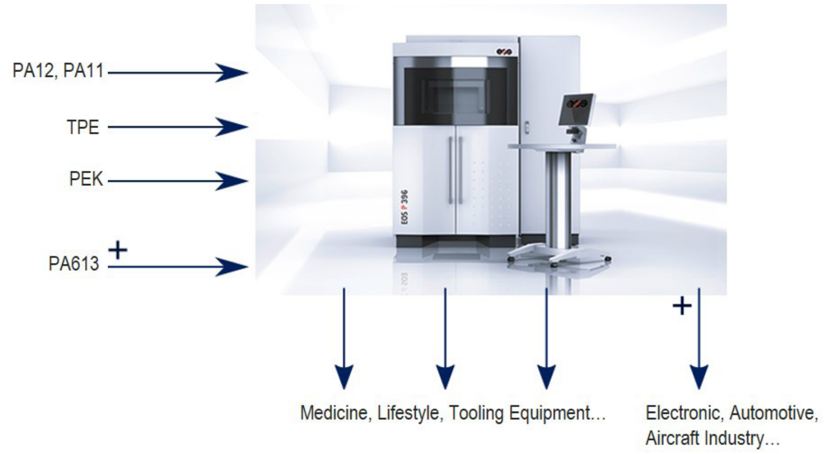

FIGURE 1 The availability of materials is increased and thus the applicability of the laser sintering process is improved

value which helps to qualify the aging stage of the powder material.

Parameter development

In order to generate material properties that are as representative and as optimal as possible, a parameter development is carried out with the aid of statistical experimental design prior to the tests. The material showed in former investigations quiet constant mechanical behaviour for a wide range of laser energy input into the hatching scanning pattern. However, the contour parameter seem to influence even more the tensile properties especially in z- build direction. Following, this project focuses the contour laser exposure parameters and strategy whereas the hatching is kept constant. Nevertheless, in order to reduce the experimental plan, a design of the experiments is created with the help of the statistical software Minitab 18 first. Test results are analysed to detect correlations between varied parameters and build part qulity. Finally, a response optimization is carried out.

Materialcharacterization - short term properties

The resulting optimized build paramaters are taken to manufacture various specimens. Beside testing tensile, impact, bending and compressive properties at different application relevant tempeartures, the material behaviour after conditioning is regarded. Conducted tests show that, as known for polyamides, the tensile strength of PA613 is decreasing with increasing temperature but is still obove 20 MPa at 120°C. On the other hand elongation at break is increasing with increasing temperature but also shows more anisotropy for x- and z- build direction.

Materialcharacterization - long term properties

To extent the comprehensive material data base, the content of this year‘s project is the determination of long-term properties, especially at high temperatures. As PA613 is a polyamide for high temperature applications, the long term resistance under thermal stress has to be investigated. Furthermore, fatigue behavior of PA613 laser sintering parts has to be known for dynamical applications like in aircraft, electronic or automotive industry. Moreover, parts are used under changing environmental conditions like temperature or moisture which decreases part life with unknown consequences. Following, long term part properties of PA613 are investigated. Hereby former DMRC Projects about PA613 quasistatic part behavior (Funding cycle 2017 and 2018) and on the other side fatigue behavior of FDM and LS parts made of PA12 (Funding cycle 2015) will set the basis for the experimental approach.

The overall aim is to characterize and to identify limits of the laser sintering PA613, to classify the material within the range of engineering plastics and to introduce a new high performance material in industry and therewith to enlarge the field of application of the Additive Manufacturing process Laser Sintering (see Figure 1).

PROCESSING OF ALTERNATIVE FDM MATERIALS

A widespread additive manufacturing process is the Fused Deposition Modeling (FDM). Not many high performance plastics are available. In theory, it is possible to process any thermoplastic polymer using the FDM process. For professional FDM machines, only a small number of different materials can be purchased. These materials are provided by the machine manufacturers and the material properties are often not sufficiently known. Therefore, this project investigates the processability of alternative high-performance polymers for the FDM process.

PROJECT OVERVIEW

DURATION

01/2018 - 12/2019

PARTNER

Industrial Consortium of DMRC

FUNDED BY

Industrial Consortium of DMRC

RESEARCHER

Research leader
Prof. Dr.-Ing. Elmar Moritzer
Research assistent
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DMRC DIRECT MANUFACTURING RESEARCH CENTER RESEARCH INNOVATION EDUCATION

Processing of alternative FDM materials

The Fused Deposition Modeling (FDM) process is an additive manufacturing process. The components are generated by a liquified thermoplastic strand, which is deposited layer by layer. The used plastic filament is drawn into the FDM head by motors, melted there and deposited on the construction platform or on the existing structure through a nozzle. Due to thermal fusion, the material bonds with the underlying layer and solidifies. The FDM process is one of the most commonly used additive manufacturing processes for the manufacture of prototypes, tools and end products.
Due to the great popularity of the FDM process, the materials market is growing with new materials. There are a variety of plastics that can be processed using the FDM process. These materials can be modified by the addition of additives in order to influence not only the basic properties but also certain material properties such as fire resistance, chemical resistance, fracture resistance or heat resistance. In principle, almost all thermoplastics are suitable for the FDM process. They are used particularly frequently, for example: ABS, PLA, PI or PA.
The aim of the research project is to investigate the processability of alternative high-performance polymers for the FDM process. The complete process chain from granulate to component will be investigated. This means that in the first step filaments must be produced from the standard granulates (as starting material). In the next step, the filaments are processed on an open-parameter FDM machine. Finally, the process parameters are optimized. The main focus for the evaluation of the processing suitability is on the weld seam strength and the warpage behaviour of the materials due to material shrinkage.

Investigations of the weld seam strength

In the past project year, the following materials were tested with regard to their processability in the FDM process in close consultation with the DMRC industrial partners: Unreinforced polyetheretherketone (PEEK), carbon fibre reinforced PEEK, thermally conductive PEEK, glass fibre reinforced polypropylene and polyphenylene sulphide (PPS). In particular, PEEK and PPS are used for high temperature applications. The processing is demanding because special equipment is required to process high-temperature materials. The weld seam strength has been considered as a criterion for evaluating the processability.
During preliminary investigations, experimental points of a test plan with suitable temperature settings of the nozzle, the build chamber and the heating bed are developed and determined. Differences due to the selected process parameters can be identified with the help of manufactured components and the following determination of the weld seam strength. For this purpose, test specimens are produced out of the components, and the strengths of these test specimens are determined in a tensile test. The real weld area between the individual strands is then determined to calculate the weld seam strength of the individual test pieces by using microsections to measure the weld seam width (see Figure 1).
In order to improve the comparability of the various filaments with regard to their processability, the weld seam strength is related to the base material strength of the respective filament and a welding factor is calculated. In order to further characterize the materials and possible components from the materials, a weld seam width factor is identified and evaluated from the width of the weld seam and the width of the deposited strand.

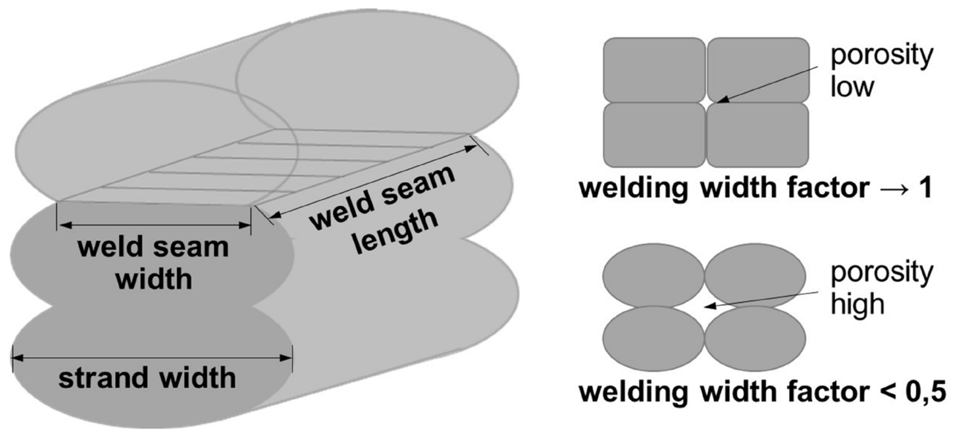

FIGURE 1 Structure of the welding surface and influence of the porosity of a component

Investigations of the warpage behavior

In the FDM process, the component is manufactured out of a large number of single layers. The strands are deposited in a defined manner, each strand cools down and shrinks separately. For example, the densities of polymers vary when the temperature changes from processing temperature to environmental temperature. The shrinkage that occurs leads to residual stresses in the component, which can lead to warpage. Excessive warpage leads to areas of the component that bend upwards from the production level and thus disrupt the process.

The aim of this section of the project is to analyse shrinkage and warpage behaviour as an additional criterion for processability. A selection of the materials that have been investigated so far with regard to the achievable weld seam strengths is used. The process parameters should be optimized under consideration of the shrinkage behaviour.
In contrast to shrinkage, warpage depends on many processing parameters and cannot be measured or taken from material data sheets. The shrinkage behaviour can be measured under defined conditions in a pvT measurement. The findings from the pvT measurements can be used in further investigations to adapt and estimate the processing conditions during the FDM process. The aim is to quantify and evaluate the warpage that occurs.

QuLS: QUALIFICATION OF LASER SINTERING SERIAL PRODUCTION

Reliable and repeatable part properties are indispensable to include polymer laser sintering in the industrial process portfolio of many companies. With the methodology presented here, not only the process flow from component to post-processing is considered, but also the machine performance is tested in an interlaboratory comparison and over a longer period of time. The backbone of the study is the DMAIC (Define - Measure - Analysis - Improve - Control) improvement cycle which originates from the Six Sigma approach. It was shown, that the proposed methodology is simple and flexible to use for the qualification of AM processes whereby the industrial level of the EOS P396 was evaluated.

PROJECT OVERVIEW

DURATION
01/2018 - 01/2019

PARTNER
Industrial Consortium of DMRC

FUNDED BY
Industrial Consortium of DMRC

RESEARCHER
Research leader
Prof. Hans-Joachim Schmid
Research assistant
Helge Klippstein, M.Sc.

WEBSITE
https://dmrc.uni-paderborn.de/content/research/internal-projects-2018/qualification-of-ls-serial-production/

DMRC DIRECT MANUFACTURING RESEARCH CENTER — RESEARCH INNOVATION EDUCATION

Qualification Methodology

Within this project the improvement cycle define - measure - analyze - improve - control (DMAIC) is applied for the qualification of the polymer laser sintering process with an EOS P396 system. This approach enables process qualification with a wide range of qualification objectives. It allows the process to be adapted flexible to the specific needs of different industries. The wor k packages for qualification are the following:

- **Definition** of a standardized workflow
- **Measureing** SLS parts based on quality criteria
- **Analyzing** the measurements and potentials
- **Improve** the standardized workflow
- **Control** of improvements and overall process

The standardized workflow focuses on the process flows: design, pre-processing, powder material, machine process and finishing. In the end-to-end process, these sub-items are complemented by general headings such as query and order creation, human resources, environment, utilities, infrastructure, finishing, quality control, warehouse, storage and logistics.

For the methodology, quality indicators are defined first to measure the performance of the process. The mechanical properties are measured by the tensile test and Charpy impact test. For the length deviation, a component is measured with the aid of an outside micrometer. The surface properties for different construction angles are measured optically. In addition, the component density is determined using the Archimedean buoyancy method. Within the test plan, several further test specimens can be added and examined.

Quality Assessment and Test Layout

As shown in the diagram (Figure 1), the performance can be measured continuously for each build job of a series production. For this, test components must be placed in the job layout of series production which reduces the usable space. At the same time, the interpretation of the results is difficult because the measurements are often dependent on the position in the build room. Alternatively, quality assessment (QA) can be performed together with the maintenance period. This would correspond to a frequently inspection of the machine. However, it would not be possible to make a statement about the intermediate manufacturing jobs. Within the scope of this project, a QA-job is produced and measured six times on three different machines. The aim is to examine the serial capability of the machine and to record the performance limits of the various quality criteria. For industrial applications, a combination of the different measuring approaches is recommended.

Since the position within the construction contract is known to have an influence on the component properties, the test specimens must be positioned over the entire construction volume. These influences can be local defects as agglomerates or systematic deviations such as temperature fluctuations, laser spot shape and focus point etc. The test volume is set at ~300 mm height of the EOS P396 machine. The entire layout of the build job and the test parts are shown in Figure 2. The build room is divided into 27 test areas bounded by cubes. Inside these cubes are different specimens and test samples for the quality criteria measurements (Figure 3). The test specimens are positioned in such a way that they cover the weakest position and building orientation as far as possible.

Summary

The laser sintering process with polymers was investigated over a period of half a year and various powder batches and machines were used to assess the influences. The results of the analysis show high deviations which are due to the measuring method as well as the laser sintering process itself. A catalogue of measures was proposed for the Improve and Control work package. These include quality control card limits for mechanics, external dimensions, surface and density and thus a continuous quality measurement. This also enables the introduction of a statistical process control system.

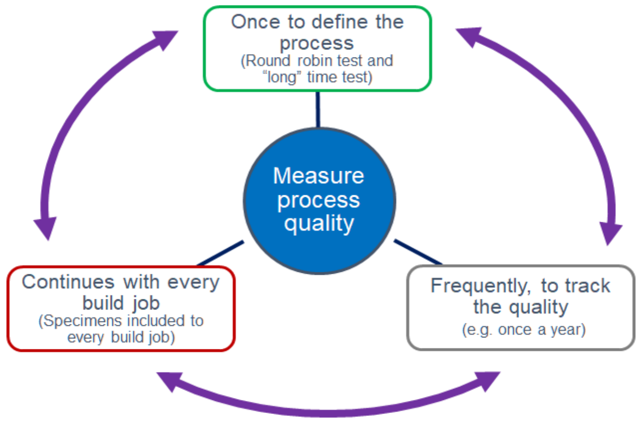

FIGURE 1 Quality assessment and assurence methodology

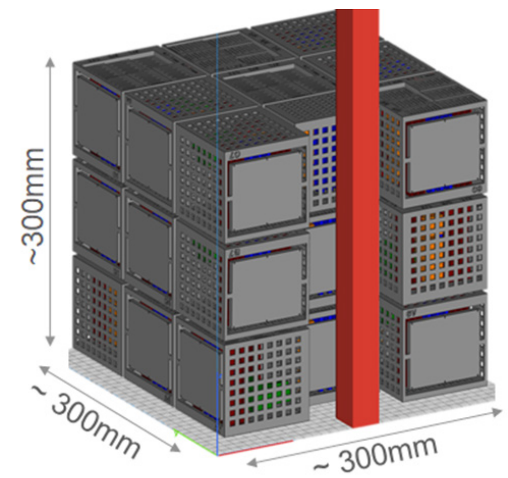

FIGURE 2 Quality assessment build job layout

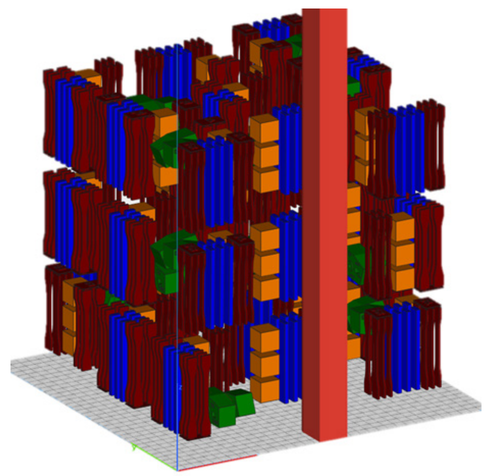

FIGURE 3 Quality assessment build job layout, without sector cubes

CONTENT

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 freedom of design 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 Universität Hannover.

PROJECT OVERVIEW

DURATION

03/2019 – 08/2020

PARTNER

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

FUNDED BY

German Research Foundation (DFG)

RESEARCHER

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Prof. Dr.-Ing. Mirko Schaper (LWK)
Prof. Dr.-Ing. Detmar Zimmer (KAt)

Research assistent
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Lennart Tasche, M.Sc. (LWK)
Stefan Urbanek, M.Sc. (IAL)

DFG Deutsche Forschungsgemeinschaft
German Research Foundation

Motivation and aims

Efficient drive systems are becoming more and more important in the context of increasing automation in both private and industrial sectors. At the same time, the demands on these systems are growing, for example in terms of emissions and space requirements. Electric motors in particular are of interest for many applications, but must meet the respective requirements. Additive Manufacturing processes offer a high freedom of design 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.

Due to the layer-wise component manufacturing in AM, complex structures are divided into a series of simple 2D elements and manufactured subsequently. This characteristic provides new possibilities for the design of motors in electrical machine construction, since in comparison to conventional production there are no restrictions which inevitably arise during the conventional layering of electrical sheets. With the help of AM, almost any three-dimensional structure can be realized, for example to achieve a modified guidance of the magnetic flux or to enable a higher degree of lightweight construction for highly dynamic drive concepts. For this purpose, further design guidelines for the selected materials and structures are necessary and will be developed within the project. In the course of this, additional guidelines for the design of the magnetic pockets have to be developed and aspects of post-processing have to be taken into consideration.

Laser Beam Melting (LBM) is considered within the project, since it allows the processing of the relevant metal alloys. Another crucial advantage of the LBM process compared to other powder-based processes is the high achievable density of over 99 % due to the local melting of the powder. This low porosity makes LBM components competitive with conventionally manufactured components made of solid material in terms of their mechanical properties and thus

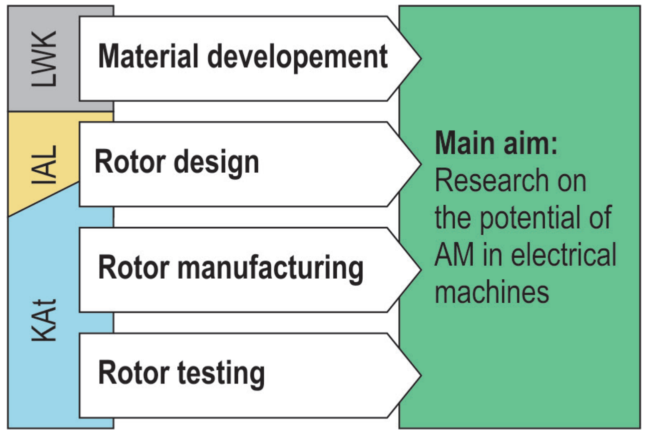

FIGURE 1 Main objective and content of the project

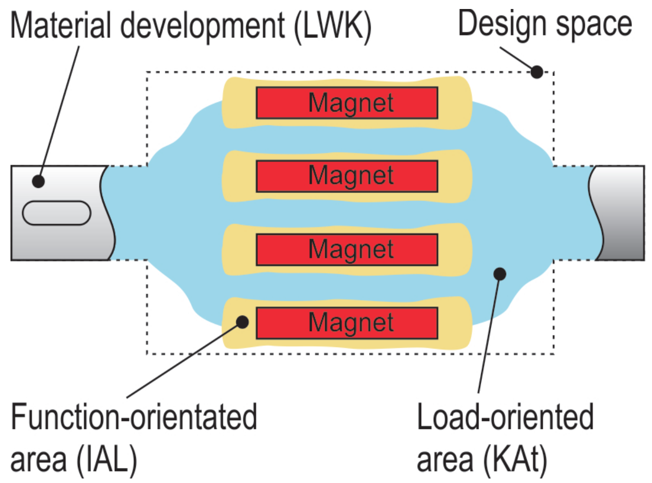

FIGURE 2 Exemplary illustration of a rotor with different functional areas

suitable for use as functional components in series production. In addition to density, the microstructure and thus the mechanical properties as well as other component properties such as surface quality, residual stresses, warpage or dimensional accuracy can be specifically influenced by adjusting the process parameters.

The overall objective of this research project is to investigate the potentials of additive manufacturing in electrical engineering (Figure 1). The existing design and construction characteristics of rotors of permanent-magnet excited synchronous machines are to be extended by the use of AM processes. 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 (Figure 2) will be implemented in an additively manufactured demonstrator to validate the developed calculation models.

Previous investigations

In previous research projects, such as the „Feasibility Study 3D Printing of Electric Motors; FVA 731I & II", completed by a cooperation of the DMRC and the IAL, as well as „Prima3D" of Chemnitz University of Technology, first investigations on the application of AM in electrical engineering were carried out. These research projects already showed a high potential of AM in electrical engineering. Nevertheless, the technologies are still at a relatively early research stage; therefore, important values, such as the electromagnetic properties of additively processed material or the influence of a design optimization on the magnetic flux guidance, have not been investigated in detail.

Proceeding

In order to exploit the above-mentioned potential, a suitable material must be identified and investigated. This is done in two steps. First, parameter studies are carried out on a selected iron-cobalt and two iron-silicon alloys. This is followed by the determination of the mechanical and magnetic properties. The material properties of the investigated alloy systems are to be optimized with regard to the operating load by means of a subsequent 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, the focus in the development of the rotor demonstrator is on a functional design that simultaneously considers the requirements of the additive manufacturing process as well as necessary post-processing steps. 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.

ADDITIVE MANUFACTURED LIGHTWEIGHT STRUCTURES FOR CIVIL AIRCRAFT COMPONENTS

The Selective Laser Melting (SLM) process provides huge advantages for aircraft components like valve blocks and structural parts. In this project funded by the BMWi – "Federal Ministry for Economic Affairs and Energy", the benefits of substituting conventionally manufactured parts by additively manufactured parts will be examined and quantified. The scopes are, reducing costs, weight and time in comparison to the traditional design and the conventional manufacturing method. Therefore, some innovative approaches are investigated such as hybrid manufacturing and developing a performance parameter to decrease process time.

PROJECT OVERVIEW

DURATION

01/2016 - 01/2019

PARTNER

Liebherr Aerospace Lindenberg GmbH

FUNDED BY

Federal Ministry of Economic Affairs and Energy (BMWI)

RESEARCHER

Research leader
Prof. Dr. Thomas Tröster

Research assistent
Dominik Ahlers, M.Sc.
Jan Gierse, M.Sc.

Supported by:
Federal Ministry for Economic Affairs and Energy
on the basis of a decision by the German Bundestag

Objectives

The aim of this project is to reduce the time required for component selection and production. For this purpose the development of a decision support scheme for future use during the product portfolio analysis was carried out. A software tool was developed to support this decision process, with this tool it is possible to find suitable AM components in an easy way and without expert knowledge in the field of AM. Moreover there is the aim to elaborate the fundamentals for an Additive Manufacturing material database for innovative structures and performance parameters for Ti6Al4V. Therefore, several lattice strucutres and support structures were analysed. The most promising structure was the gyroid structure (Fig. 3), which has many potential as support structure. Moreover, investigations working on improving the process, which includes increasing the building speed of the SLM process and to develop fast and stable process routes that can be used for serial production, were acquired. The intention was to reduce the processing time in every stage of the process chain, particularly in the Additive Manufacturing process. The validation on component level shows a time saving potential of around 25% in consideration of the total processing time.

Workpackages

The project is divided into two work packages, the first work package works on identifying promising aircraft components and to adapt a trade-off methodology to rank these parts. According to this trade-off methodology, a decision scheme for future decisions is developed with a complete description of process chain mapping possibilities and influencing factors for the process. Within the scope of this work package, about 20 components were analysed and ranked. For a detailed elaboration in this project, one component was identified and topology optimized concerning the requirements of the conventional component (comp. Fig. 1). A weight reduction of 35% was achieved while having the same stiffness.

The second workpackage works on the development of a stable process route, based on the aim of increasing the building speed. In this case, a performance parameter was developed and validated (Fig. 1). Therefore several mechanical properties like hardness, tensile strength and fatigue behavior were determined. The gained knowledge of the different working steps were merged in the topology-optimized component to demonstrate the possibilities of Additive Manufacturing as a key technology of the future.

Since the project started in January 2016, the fundamentals for the different working steps are finalized. The material database is discussed and the programming of a decision support tool was done. Furthermore, the initial steps for the determination of mechanical properties of the structures to be examined were finalized. A knowledge base of the behavior of lattice, composite, support structures, and the influence of the part position on the building plate has been established. In addition to that, powder ageing effects in different build jobs with the same powder were analyzed. Investigations on adapting the default process route for Ti6Al4V and for increasing the building speed through parameter optimization has been done. Therefore the limits and potentials of HIP processes were investigated and the influence of the performance parameter on residual stresses and distortions were determined (Fig. 2).

Conclusion

In summary, it can be said that the project showed that the basis for the success of additive manufacturing is a diligent component selection. The component selection determines the success of the application of AM. Furthermore, it could be shown that the optimization of the process parameters for the titanium alloy Ti6Al4V in combination with the HIP process has great economic potential.

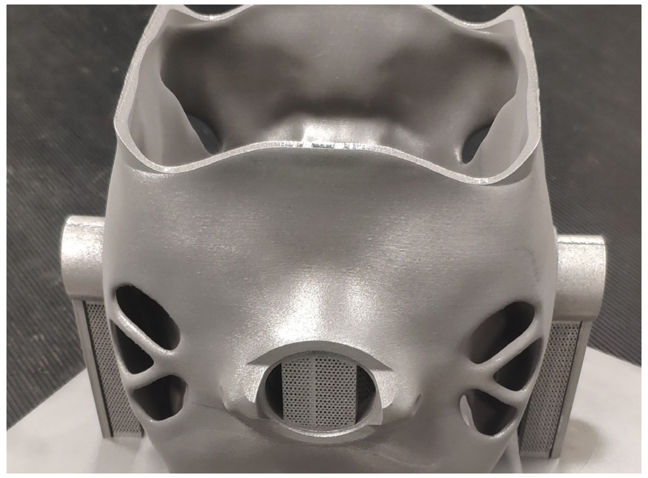

FIGURE 1 Validation of performance parameter

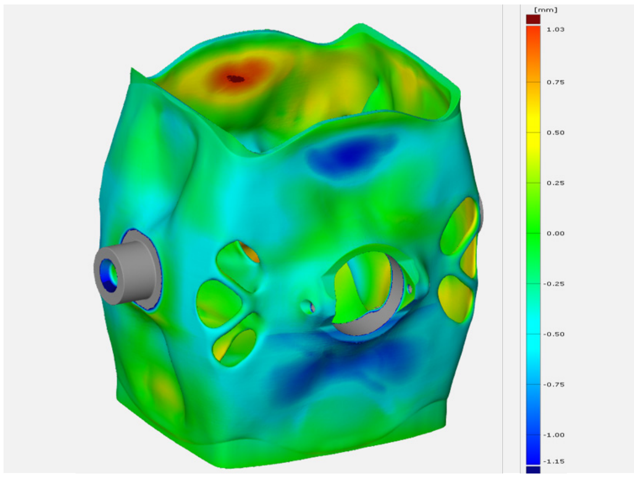

FIGURE 2 Distrotion measurement with CT analysis of the component

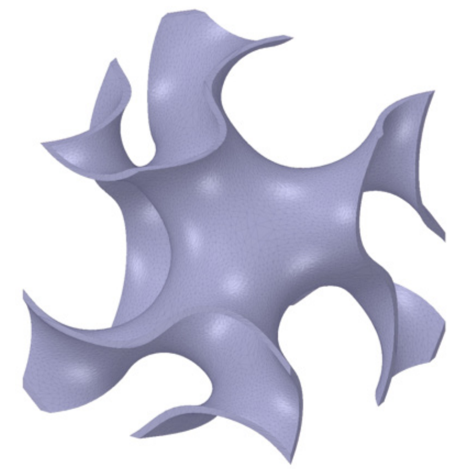

FIGURE 3 Gyroid structure as high performance support structure

COATING OF NEAR-NET SHAPED ADDITIVELY MANUFACTURED COMPONENTS WITH BIOCOMPATIBLE PROPERTIES

The properties of additively manufactured, biomedical components made of titanium alloys coated by PVD are investigated. The focus of the investigation is on TiAl6Nb7 (α+β) and TiNb24Zr4Sn8 (β) processed by selective laser melting. Both alloys have the required mechanical properties and corrosion resistance for use as an implant. The mechanical properties, corrosion and fatigue behavior is determined by means of material analysis and mechanical characterization. The biocompatibility is increased by multilayered or graded coating systems of Ti(Zr,Hf)CN and verified by biological investigations (e.g. cell adhesion, cell culture growth or bio-film formation).

PROJECT OVERVIEW

DURATION

01/2019 – 12/2021

PARTNER

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

FUNDED BY

German Research Foundation (DFG)

RESEARCHER

Research leader
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Prof. Dr.-Ing. Wolfgang Tillmann
Dr. Jessica Meißner

Research assistant
Maxwell Hein, 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 adjusting the proportions of α- and β-phase, the mechanical properties of the addresed alloys (TiAl6Nb7 (α+β) and TiNb24Zr4Sn8 (β)) can be adapted, so that the requirements for biomedical applications can be achieved.

The aim of this research project is the analysis of the coatability of additively manufactured components, which have a contrary residual stress state compared to PVD coatings. Furthermore, the influence of the coatings on the biocompatibility and fatigue behaviour of the components used as implants will be investigated.

The Chair of Materials Science (LWK) analyses the processing parameters for the additive manufacturing of TiAl6Nb7- (α+β) and TiNb24Zr4Sn8-alloy (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-bad-based selective laser melting the process parameters have to be adapted for each alloy. Additively and conventionally manufactured components of both alloys, TiAl6Nb7 and TiNb24Zr4Sn8, are investigated to provide information about the processability of the materials and compared with components made of TiAl6V4 alloy.
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 and TiNb24Zr4Sn8 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)
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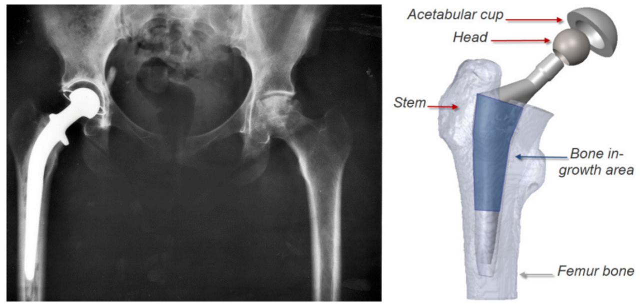

FIGURE 1 X-ray of a total hip replacement (left) and schematic overview of the different parts of an permanent implanted hip endoprosthesis (right); [1].

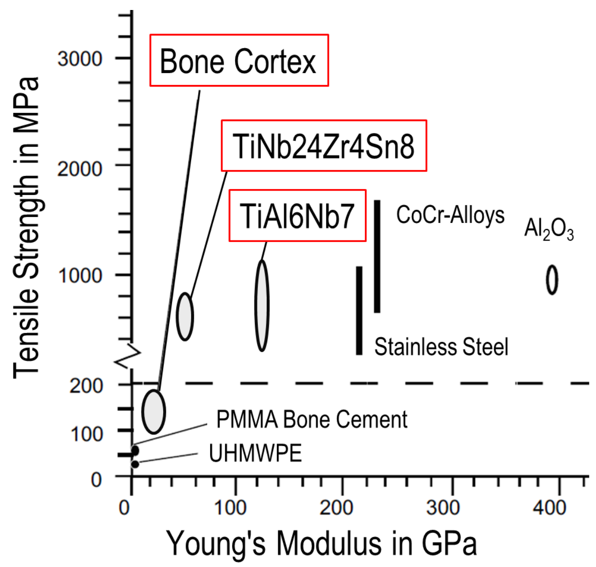

FIGURE 2 Comparison of mechanical properties of different implant materials used in hip arthroplasty and bone cortex; based on [2].

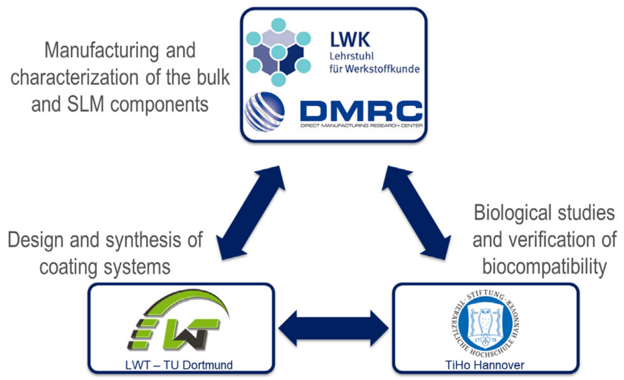

FIGURE 3 Organization and responsibilities within the DFG project.

COMBINATION AND INTEGRATION OF ESTABLISHED TECHNOLOGIES WITH ADDITIVE MANUFACTURING PROCESSES IN A SINGLE PROCESS CHAIN (KitkAdd)

The research project "KitkAdd" refers to the topic „Additive Manufacturing - Individualized Products, Complex Mass Products, Innovative Materials (ProMat_3D)" and was published in the announcement of the Federal Ministry for Education and Research (BMBF) on March 27, 2015. The project focuses on individualized products and complex mass products manufactured by additive manufacturing and aims to increase the economics of Selective Laser Melting (SLM) by combining it with established manufacturing processes. In order to achieve this, an interdisciplinary view of the areas of development, design, process chain integration and quality assurance will be focused.

PROJECT OVERVIEW

DURATION

01/2017 – 12/2019

PARTNER

- Siemens AG,
- H&H mbH
- Eisenhuth GmbH & Co. KG
- GKN Powder Metallurgy
- John Deere GmbH & Co. KG
- Schübel primeparts GmbH
- Karlsruhe Institute of Technology (KIT/wbk)
- Paderborn University (KAt)

FUNDED BY

Federal Ministry of Education and Research (BMBF)

RESEARCHER

Research leader
Prof. Dr.-Ing. Lanza (wbk)
Prof. Dr.-Ing. Zimmer (KAt)

Research assistant
Tobias Lieneke, M.Sc. (KAt)
Thomas Künneke, M.Sc. (KAt)
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WEBSITE

www.kitkadd.de

Federal Ministry of Education and Research

Motivation

Due to the dynamic competitive environment in industry, there is an increasing urge for shorter product development times, high functional integration and individualized products. As a result, additive manufacturing processes are gaining increasing industrial significance. In this area, Selective Laser Melting (SLM) as an additive manufacturing process should be emphasized, since it is already an established process in the area of prototyping and small series production, which is on the threshold of being used in series production. The main obstacle to a further spread of this technology has hereto been the low cost-effectiveness, which can be attributed to three essential criteria: the low productivity of the process, the insufficient process capability, e.g. insufficiently replicable component properties and a product benefit that does not live up to expectations due to the lack of consistency in exploiting design freedom.

Approach

As an approach to increasing productivity, individual components of a part or system in which SLM can offer added value can be manufactured additively. By contrast, primary forming and machining processes are always used where they remain more economical or where the application field cannot yet be covered by the conditions of series production by SLM. A contribution to the increase of the process capability can be made by innovative measuring technology as well as by adapted quality assurance measures, as a high process integration allows dynamic process control loops. Previous process-integrated methods are merely limited to the two-dimensional monitoring of the uppermost process layer and do not offer any approaches for the reliable monitoring of internal structures of the manufactured components. In order to enable the available SLM characteristic design freedoms in a targeted manner, an optimum must be found from the available design freedom with simultaneous consideration of existing requirements

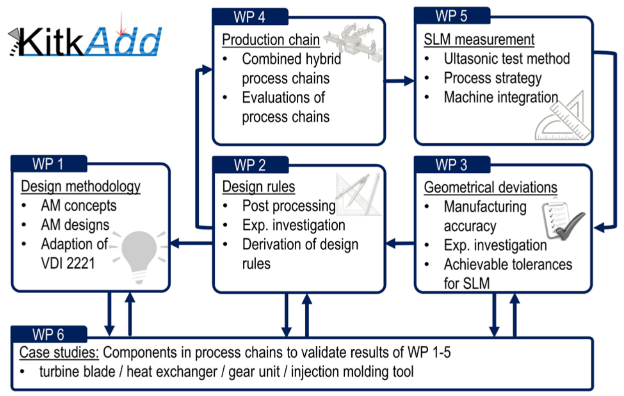

FIGURE 1 Work packages of KitkAdd project

FIGURE 2 Cross sectional area of additively manufactured aluminium heat exchanger (John Deere)

by the SLM process and new restrictions by combination with established manufacturing processes.

Objectives and results

The development of innovative methods and design guidelines is one way to make this challenge manageable in industrial applications. In view of these challenges, in particular individualized products and complex mass products, new development processes as well as intelligent processes, machines and plants are to be addressed as the main topics of the ProMat3D call for tenders of the Federal Ministry of Education and Research.

The overall objective of the planned project is to increase the productivity of SLM process chains significantly. This is achieved by:

Integrative consideration of the entire process chain of SLM with post-processing and further processing by established production methods, a design methodology adapted to the entire SLM process chain by complementing relevant design guidelines and achievable manufacturing accuracies, as well as a measurement technology developed for the quality-critical SLM process for component monitoring during the design process.

As a result, a design method for SLM components and their processing steps is available which, in addition to a design that is suitable for production and load, also intuitively conveys and takes into account the necessary post-processing and the innovative potential of the manufacturing processes. Furthermore, geometric deviations can already be limited by specifying realistic tolerances in the drawing entry. For the applications considered, statements are available regarding the effects and relationships between relevant influencing parameters and suitable evaluation parameters, above all the quality and costs of the SLM process in series production. In addition, a measurement system will be developed and integrated into the SLM process, which is suitable for innovative process control approaches as well as for verification of design methods, design guidelines and tolerances to be developed. The project pursues an interdisciplinary approach of product development, production planning and quality assurance.

UNIVERSITY OF PADERBORN RECEIVES FINANCIAL INCREASE IN THE RESEARCH PROJECT „KITKADD“ BY THE FEDERAL MINISTRY OF EDUCATION AND RESEARCH (BMBF)

The research project „Combination and integration of established technologies with additive manufacturing processes in a process chain - KitkAdd“ started in 2017 and focuses on the development of innovative, hybrid process chains and consists of eight research and industry partners under the leadership of Siemens AG. On behalf of the Paderborn University (KAt – Prof. Dr.-Ing. Detmar Zimmer), the Karlsruhe Institute of Technology (KIT/wbk, Prof. Dr.-Ing. Gisela Lanza) is a further research institution within the project. The research project with a total duration of three years runs until the end of 2019 and will result in hybrid process chains, an adapted design methodology, design guidelines and achievable manufacturing accuracies for Laser Beam Melting (LBM).

PROJECT OVERVIEW

DURATION

01/2017 – 12/2019

PARTNER

- Siemens AG,
- H&H mbH
- Eisenhuth GmbH & Co. KG
- GKN Powder Metallurgy
- John Deere GmbH & Co. KG
- Schübel primeparts GmbH
- Karlsruhe Institute of Technology (KIT/wbk)
- Paderborn University (KAt)

FUNDED BY

Federal Ministry of Education and Research (BMBF)

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WEBSITE

www.kitkadd.de

Finacial support

The BMBF increases the financial support for the research project „KitkAdd“ (total budget 5.3 million €) in 2018 and enables the Paderborn University to extent the laboratory in the field of metal additive manufacturing with the objective to develop concept for the appropriate positioning of semi-finished products in LBM machines, taking into account extended design guidelines and geometric deviations.

Objective

Due to the forward-looking results in the current project, the Project Management Agency Karlsruhe (PTKA) granted the Paderborn University the requested funds to be able to investigate the hybrid process chains for metallic 3D printing in more detail with additional machine capacity. The work contents relate specifically to a turbine blade provided by Siemens AG, which should be produced by combining additive and established production processes. Research generally promotes the hybrid production of components with a high functional density, which significantly increases the technical product benefit. By outsourcing less complex component areas to established manufacturing processes, manufacturing costs are reduced compared to pure additive manufacturing.

Extention of LBM labatory area

After the approval, comprehensive construction measures in the P-building of Paderborn University and the procurement of a LBM machine with peripheral systems was carried out. The cooperation of all involved departments of Paderborn University enabled the laboratory to be commissioned promptly with the following equipment (Fig. 2):

- Laser beam melting machine
- Sieving station for powder processing
- Vacuum cleaner with wet separator
- Annealing furnace for thermal post processing

FIGURE 1 Opening of the LBM Laboratory: Tobias Lieneke, Dr.-Ing. Christian Lindemann, Thomas Künneke, Klaus Watermeier, Marius Bröker, Diana Riedel, Martin Hohrath and Prof. Dr.-Ing. Detmar Zimmer

FIGURE 2 Representation of the purchased LBM machine and associated peripheral systems for the LBM process chain

DESIGN OF MICROSTRUCTURE AND DEGRADATION BEHAVIOR OF OXIDE-PARTICLE MODIFIED FE-BASED ALLOYS PROCESSED BY SELECTIVE ELECTRON BEAM MELTING

Bioresorbable iron alloys are of high in biomedical applications. However, in most cases the dissolution rate of iron-based alloys in physiological environments is to low. In this project EBM is used as for additive manufacturing of surface modified iron particles. The aim is to control mechanical properties and corrosion rates of iron allys based on the control of the dimensions and the presence or absence of oxides in the created part. The competences in the field of EBM (Thomas Niendorf, Universität Kassel), fatigue (Hans Jürgen Maier, Leibniz Universität Hannover) and interface chemistry and corrosion (Guido Grundmeier, Universität Paderborn) are joined in this project.

PROJECT OVERVIEW

DURATION

09/2018 – 08/2020

PARTNER

- Institute for material science (IfW) of Kassel University
- Institute for engineering (IW), Hannover Leibniz University
- Technical and Macromolecular Chemistry, Paderborn University

FUNDED BY

German Research Foundation (DFG)

RESEARCHER

Research leader
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Prof. Dr. Hans Jürgen Maier
Dr. Florian Nürnberger
Prof. Dr. Guido Grundmeier

Research assistant
Richard Grothe, M.Sc.
Dr. Christoph Ebbert

DFG Deutsche Forschungsgemeinschaft
German Research Foundation

Objectives

Implant materials have to meet various demands. A high structural strength of both solid and filigree structures as well as tailored degradation behavior are desired. In this regard, Mg-alloys employed suffer too rapid degradation, while Fe-based systems are characterized by sluggish dissolution. The aim of this project is to significantly increase dissolution rates of Fe-alloys by design of new oxide-modified Fe-based alloys. Additive manufacturing (AM) using metal powders, e.g. the selective electron beam melting (EBM) process, allows for realization of new alloys due to unique melting- and solidification conditions prevailing in the process.

Scientific Approach

In comparison to the laser-based SLM technique, EBM is characterized by processing in vacuum atmosphere at elevated temperatures. In light of the general aims of the project, only the conditions prevailing in EBM will allow for analysis of elementary degradation mechanisms as a function of the composition of the new alloys. As is well-known, SLM processing leads to a non-defined, slight enrichment of light elements such as oxygen in the material processed as well as to the evolution of relatively high residual stresses. These factors will strongly affect initial corrosion behaviour and, thus, will impede in-depth evaluation of corrosion induced by the alloy design being in focus of the project. The material in focus of evaluation will be iron modified by different kinds of oxide particles. Initial corrosion will be analyzed in load-free and mechanically loaded structures in selected electrolytes. Based on current literature, the role of the process induced microstructure, the surface condition as well as the alloy design on mechanical and corrosive performance cannot be evaluated. Pure iron as matrix and reference, respectively, and different modifications of iron- and oxide-particles will be processed by EBM. The EBM process technology is developed by the group of Prof. Niendorf in Kassel. Oxides will be introduced differently. Firstly, micron-scale oxide particles will be incorporated by mixing of relatively large fractions of these particles with pure Fe-powder. Secondly, nano-scale oxide phases will be grown on the Fe-particle surfaces by a wet-chemical approach. Consequently, the differently processed oxide-modified powders will be variable in terms of overall oxide fraction, surface morphology and oxide-iron particle bonding. The impact of these differences on processability, microstructure evolution as well as mechanical and corrosion performance will be evaluated thoroughly. The relationships revealed will serve as basis for development of new biodegradable implants in future studies.

Outlook

The project started end of 2018. In 2019 first alloys based on surface modified iron particles will be produced and characterised.

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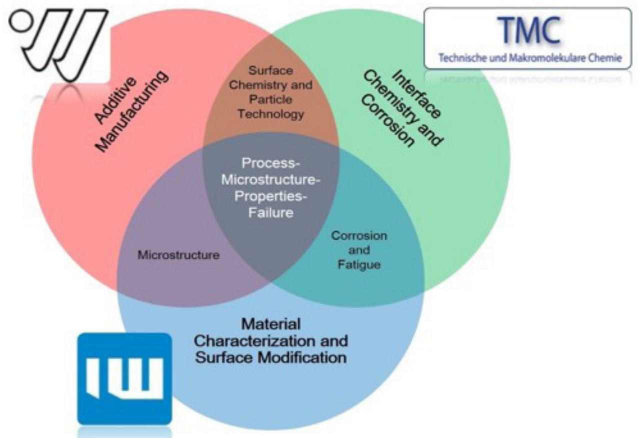

FIGURE 1 Cooperative approach

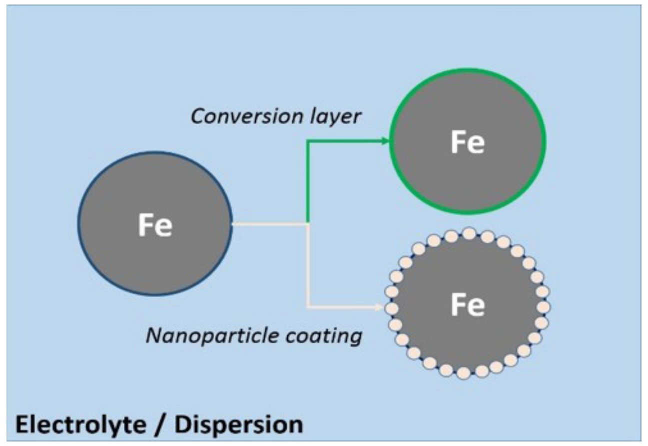

FIGURE 2 Particle surface modification stratgeies at the TMC

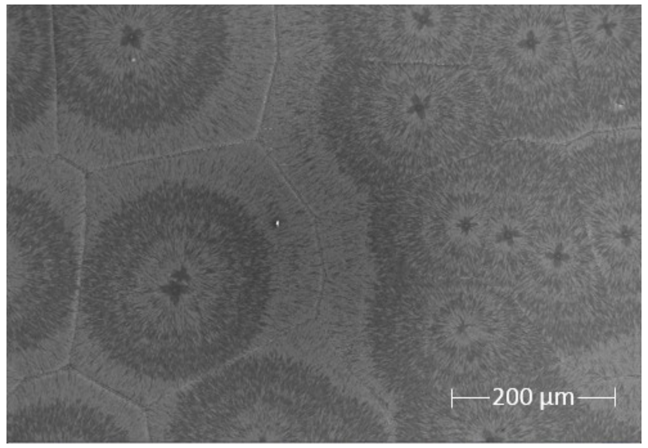

FIGURE 3 FE-SEM image of a PEG based film simulating the barrier properties of an extra cellular matrix

DEVELOPMENT AND OPTIMIZATION OF ADDITIVELY MANUFACTURED TOOL COMPONENTS FOR A HIGH-SPEED FORMING PROCESS

This project is about the ability how to use AM components for forming processes. Innovative rupture discs shall be produced with a high-speed forming process called HGU (German: "Hochgeschwindigkeitsumformung – HGU). The challenge is to ensure a stable application even with small nominal sizes of the rupture discs. A significant innovation is the insertion of predetermined breaking points by secondary features in the forming process. These shall be implemented in a thermoplastic FDM die. Therefore, the development of a tool system with additively manufactured components (die and plunger) is planned for the production of innovative rupture discs. This will combine the advantages of a quasi-static and high-speed forming process in an innovative, efficient and unique tool system.

PROJECT OVERVIEW

DURATION

08/2016 – 08/2018

PARTNER

- Poynting GmbH
- Rembe GmbH
- Kunststofftechnik Paderborn (KTP)

FUNDED BY

Federal Ministry of Economic Affairs and Energy (BMWI), Central Innovation Programme for SMEs (ZIM)

RESEARCHER

Research leader
Prof. Dr.-Ing. Volker Schöppner
Research assistant
Frederick Knoop, M.Sc.

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages
ZIM Zentrales Innovationsprogramm Mittelstand

Objectives

The field of application of rupture discs as pressure protections is limited due to the restricted geometry as well as the inflexible production (Figure 1). A challenge by the application of very small nominal diameters (of the rupture disc) combined with a low pressure range, is the reliable and stable operation in terms of the response behavior. Furthermore, many process steps are required for the manufacturing of these types of rupture discs. The aim of the project is to develop a new rupture disc (Rembe GmbH) with a small diameter, which shows a very good response behavior even at very low pressures. A significant innovation is the implementation of secondary design features as weakening geometries. These should be integrated as metallic inserts into a thermoplastic die manufactured with Fused Deposition Modeling (FDM). The aim is a defined weakening of the material during the forming process, so that a suitable forming process is necessary. Fine geometries of the required quality can be achieved by means of a high-speed forming processes (Poynting GmbH).

Procedure

Within the HGU a short-term but very strong electromagnetic field is generated that accelerates the plunger. The acceleration takes place in the direction of the workpiece and the plunger strikes on a forming medium which generates a pulsed pressure state. This pressure ensures that the sheet metal is formed in the die. The plunger must have a very high conductivity with high strength and low mass at the same time.

The research focus is on an additively manufactured die using the FDM process. The aim is to produce thermoplastic dies which satisfy the mechanical loads of the HGU process. The big advantage of complex component design through AM should be exploited in this project to produce innovative rupture discs in the considered forming process. For this purpose, the materials Polycarbonate (PC) and Ultem 9085 (blend of PEI and PC) were investigated, since both materials offer good mechanical properties with regard to the compressive strength. Another aim for the material selection is the achievable layer thickness in the FDM process. PC can be processed with a minimum layer thickness of 0.127 mm (Ultem 9085 only with 0.254 mm), which leads to a higher geometrical accuracy and better surface finish without post-processing. Another process characteristic is to be used for the forming process: the porosity of the FDM structure. The idea is to use the porosity for venting the forming process. The filament deposition and the layer-by-layer principle lead to process-related porosity in the structure (see Figure 2).

Latest Results

The process-related porosity is analyzed by using computed tomography (CT). For this purpose, specimens are manufactured with different materials, orientations and toolpath parameters. Investigations showed that the parameter "air gap" has the highest influence on the porosity and that it can be used to change the porosity in a defined manner. The lowest porosity results from a negative air gap of -5% and amounts 3.74% for the materialUltem 9085 (cf. Figure 3). To determine the correlation between porosity and venting, an air permeability test setup was developed. FDM samples are be tested with 10 bar air pressure and the pressure drop is measured over time. The results from this test can be used to develop a certain area in a FDM part which should have a defined air permeability. This function integration can have an additional value to FDM components. To ensure a good quality of the final FDM part, some design and manufacturing-related restrictions must be observed, so that 18 applicable design rules have emerged. Furthermore, this project develops surface treatment methods to improve the surface roughness of PC and Ultem 9085 parts. The forming process can lead to a mapping of the typical FDM structure into the sheet-metal workpiece. Therefore, chemical surface smoothing methods are developed and analyzed to reduce the roughness of the complex freeform surfaces of FDM dies.

FIGURE 1 Rupture Disc (Reverse Acting Rupture Disc KUB® by Rembe)

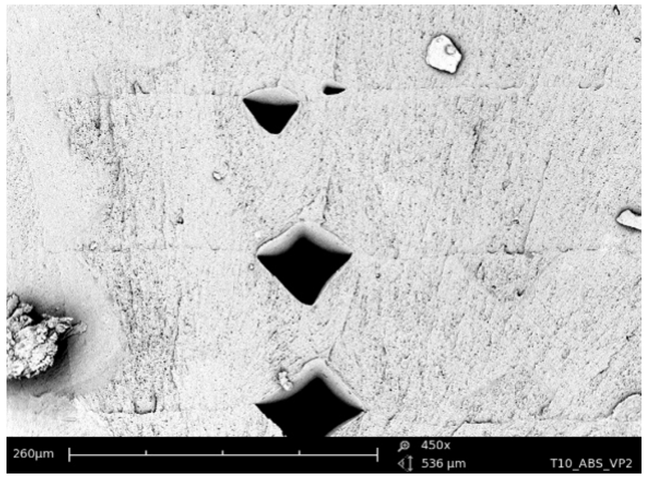

FIGURE 2 SEM-Image of a FDM Structure Shows Process-Related Porosity

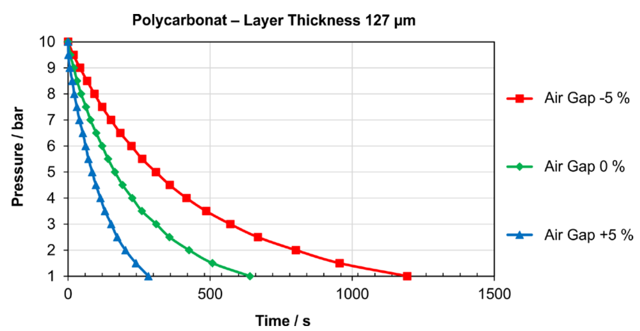

FIGURE 3 Influence of the Air Gap on the Pressure Time Behaviour

DEVELOPMENT OF DESIGN AND MANUFACTURING GUIDELINES FOR ARBURG PLASTIC FREEFORMING

The Plastic Freeforming (PF) is an additive manufacturing process with which three-dimensional, thermoplastic plastic components can be produced. The components are produced by depositing fine, molten plastic droplets. The advantage of the PF process lies in the open control of the associated machine system, whereby the process parameters can be adapted and optimised for the specific application. The aim of this research project is to determine the potential and process limits of the PF process. The focus is on the mechanical properties in correlation to porosity, optical properties and component dimensional stability. In addition, the wetting behavior of the plastic droplets and the influence of the material degradation due to a possible thermal degradation will be investigated.

PROJECT OVERVIEW

DURATION

07/2018 – 12/2020

PARTNER

Kunststofftechnik Paderborn (KTP)

FUNDED BY

German Research Foundation (DFG)

RESEARCHER

Research leader
Prof. Dr.-Ing. Elmar Moritzer

Research assistent
Andre Hirsch, M.Sc.

DFG Deutsche Forschungsgemeinschaft
German Research Foundation

Objectives

The aim of this research project is the development of design and manufacturing guidelines for the Plastic Freeforming (PF) process, which are adapted to the material and supply information about the main parameters (mechanical characteristics, warpage and optical properties). The guidelines should show the performance but also the process limits of the Plastic Freeforming process. In particular, the properties of PF components are to be compared with injection-molded and Fused Deposition Modeling (FDM) components. For this purpose, the mechanical characteristic values (tensile, bending and compression loads) are determined under consideration of the porosity. In addition to the variation of the manufacturing parameters, the influence of the material viscosity on the porosity is investigated. Computer tomography is used to detect the pores in the component and to investigate their size and number. A further target variable is the process-related material degradation due to the long residence time in the plasticizing unit. The influence on the mechanical properties is to be limited by the development of strategies for minimizing material degradation. As part of this research project, the investigations will be carried out with ABS. This is one of the most frequently used amorphous thermosplastics in the field of thermoplastic additive manufacturing.

Procedure

At the beginning of the investigations, an analysis of the manufacturing restrictions was carried out. The focus was on the influenceable and non-influenceable manufacturing constraints. The resulting understanding of the process forms the basis for all further investigations.
In the following progress of the research project the mechanical properties for the characterization of the additive produced test specimens will be determined. In addition to process-specific parameters such as form factor, layer thickness and process temperature, the viscosity of the materials used are also investigated as influencing factors.
The process understanding developed in the preliminary investigations provides the basis for the preparation of the statistical test plan. Response-surface test plans are used to design the test plan, because they allow the identification of square effects in addition to the determination of the main effects and interactions. Based on the statistical test plan, all specimens are produced and then tested.
The underlying functional principle of the PF process is the settling of individual liquid volume elements that are supposed to combine with an already solidified surface of the same material type. The ratio between the surface tension of the wetting liquid and the solid surface to be wetted is decisive for the success of good wetting. Since the surface tension depends strongly on the temperature, it cannot be assumed that the surface tension of the molten plastic is the same as that of the solid plastic. Another important influencing factor is the viscosity or melt flow rate of the materials which will be used. To determine these influences, the surface tension of the solid as well as the characteristic value of different ABS types with different viscosities in the molten state are therefore determined.
A challenge of this research project is the disruptive factor of the expected material degradation due to different building strategies. Therefore, it is an essential aim to gain a basic understanding of the expected material degradation in the PF process. The material degradation is investigated with regard to both the molecular mass distribution and its effects on the rheological behaviour.
In addition, it will be investigated how the building strategy influences the dimensional stability of the additive produced samples. In this context, component dimensional stability describes the resulting warpage of the components and the achievable visual quality of the PF process. The visual quality is the ability of the system to produce detailed surface contours. The type of surface structure and the roughness are used as quality parameters.
Finally, the findings and results from the experimental investigations will be summarized in the form of design and manufacturing guidelines. The aim is to support the user in early and detailed process design of the Plastic Freeforming.

FIGURE 1 Additive production of three-dimensional components from standard plastic granules

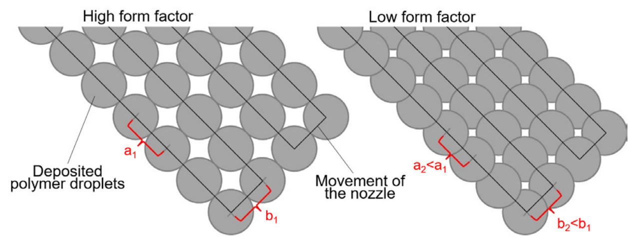

FIGURE 2 One of the most important process parameters: Schematic visualization of the form factor

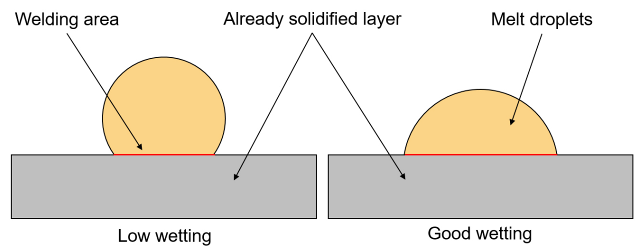

FIGURE 3 Wetting behavior with different surface tensions

DEVELOPMENT AND CHARACTERIZATION OF BIODEGRADABLE FEMNAG-MATERIALS USED FOR THE SLM-PROCESS

Since bioresorbable, metal alloys like magnesium and iron are highly interesting in biomedical applications; significant efforts are ongoing to decrease the degradation rate of magnesium alloys, as well as to increase the degradation rate of iron-based alloys. As silver acts as a cathodic element in combination with iron, in addition to its antibacterial behaviour, it is gaining interest as an alloying element to promote iron corrosion. Therefore, new silver alloys based on rare earth elements, as well as on typical elements for biomedical applications (Ca, Mg, Zn) with an adapted degradation profile, are a focal point of this work. Due to the immiscibility of iron and silver, it is not possible to cast iron-silver-X-alloys, but it is feasible to manufacture these alloys using powder-based additive technologies.

PROJECT OVERVIEW

DURATION

04/2019 – 03/2021

PARTNER

- Department of Technical and Macromolecular Chemistry (TMC) Paderborn, Germany
- University of Veterinary Medicine Hanover, Foundation (TiHo), Hanover, Germany

FUNDED BY

German Research Foundation (DFG)

RESEARCHER

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DFG Deutsche Forschungsgemeinschaft
German Research Foundation

Objective

The aim of the research project is to develop and characterize bioresorbable FeMnAg-alloys and their additive manufacturing qualification, specifically in Laser Beam Melting (LBM). The cooperative approach includes the development, production and characterization of additively manufactured structures made of conventionally immiscible alloys with strongly different melting points such as FeAg. Because of the potential application of resorbable implants in biomedical engineering, the biocompatibility and lower degradation rates of these structures compared to pure iron alloys are of particular interest aside from consistent production.

These new and innovative alloys present novel challenges to process management in LBM and in the post-processing of the manufactured to some extend complex components. In addition to the microstructural properties, the distribution, including size, structure and shape of the alloying partner, has to be adjusted to control the degradation rates. Since particles released into the tissue during the implant's degradation will be phagocytized, they must consist of a modified, biocompatible, non-corrosion-resistant noble metal alloy, which needs to be developed. The interaction of the alloying elements, specifically manganese, with more noble metals is addressed. Due to its antibacterial effect, the investigations will begin with silver as the main alloying element. Unfortunately, silver corrodes extremely slowly and in behaving this way, the remaining silver particles would lead to an intolerable enrichment in the biological environment. Therefore, further alloying elements are added to silver as well as a modification of the silver particles itself is focussed to force the silver to corrode due to the formation of intermetallic phases or eutectica as well as a result of the modified surface composition and morphology.

Approach

Primary to the fabrication of specimens via additive manufacturing, the base materials (FeMn, Ag) as well as the alloying materials (Ca, Ce, Nd, Zn,…) are characterized regarding their chemical composition (spark spectroscopy). Once the base materials are gas-atomized and sieved they are analyzed concerning their particle size distribution (mastersizer), particle morphology (light microscopy, scanning electron microspcopy), porosity (micro-computertomography, scanning electron microscopy) and chemical composition (spark spectrometry). Subsequently, the selected silver-X-alloys are melted in a vacuum induction furnace. Prior to any additive manufacturing, these new silver-based alloys are fundamentally investigated regarding their microstructure using among others light and scanning microscopy, micro-computertomography, x-ray diffraction and spark spectroscopy. Afterwards, the surface chemistry of the silver-based alloys is characterized at the Department of Technical and Macromolecular Chemistry (TMC) and the biocompatibility is investigated at the University of Veterinary Medicine Hanover, Foundation (TiHo). Conventionally casted bulk material is taken as reference throughout the investigations as well as for the fundamental research (formation of phases, degradation behavior, biocompatibility…) for it will not be expedient to gas-atomize every new silver-alloy. Corrosion tests are conducted in Ringer's lactate and modified simulated body fluid (m-SBF) solutions to identify promising alloy systems and to characterize the corrosion properties (TMC, TiHo). Parallel to the alloy-design, a modification of the iron powder particles is addressed within the synthesis of nano-particular silver on the surface of the iron powder particles at the TMC. All promising alloy systems are then investigated in terms of dergradation behavior (ex-vivo and in-vitro), immunotoxicity and microbiological behavior at the TiHo. At least, two or three of the new silver alloys are than casted in a higher amount and gas-atomized. The powder characteristics and quality will be investigated and the powder is mechanically mixed with the base alloy iron-manganese for Laser Beam Melting (LBM).

FIGURE 1 Addressed applications: nails, screws, osteosynthesis plates [1,2]

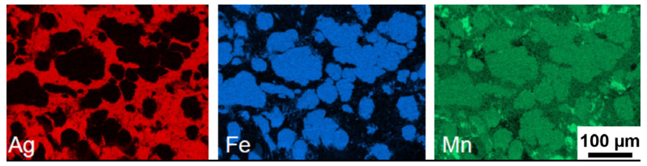

FIGURE 2 EDS mapping: iron-manganese-silver alloy processed via additive manufacturing (SLM)

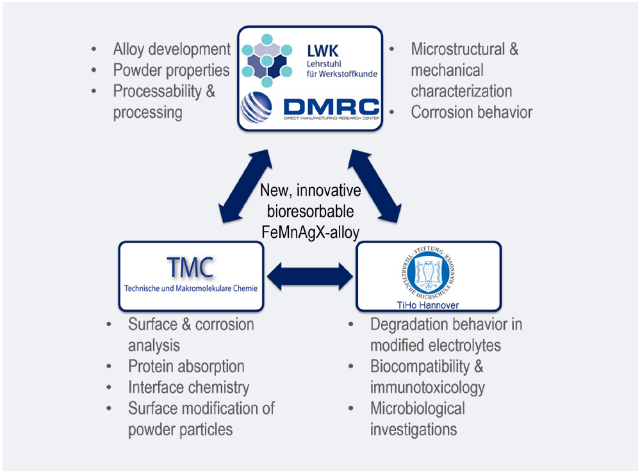

FIGURE 3 Organization and responsibilities within the DFG project

Outlook

Finally, the biocompatibility and degradation characteristics under conditions similar to those experienced in the human body will be examined for additively manufactured specimens.

[1, 2] www.micromed.com, www.syntellix.de

FDM-STRUCTURES FOR THE PARTIAL REINFORCEMENT OF HYBRID STRUCTURES

The mechanical properties of thin-walled plastic components are limited. One approach of improving the strength is to apply individual adapted Fused Deposition Modeling (FDM) structures onto the thin-walled components. To achieve an optimal reinforcing effect, the properties of the FDM-structure must be optimized first. This project will focus on the variation of the FDM process parameters, due to the fact that they have the most significant impact on the mechanical properties. The results of the parameter variation shall provide findings to develop design and process guidelines for FDM-structures that are used for the partial reinforcement of hybrid structures. Besides the mechanical properties, the lightweight potential of the FDM-structure must be also considered.

PROJECT OVERVIEW

DURATION

07/2015 – 12/2018

PARTNER

Kunststofftechnik Paderborn (KTP)

FUNDED BY

German Research Foundation (DFG)

RESEARCHER

Research leader
Prof. Dr.-Ing. Elmar Moritzer

Research assistant
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Deutsche Forschungsgemeinschaft
German Research Foundation

Objectives

The aim of the research project is the development and modeling of design and manufacturing guidelines for FDM reinforcement structures which are adapted to the load case and are to be used as partial reinforcement of hybrid structures. The research focus is on the strength optimization of the FDM reinforcement structure by means of a specific configuration of the manufacturing process in the FDM process. During the production of the FDM reinforcement structures, the process parameters are varied in addition to the building direction, as these have a major influence on the mechanical properties. Furthermore, depending on the shape of the FDM reinforcement structure, a targeted increase in strength or stiffness for the respective load case is to be achieved with the aid of topology optimization, whereby the generated structure is to have the lowest possible weight in order to save resources. In addition, the crack and fracture behavior is analyzed and the fatigue behavior of the FDM reinforcement structures is determined. Finally, the optimized FDM reinforcement structure in the composite system will increase the strength and stiffness of the base carrier. To achieve this, the manufacturing process of the hybrid structure must first be integrated into the existing GITBlow process.

Procedure

At the beginning of the research project, the analysis of the manufacturing restrictions for the FDM process was carried out. This includes the influenceable production parameters and the not influenceable production restrictions. The systematic determination and early analysis of these boundary conditions is necessary in order to clearly define the manufacturing limits for the subsequent investigations. In the next step, a statistical test plan with the Response Surface Method (RSM) was developed on the basis of the manufacturing boundary conditions. The analysis of the quasi-static strength values was initially carried out using various tests (tension, compression, bending, notched bar impact strength and torsion). This made it possible to determine the respective strength and stiffness values for the different load types, depending on the existing structure of the FDM component. Based on these results, mathematical models were determined for each of the five load types. The models were validated on the basis of the following target value optimizations. Furthermore, a topology optimization was carried out in order to optimize the FDM reinforcement structure according to the load case to achieve the highest possible specific stiffness.

As part of this research project, an extended strength verification and a service life estimation were also carried out with the aid of dynamic investigations. This allows statements to be made about the crack growth mechanisms and the influence of process-related defects or pores. Finally, a procedure for an automated insertion of the FDM reinforcement structures into the GITBlow process was developed. Subsequently, the hybrid components were manufactured using the standard parameters as well as the load case optimized process parameters. The investigations were completed by reviewing the manufacturing guidelines in the composite system and characterizing the bond strength between the FDM reinforcement structure and the GITBlow component.

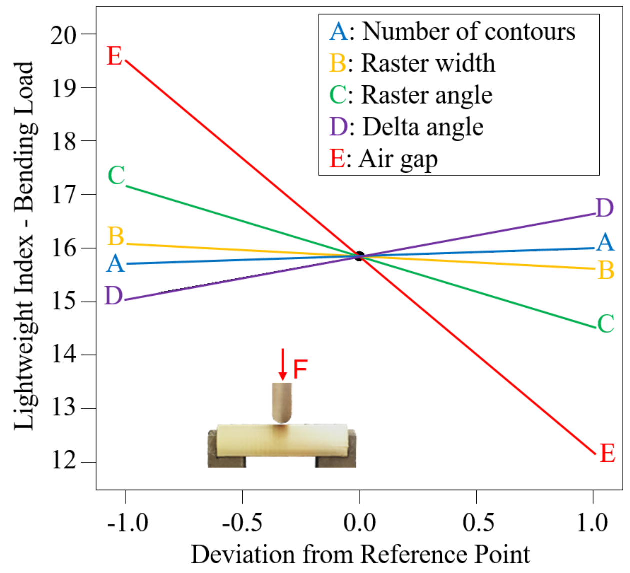

FIGURE 1 Model of the influencing variables on the lightweight index for bending load

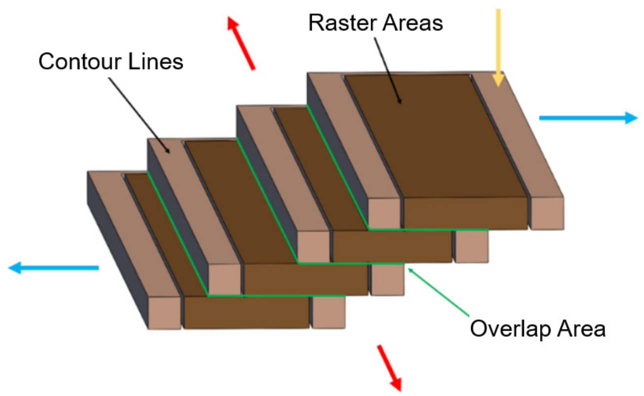

FIGURE 2 Schematic illustration of the layer overlap for peak overhang angles

Summary

Through the experimental investigations, a detailed understanding of the FDM process was developed. The combination of the summarizing manufacturing guidelines and the comprehensive process understanding enables the user to optimize the process design. In particular, FDM structures for the reinforcement of thin-walled plastic components are in the focus. However, the findings can also be used for the optimization of self-supporting, lightweight geometries and applications. In addition, the dynamic investigations revealed typical weak points and failure mechanisms of FDM structures, which should be taken into account during component design.

FIGURE 3 Finished hybrid component

iBUS - AN INTEGRATED BUSINESS MODEL FOR CUSTOMER DRIVEN CUSTOM PRODUCT SUPPLY CHAINS

The overall objective for iBUS is to develop and demonstrate by August 2019 an innovative internet based business model for the sustainable supply of traditional toy and furniture products that is demand driven, manufactured locally and sustainably, meeting all product safety guidelines, within the EU. The iBUS model focuses on the capture, creation and delivery of value for all stakeholders – consumers, suppliers, manufacturers, distributors and retailers.

PROJECT OVERVIEW

DURATION

09/ 2015 – 08/2019

PARTNER

- Paderborn University (C.I.K)
- University of Limerick
- Fabrica de Juguetes SL
- Juguettos central de compras scoop
- MCOR Technologies Limited
- ManOpt Systems Limited
- Daussalt Systems UK Ltd.
- AIJU: Technological Institute for Toys
- Cartamundi Digital
- WAZP
- SDRUŽENÍ PRO HRAČKU A HRU

FUNDED BY

EU Horizont 2020 (Grant Agreement No 646167)

RESEARCHER

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Dr.-Ing. Ulrich Jahnke

WEBSITE

www.h2020ibus.eu
facebook.com/h2020ibus/
twitter.com/designibus

Objectives

Traditionally, the process of making has been linearly with a number of distinguishable steps. Internal R&D personnel designed new products, purchasing personnel managed suppliers, products were made by manufacturing (often standard products in large volume), marketing and sold products.

iBUS model changes this paradigm. Its overall objective is to develop and demonstrate an innovative integrated business model for the sustainable supply and manufacture of safe traditional toys and nursery furniture. The model is demand driven, whereby products are customised and designed online by consumers or home-based designers, manufactured locally and sustainably to order, and meet product safety guidelines.

Procedure

For supporting the customers embedded services in iBUS will be developed in the main by SME Technology providers. These services include augmented reality design assistants, design verification tools for compliance with EU product safety guidelines, analysis of environmental footprint and prototyping with additive layer / 3D printing. Subsequently, parametric engineering design principles will take the design from concept to demand. This demand will then be synchronised and optimised across the supply chain, supported by the embedded supply chain optimisation tools, to produce sustainable demand driven production and supply plans.

Manufacturers will then produce the furniture and toys in small scale series production driven by the actual customer demand. Suppliers will have visibility of, and make decisions based on, end-customer demand. Likewise customers will have visibility of their orders through all stages of production and delivery. The infrastructure will be cloud based using internet and social media technologies, allowing interaction and collaboration, but also accessible to homebased or small business users, promoting social inclusion.

iBus has a budget of 7.440.362€ whereas 6.065.305€ are funded by the European H2020 programme.

Main participation of DMRC is in the WP3 "Customised Product Design Virtual Environment". Here a software system is in focus of development enabling the customer to design or adapt the product by himself. Self-designed products have to be manufacturable and to meet the European safety guidelines. Therefore an automated safety check has to be performed by the system to ensure these requirements leading to a safe production and use. The manufacturing is supposed to be done locally and demand driven at home or at small fab shops near to the customer, mainly by additive manufacturing.

Latest results

Key progress of the iBUS business project during the last year of the project can be summarized as getting closer to the overall objective step by step. A first demonstrator to transfer the main idea of self-customization has been developed and successfully validated. The platform demonstrator allows customization of use cases defined in the project embedding different software solutions. Enabling a parametrization of products following specific rules has been achieved so that customers come up with individualized toys in safe borders. Design Rules as well as safety rules for to meet all requirements regarding EU regulations for toys safety have been derived considering different manufacturing processes and materials.

As a cost calculation is also in focus of the WP3 objective existing approaches have been developed further. So a formalized concept to calculate nested build jobs has been created. In the context of iBUS this is very important to achieve an accurate on-the-fly calculation so that the acceptance of end-customers for additively manufactured product can be increased by showing effects of selecting different material and therefore manufacturing processes as well as batch sizes or combination with multiple products monetary.

Outlook

In the last period of the project, the web based software solution will be developed further to integrate more features bringing the envisaged stakeholders closer together. Furthermore the iBUS project is looking for further use cases to validate the functionalities of the already existing modules to check manufacturability and safety issues as well as cost calculations. To bring the whole platform in a working status the demand as well as the supply network needs become broader. Interested companies are very much invited to contribute and participate from the iBUS vision by joining the special interested group. There are a lot of interesting areas for different players: From Toy manufacturers to AM and logistics service providers but also for all creative minds out there!

FIGURE 1 Customized toy car bodies meeting european safety requirements

INNOVATIVE ALLOYING CONCEPTS FOR ADDITIVE MANUFACTURING

Selektive Laser Melting (SLM) allows not only cost-effective production of metal components with complex geometries, but also processing of materials, which are not processible using conventional methods such as casting. Therefore, the design of new application-adapted alloys allows on the one hand, the fabrication of intelligent products with superior properties and, on the other hand, to extend additive manufacturing into new application fields. The main idea of the project is establishing the process chain from alloy design and powder production up to material analysis and quality control.

PROJECT OVERVIEW

DURATION

09/2018-08/2021

FUNDED BY

- European Regional Development Fund
- Ministry of Economic Affairs Innovation
- Digitalisation and Energy of the State of North Rhine-Westphalia

RESEARCHER

Research leader
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Research assistent
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Dr.-Ing. Kay-Peter Hoyer

WEBSITE

https://dmrc.uni-paderborn.de/content/research/

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Ministerium für Wirtschaft, Innovation, Digitalisierung und Energie des Landes Nordrhein-Westfalen

Problem statement

One of the biggest challenges in SLM is the quality of powder, which is commonly produced by one of the few external companies. Although the material and the desired powder fraction are specified, the amount of the ordered powder is not always sufficient due to high production costs. Furthermore, the process of the powder production itself is not always prescribed and can take long time restricting research activities within ongoing projects. Finally, powder producents do not guarantee the desired particle morphology, particle size distribution, as well as precise chemical compositions – first of all, in therms of light elements, like nitrogen. Since, a precise chemical composition as well as the powder quality, i.e. particle size and morphology, have a crucial influence on the microstructural and mechanical characteristics of the additively manufactured components, the research should be focused not only on the SLM itself, but also consider the powder production and characterization.

Approach

The project aim is implemented through the individualized „in-house" production and control of high-quality powder with subsequent processing via SLM in order to generate intelligent components cost-efficiently and quickly in small series, which exhibit outstanding properties in comparison with conventionally produced components.

The design of new alloy concepts is performed using available simulation softwares, for example, JMatPro. Thereafter, the designed alloy is melted in a vacuum induction furnace. The powder will be gas-atomized in argon or nitrogen atmosphere with the desired morphology in the atomizer AU3000 from BluePower Casting Systems. Then, the powder is processed via the air classifier AC1000 from BluePower Casting Systems in order to separate the powder with extremely small particle sizes, for these small

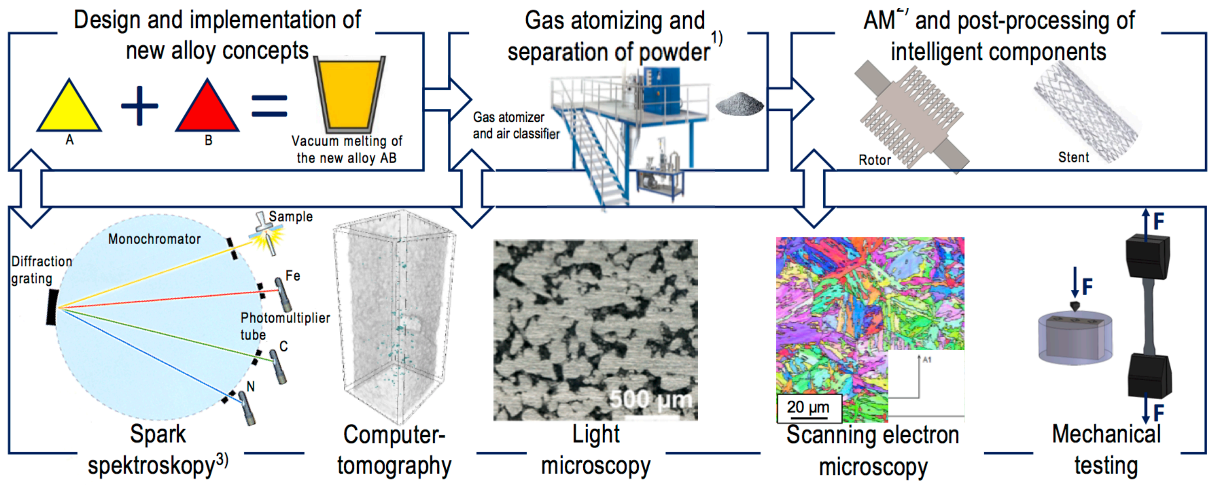

FIGURE 1 Overview on project flow. 1) https://www.materials.sandvik/en/; 2) https://www.shimadzucom

particles are unfavorable in terms of SLM. Subsequently, the additively manufactured parts undergo corresponding post-treatment, such as heat- and/or surface treatment (Figure 1).

The control of the chemical composition is performed after each processing step, i.e. alloy melting, powder atomization and SLM, with the help of the spark spectrometer Q4 Tasman from Bruker. The spectrometer allows the quantitative measurement of light elements, like carbon and nitrogen, in the ppm range, which strongly influence both the quality and resulting properties of produced parts, and is mandatory to specifiy the chemical composition in terms of alloy-development, especially for iron-based alloys. Detailed characterization regading the designed alloys, powders and additively manufactured products are conducted by micro-computed tomography (µCT) with the SkyScan 1275 from Bruker. This technique allows both the analysis of the microporosity of the material after each processing step as well as a 3D-characterization of the powder morphology and the manufactured components. Additionally, the powder morphology as well as microstructure and phase distribution in the additively manufactured and post-processed parts are characterized using the Digital Microscope VHX 500 from Keyence as well as the Scanning Electron Microscope Ultra Plus from Zeiss. Finally, the characterization of the relevant material characteristics, such as mechanical and magnetic properties, is performed.

Thus, the multilateral and deep characterization of the material allows for an adequate adjustment of the process parameters at each stage in the production chain "Alloy-Design – Vacuum Induction Melting – Atomizing – Separation – Laser Beam Melting – Post-Treatment" in order to manufacture intelligent and application-adapted parts with guaranteed and reproducable properties.

In this project, the design of new alloy concepts addresses three main scientific issues:

- Soft magnetic Fe-based alloys, which should combine the necessary strength, high electrical resistance and permeability, high saturation flux density, negligible magnetostriction as well as low hysteresis and eddy current losses for the application as soft magnetic materials for additive manufacturing of electric motors.
- Functional graded materials with defined local differences in microstructure and/or chemical composition allowing for individual adaptation of separate parts on application conditions as well as additive manufacturing of complete assembly part, such as rotors, within one processing step.
- Completely new Ag-containing Fe-based alloys for bio-medical applications, which dissolve within the human body at a pre-defined rate. Furthermore, the new and innovative Ag-based alloys, that should degradate parallel to the dissolution of the Fe-matrix, are to be developed.

INVESTIGATION OF THE EFFECT OF RESIDUAL STRESSES AND ROUGHNESS OF ADDITIVE MANUFACTURED COMPONENTS ON THE COATABILITY AND FATIGUE STRENGTH OF THE COMPOSITE SYSTEM

In order to achieve the performance of conventionally fabricated components, additively manufactured components must be able to fulfill at least the same requirements. Among other things, this includes the possibility of functionalizing surfaces by means of coatings and of being able to realize a sufficient fatigue strength of the overall system (component coating). In the present project, therefore, the effects of residual stress and surface roughness, known as the restriction of the SLM process, on the coatability are fundamentally examined and the dynamic strength of the overall system is considered.

PROJECT OVERVIEW

DURATION

04/2017 - 03/2020

PARTNER

Institute of Materials Engineering, TU Dortmund University, Germany

FUNDED BY

German Research Foundation (DFG)

RESEARCHER

Research leader
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Prof. Wolfgang Tillmann

Research assistant
Kai-Uwe Garthe, M.Sc.
Dipl.-Wirt.Ing. Leif Hagen

Deutsche Forschungsgemeinschaft
German Research Foundation

Objectiv:

This project investigates the effects of residual stresses and surface roughness of additively manufactured components on the coatability and fatigue properties of the composite system (coated component). The materials 316L and IN718 are analysed. The aim of these investigations is to achieve a qualitative statement regarding the effects of residual stresses and roughness on the coatability. This includes the determination of the adhesion strength of the coating as well as the generation of coating optimized SLM- and post-processing parameters which guarantee a gap- and pore-free bond with high cohesion and adhesion. Further goals are the determination of the fatigue strength, the identification of failure mechanisms as well as the crack origin. Furthermore, a better understanding of the process and the combination of the advantages of both process steps should substitute further process steps, such as metal-cutting surface treatments. Based on a better understanding of the process, the quality of the additive components should also be optimized to such an extent that at least the level of conventional cast or forged components is reached.

Approach:

The initial step of the investigations is the characterization of the powder (see Figure 1) with regard to the chemical composition, the particle distribution and any defects that may occur, such as pores, etc. During the production of the samples, an investigation of the production parameters and strategies is carried out. In doing so, successfully used sample geometries for tensile and fatigue tests (dog bone samples at room temperature and cylinder samples at 650 °C) are applied. The examination of the production parameters guarantee repeatable and defined sample properties, whereby the occurring porosity should be kept as low as possible in order to minimize their influence on the results of the later tests. After manufacture, the specimens are examined regarding roughness, residual stresses (in the surface layer area) and porosity. This is followed by pretreatments such as grinding, pressure blasting or similar methods, including the characterization of the resulting roughness and residual stresses. The effects of the respective pretreatment methods on the surface are measured and correlated. Untreated samples are also further processed as reference. The samples are then completely coated by thermal spraying (HVOF and APS) or Arc-PVD (see Figure 2) using various coating materials (NiCrAlY, WC-CoCr, YSZ, Al_2O_3). With both types of process, extensive experience can be drawn upon, so that a new layer development is not necessary. Morphology and adhesion are characterized by metallographic cross sections which are examined by light and scanning electron microscopy. Furthermore, the porosity is measured quantitatively by image analysis and computer tomography for selected specimens. For the PVD process, the layer adhesion is also determined by means of scratch tests and the layer hardness by means of Brinell testers. The adhesion of thermal spray coatings, on the other hand, is determined in a 3-point bending test as well as in conventional tensile adhesion tests. The final step of the investigations is the performance of fatigue tests and the characterization of the fracture pattern and crack propagation. These tests are performed both for 316L and for IN718 at room temperature and for IN718 additionally at 650°C. The fatigue tests are carried out at room temperature. Knowledge concerning the hardening and softening behaviour shall be gained by recording stress-strain curves (hysteresis curve).

Outlook:

The restrictions currently present in the SLM process, such as porosity, residual stresses and surface roughness, are to be minimized by the parameter studies carried out in this project, which should lead to a general quality improvement of 316L and Inconel 718 SLM components. Furthermore, statements on the adhesion of different coating materials to different coating processes and their influence on the short-term fatigue of SLM components are addressed. The results are correlated with post-treatment methods, for the post-treatment processes, like coating processes and the material pairing, are assumed to be a critical criterion for adhesion. Improving coatability in general allows non-corrosion resistant materials to be coated with a corrosion resistant coating and the surfaces of SLM components to be annealed.

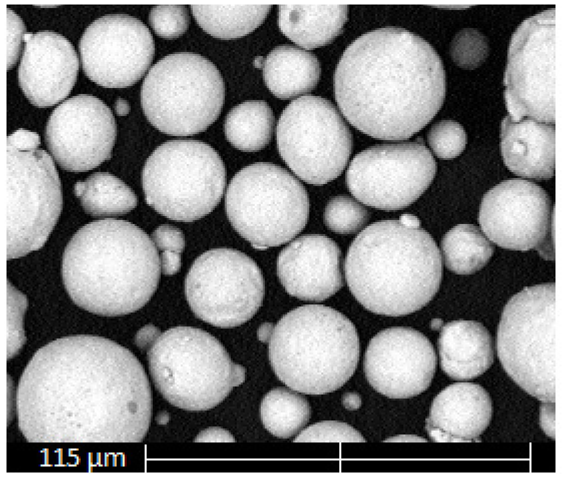

FIGURE 1 Characterization of 316L powder by means of a scanning electron microscope

FIGURE 2 Arc-PVD method

MANUFACTURING TECHNOLOGY – ADDITIVE MANUFACTURING FOR THE PRODUCTION OF POLYMERIC COMPONENTS

For the successful application of additive manufacturing processes in technically demanding plastic applications in drive technology, the optimal selection of processes and material as well as practical and accurate design and construction guidelines is necessary. The specific and closely linked dependencies of production processes, materials and component design represent a challenge. This basic-oriented preliminary project compiled a targeted literature research with regard to relevant application potentials. The work is carried out jointly by the Direct Manufacturing Research Center (DMRC) and the Institute for Composite Materials (IVW).

PROJECT OVERVIEW

DURATION

02/2018 - 04/2018

PARTNER

Institut für Verbundwerkstoffe GmbH
Kaiserslautern (IVW)

FUNDED BY

FVA e.V. (Forschungsvereinigung Antriebstechnik – Research Association for Drive Technology)

RESEARCHER

Research leader
Prof. Dr.-Ing. Hans Joachim Schmid (DMRC)
Prof. Dr.-Ing. Ulf Breuer (IVW)

Research assistent
Dennis Menge, M.Sc.

FVA Forschungsvereinigung Antriebstechnik e.V.

Motivation and aim

The aim of this project is to introduce the FVA members to the use of additive manufacturing methods for plastic components in drive technology and thus to open up the potential of additive manufacturing for innovative components with lower costs, higher power densities and shorter development times (time to market). Furthermore additive manufacturing can help to make their production environmentally sustainable and with a high degree of digitalisation.

Proceeding

The project is divided into two main work packages – a literature research and an experimental investigation.

1. Literature research

The systematic literature research is adapted to the substantial aspects of the application of additive manufactured polymer parts in drive technology and focuses on

- an overview of the available AM technologies and processes,
- an explanation of the new design possibilities (bionic design, time to market,…),
- the potential for innovation for components or assemblies,
- material properties,
- process, design and material-limited performance limits of AM processes,
- cost-effectiveness analysis and
- determination of available, relevant design guidelines and tolerances as well as standards.

2. Experimental investigation

Within the framework of the experimental investigation, the specific application potential of additive manufacturing processes and materials available on the market for drive components is determined. For this purpose, tribological and mechanical experiments with various materials are performed and thereby the following properties are examined.

- Specific wear rate
- Coefficient of friction
- Tensile strength
- Young´s Modulus
- Elongation at break

Block on ring tests (ASTM G 137) (Figure 1) were carried out to determine the wear rate and the coefficient of friction as well as tensile tests to determine the mechanical parameters. Figure 2 shows a worn surface of PA12 specimen. The test specimens are produced by different technologies with various materials and a subsequent comparison with characteristic values of conventionally injection-molded samples was performed after the experiments (Figure 3). Literature data of the corresponding materials complete the estimation of the potential.

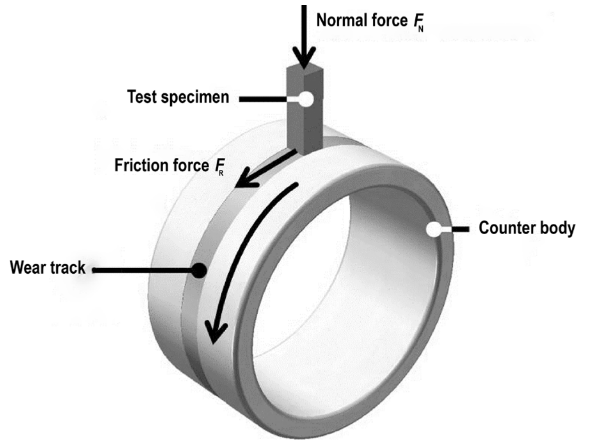

FIGURE 1 Block on Ring test according to ASTM G 137 [ASTM G 137]

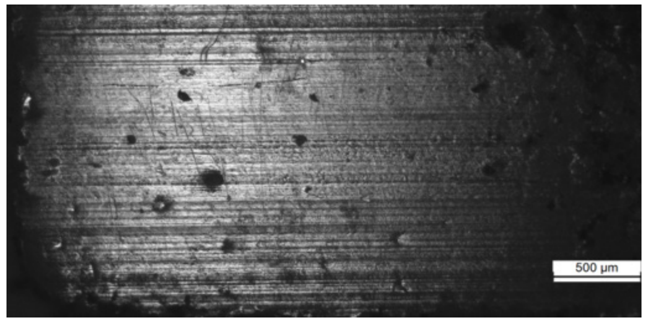

FIGURE 2 Worn surface of a laser sintered PA12 specimen

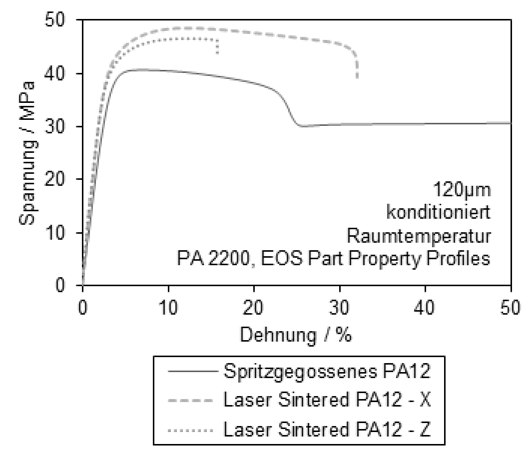

FIGURE 3 Comparison of laser sintered and injection molded PA12 mechanics

MATERIAL DEVELOPMENT OF NON-REINFORCED AND FIBER-REINFORCED POLYMERS FOR FUSED DEPOSITION MODELING

The aim of this project is to investigate the requirements for materials and semi-finished products that are processed in the Fused Deposition Modeling (FDM) process. By gainig a better understanding of the FDM process, a knowledge base should be created to increase the variety of materials that are available. This project is conducted in cooperation with Albis Plastic and in the NRW Fortschrittskolleg "Lightweight – Efficient – Mobile" (FK LEM). As one of the six Fortschrittkollegs established in 2014, the FK LEM is sponsored by the Ministry of Culture and Science of the German State of North Rhine-Westphalia.

PROJECT OVERVIEW

DURATION

06/2015 - 03/2019

PARTNER

ALBIS Plastics GmbH

FUNDED BY

- ALBIS Plastics GmbH
- Ministry of Culture and Science of the German State of North Rhine-Westphalia

RESEARCHER

Research leader
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Research assistent.
Christian Schumacher, M. Sc.

ALBIS

Ministerium für
Kultur und Wissenschaft
des Landes Nordrhein-Westfalen

Objectives

The Fused Deposition Modeling process is one of the most commonly used additive manufacturing processes. It is also known by the terms Fused Layer Modeling (FLM) or Fused Filament Fabrication (FFF). In the FDM process, the semi-finished product, commonly a wire of a thermoplastic polymer (the filament) is molten and forced through a nozzle. The continuous positioning of this nozzle allows the polymer to weld together strand by strand and layer by layer to produce a component. The energy for the welding of the individual strands largely results from the thermal energy of the deposited polymer melt.
It is desirable to be able to use a similarly wide variety of materials in the FDM process as, for example, in the profile extrusion or injection molding technology. Therefore, the processing suitability of any thermoplastic polymer should be predictable based on the material properties or process charactersistics in advance of the processing. This is currently not possible because, in contrast to conventional methods, little is known about the required and desirable material properties for the processing in FDM.

Procedure

To compare and rate different materials for a manufacturing process the processing suitability of a material has to be defnied. Therefor, significant characteristics like the process specific tensile strength of the welding seams or the warpage of manufactured parts are identified. Other factors like machine quality or data processing should have no or minimal influence on the investigated characteristics. For that reason machine and processing specific influences are considered prior to the investigations and custom-built specimens are created during this project to evaluate the identified characteristics.
After the specimens have been verified on well-known materials, for which a good processing suitability has been prooven, series of tests are run for each characteristics with diffent polymers. Especially different Polyamide 6 (PA 6) and blend systems on the basis of PA 6 are created, processed and investigated during this project.
By varying important material properties, such as the viscosity or the cristallinity, suitable material properties are identified and connected to processing properties. To keep track of this the material properties are supervised during the whole project by methods like differential scanning calorimetry or high pressure capillary rheometry.

Findings

The properties of parts that are manufactured in the FDM process are mainly influenced by the machine quality and the data processing. For this reason, a machine- and process-independent rating of the processing suitability was developed during this project. Different process characteristics like the tensile strength of the welding seams and the process specific warpage were investigated for different materials. These criteria were quantified to rate the material specific processing suitability.
By considering the experimentally investigations, the material specific processing suitability was connected to some important material properties. For that purpose e. g. the weld seam strength was compared to the tensile strength of injection molded parts and the warpage was compared to the shrinkage investigated in pvT measurements.
Additionally the influences of fibre reinforcment was investigated for the identified characteristics regarding processing suitability and part properties. For the production of the short fiber reinforced parts and specimens, short fiber-reinforced filaments were processed. The process properties and the resulting part properties were investigated with regard to fiber-specific influences. Additionally, the effects of different process parameters on the fiber orientation and mechanical part properties were investigated.

FIGURE 1 Granules and filaments for FDM processing

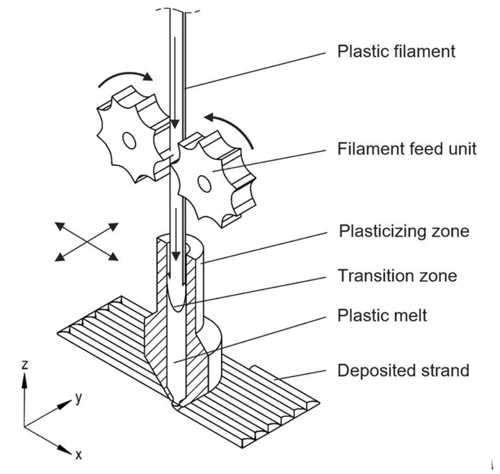

FIGURE 2 Process principle of the FDM process

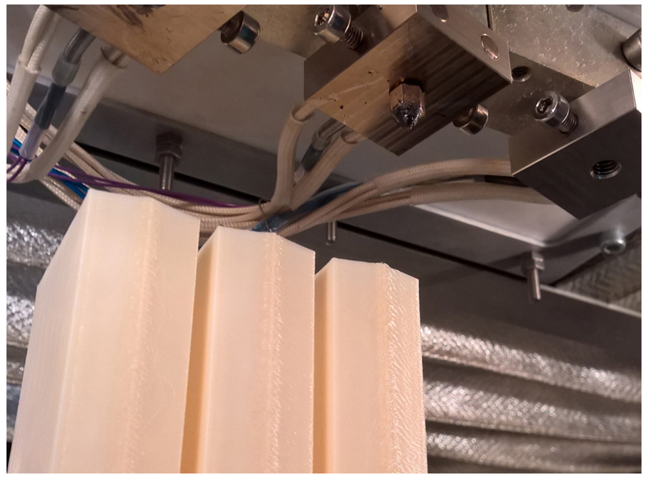

FIGURE 3 Custom built specimen in a build chamber of an FDM machine

OptiAMix – MULTI-TARGET-OPTIMIZED PRODUCT DESIGN FOR ADDITIVE MANUFACTURING

The overall objective for OptiAMix is to develop various methods and tools for the introduction and use of additive manufacturing in the industrial environment. These include the development of a software for automated and multi-target-optimized component design, methods for the strategic-technical component selection, the derivation of design rules and component identification as well as a general integration methodology for additive manufacturing into companies.

PROJECT OVERVIEW

DURATION

01/2017 – 12/2019

PARTNER

- UPB (C.I.K.; KAt; LiA; HNI-PE)
- Krause DiMaTec GmbH
- EDAG Engineering GmbH
- INTES GmbH
- Hirschvogel Umformtechnik GmbH
- WP Kemper GmbH

FUNDED BY

Federal Ministry of Education and Research (BMBF)

RESEARCHER

Research leader
Prof. Rainer Koch

Coordination
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Research assistent
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Dr.-Ing. Ulrich Jahnke
Anne Kruse, M.Sc.
Dr.-Ing. Thomas Reiher
Stefan Lammers, M.Sc.
Johannes Tominski, M.Sc.
Jan Gierse, M.Sc.
Philipp Scholle, M.Sc.
Christian Oleff, M.Sc.

WEBSITE

www.optiamix.de

General Situation

Due to high constructive freedoms, additive manufacturing processes are gaining increasing interest in industry and research. For example, the VDI confirms that the technology is of outstanding importance for Germany as a business location: additive manufacturing processes promote the implementation of the Industry 4.0 strategy, secure jobs, shorten transport routes and offer opportunities for new business models. At the same time, the industrial applicability of additive manufacturing processes has so far been rather low due to various limiting factors. For the industrial application of AM knowledge within the strategic product planning, software for AM-compliant design as well as methods for interdisciplinary cooperation in product development, which take a holistic view from the idea to the products as well as the entire process, are missing.

Solutions within OptiAMix

Addressing these problems, the aim of the project „OptiAMix" is the multi-target-optimized and fully automated component development for additive manufacturing processes throughout the product development process. In order to be able to carry out a multi-target optimization with regard to diverging factors, such as low costs or a load-oriented design, a new software tool is developed for AM-compliant design in terms of technology, post processing, load and cost and combined with known software tools. Thus, the increasing product complexity can be mastered and a high level of data security can be guaranteed. At the same time, methods will be developed and consolidated to generate and use the relevant information; these include, for example, the potential estimation of additive manufacturing processes, design guidelines as well as process and material parameters, which are needed for the requirement-oriented, automated design and thus considerably shorten the design time. The process chain itself is also considered within OptiAMix, a standardized and optimized solution is developed together with the project partners, and a methodology for the integration of additive manufacturing into the existing processes of the companies is developed.

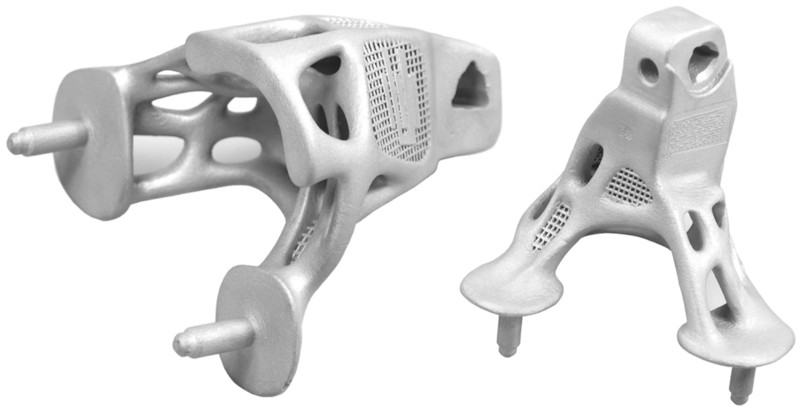

FIGURE 1 Car Door Hinge by EDAG Engineering

Latest Results

In the second year, further promising progress has been achieved in all sub-objectives of the project. In the subgoal „Method for strategic-technical part selection", the researchers of the C.I.K. continued the development of the methodology for cross-industrial AM-part selection, for the branches automotive, food technology and plant and mechanical engineering. A software demonstrator has been designed.
Regarding the requirement-based part selection and development, a new method for semi-automized risk assessment of requirement changes was developed and implemented into a software prototype by the research group for product creation.
The developed design guidelines for the focused topic "production" were included by INTES in the current version of the further developed „Tool for automated and multi-target optimized component design".
As base for the development of the methodology "Integration of additive manufacturing in companies" the processes of all project partners were analyzed within the targeted limits. From this, the derived "ideal AM process" was refined. Part of the optimization of the "ideal AM process" was the integration of the results from the development of the "Method for strategic-technical part selection" as well as the "Method for Part Marking".

Outlook

The last year of the project will be used to further develop the tool for automated and multi-target optimized component design and to finalize the method for the integration of additive manufacturing in companies. In addition to the various sub-goals, different support tools will be created for manufacturing documentation as well as for accompanying the product development.

Project Information

Within OptiAMix five companies are working together with the Paderborn University on various methods and tools for the industrial application of additive manufacturing since the beginning of 2017. The project is funded with € 2.4 million by the BMBF and is managed by the DMRC industrial partner Krause DiMaTec and coordinated by the C.I.K. Other participating chairs are KAt, LiA and HNI-PE.

Federal Ministry of Education and Research

proDruck
3D PRINTING – TECHNOLOGY OF INDUSTRY 4.0 – AS A MEDIUM FOR INCLUSION OF PEOPLE WITH DISABILITIES IN THE WORK WORLD

In the project proDruck a holistic employment model for people with disabilities will be developed. Focus should be the development and 3D printing of individual technical assistance systems for people with disabilities, which enables help for self-help. With the development of new business models and web-based training concepts, the participation in sustainable technologies and their active co-creation will be possible. A 3D printing workshop will be setup, which is geared to the specific needs of people with disabilities.

PROJECT OVERVIEW

DURATION

10/2018 – 09/2021

PARTNER

- Paderborn University (C.I.K.; FAM)
- von Bodelschwinghsche Stiftung Bethel
- LEONEX Internet GmbH
- trinckle 3D GmbH

FUNDED BY

Federal Ministry of Education and Research (BMBF)

RESEARCHER

Research leader
Prof. Rainer Koch

Coordination
Anne Kruse, M.Sc.

Research assistent
Manuel Ott, M.Sc.

WEBSITE

www.prodruck-projekt.de

Federal Ministry of Education and Research

Project aim

The project has two main aims, the building of a 3D printing workshop and the development of a 3D printing online platform (see figure1). The workshop will be supplemented trough the development of training concepts, which impart knowledge about the arranged workplaces and 3D printer, adjusted to the different learning levels. Parallel a 3D printing online platform will be implemented with a communication forum for users. Online trainings will be implemented which impart knowledge about construction, parametrization and manufacturability of 3D printed parts. Furthermore the possibility of the upload of self-designed parts will be given. This gives other users the opportunity to buy the part with individual changes. A special quality program checked the manufacturability of the part and ordered it in the 3D printing workshop. With the successful implementation, the online platform enable the transfer of the idea of a unique one across Germany. Beyond the developed installation aids can be conduce as a role model for the industry to enable people with disabilities to have access to many sectors of the economy, which has been lacking so far. This can promote inclusion and create more jobs for people with disabilities.

First results

First product ideas, espacially in the assambly aids area were realized and tested at the Bethel workshops. The example schown in figure 2 is for the assamble of small srews and nuts. This enables the affected persons to assemble even small screws and nuts without any problems. This increases the proportion of people who are capable of this work and thus the scope of duties of the affected persons.
First ideas for everyday aids were development and the manufacturability and usability will be tested at the university. First ideas are attachments for cutlery for better manageability with certain physical limitations.
For the workshop, the location was already selected under consideration of diffenret requirments, which are important for a location that works for and with people with disabilities.
For the online platform a first mock up were developed. This first development includes the selection page of the offered products and the way of the e-commerce system from the selection of the products to the shopping cart. Affected persons, relatives and guardians did a first evaluation.

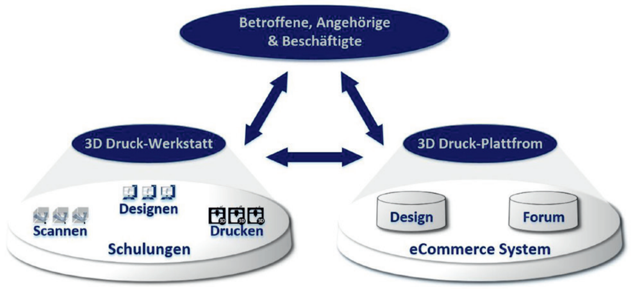

FIGURE 1 Aim of the Project

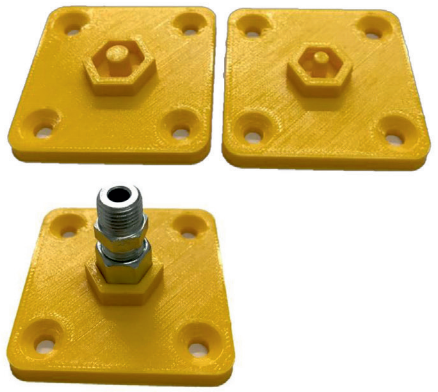

FIGURE 2 Screws and nuts assembly aid (left: 6mm, right: 4mm)

Outlook

The next steps in the project are the development of the workshop concept for the selected location. This includes choosing the right 3D printer for the needs of people with disabilities and the number of printers and computers to be purchased.
The first evaluation results of the online platform will be used for the further development of the platform, especially in the area of the disease-related functions for the people with disabilities.
Further more the development of the trainigs for the online platform and the 3D printing workshop will start.
The overall project aim of finding needed products for people with disabilities will be increased. Bethel has over 70 workshops, who all have diffenret assembly aids, which will checked if there are any possibities to improve this aids through the manufacturing with 3D printing. As the project progresses, the acceptance of 3D-printed components will increase among the people working in the Bethel workshops. The knowledge about the possibilities of 3D printing will also grow, so that in the course of the project the ideas for everyday aids will also come directly from those affected persons.

Project information

In addition to the above named project partners an associated network is intended, with organizations like the BeB (Bundesverband evangelische Behindertenhilfe) and the BAG (Bundesarbeitsgemeinschaft Werkstätten für behinderte Menschen e.V.), medical houses with interest in 3D printing and companies with interest in inclusion especially in the production area.
The research project prevailed within the framework of the research program „Innovation for tomorrow's production, services and work" of the Federal Ministry of Education and Research (BMBF) in the competition for „Personal Services". It is funded with 1.4 Mio. € by the BMBF and supported by the PTKA (Projektträger Karlsruhe).

RESEARCH OF INNOVATIVE AND BREAKTHROUGH ADDITIVE MANUFACTURED LEADING-EDGE CONCEPT (RIB-AM)

This project is part of the Clean Sky 2 funding program and is carried out in cooperation with other research institutes. Clean Sky 2 is a joint undertaking through a public-private partnership between the European Commission and the European aeronautics industry to achieve defined environmental objectives. Environmental goals are, for example, the reduction of CO2, gas emissions and noise level by aircraft. This project aims to develop a novel leading edge concept based on advanced manufacturing and integration techniques.

PROJECT OVERVIEW

DURATION

11/2018 - 09/2021

PARTNER

- AIRBUS
- AMRC
- TWI
- FADA-CATEC

FUNDED BY

Clean Sky 2

RESEARCHER

Research leader
Prof. Dr. Elmar Moritzer

Research assistent
Julian Wächter, M. Sc.

Clean Sky 2

Project goal

The aim of the project is to develop novel manufacturing technologies applied to large size components belonging to the primary structure of aircrafts. To achieve this goal, the focus will be on the following three areas: The automated placement of fibres with thermoplastic resins, the use of the FDM process with short fibre reinforced thermoplastics and the development of a new method for joining components on the basis of rivet-free applications.

Structure of the project

The work program proposed in the RIB-AM project has been designed to accomplish the final goal in an efficient way and facilitating the project development and advances. The strategy proposed is based on seven Work Packages (WPs). The first WP adresses the whole project and is focused in the management and administrative activities. The next three work packages are organized by technological challenges: The development of automated fibre placement (AFP) technology for long fibre reinforced thermoplastic materials, the design and manufacture of light and optimized ribs by means of the additive manufacturing technology with short fibre reinforced thermoplastics and the investigation and development of new ways of integration and joints. The improvements and progresses reaching in each technology will be applied for the manufacturing of the leading edge demonstrator. The mechanical and non destructive inspections will be executed in another WP, from coupon to demonstrator level.

Structure of the consortium

The consortium consists of four partners from three different countries. In addition to the University of Paderborn, the consortium includes the AMRC and the TWI from England as well as FADA-CATEC from Spain. The TWI is a non-profit research organization with research focus on integrity management, materials and joining processes. The AMRC

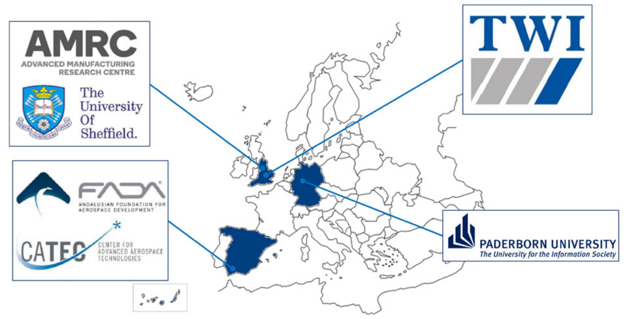

FIGURE 1 Consortium RIB-AM

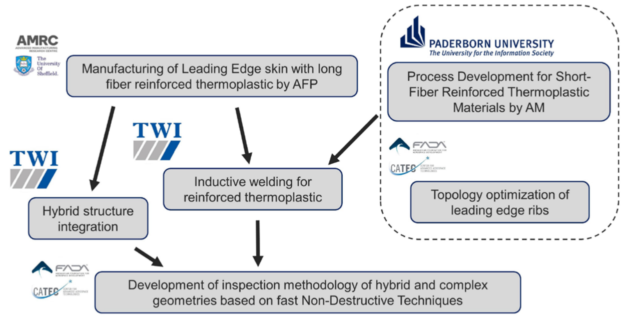

FIGURE 2 Workflow RIB-AM

was founded in 2001 in collaboration between Boeing and the University of Sheffield. It is specialized in research in advanced machining, manufacturing and materials. Seville is home of the non-profit Center for Advanced Aerospace Technologies (CATEC). The main objective of this research facility is the development of technological knowledge and technology transfer. The project is coordinated by Airbus.

Project role

The University of Paderborn will be working on the additive manufacturing of rib structures within the project. The focus is on the development and optimization of the FDM process for short fiber reinforced thermoplastics. As a first step the current state of the art has to be assessed and requirements have to be defined. Subsequently, relevant materials for the project are selected and determined. After the material selection has been completed, filaments are developed and produced that can be processed using the FDM process. The aim is to select the material and the machine used in such a way that satisfactory processability and quality of the resulting parts are achieved. This is followed by the determination of a complete set of parameters for the selected material and the production of samples. The samples are used to define the FDM specific mechanical properties that can be achieved with the new material for the topology optimized rib design. The topology optimization aims to create a new and lighter rib design that improves mechanical performance and fulfills the requirements of FDM manufacturing. The topology optimization is done by CATEC with the support of the University of Paderborn through AM manufacturing rules and FDM specific restrictions. Further project contents and the interaction between the partners in the consortium of the RIB-AM project can be seen in Figure 2.

Further procedure

The project started in November 2018 and material selection and preliminary processing tests are being carried out in cooperation with two material suppliers. In the further course, first welding tests will follow with a final determination of the material to be used. Subsequently, a detailed characterization of the material for the FDM process will take place.

SURFACE 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), the Chair of Technical and Macromolecular Chemistry (TMC) 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

10/2018 – 09/2021

PARTNER

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

FUNDED BY

German Research Foundation (DFG)

RESEARCHER

Research leader
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Prof. Dr.-Ing. habil. Mirko Schaper (LWK)
Prof. Dr.-Ing. Guido Grundmeier (TMC)

Research assistant
Dr. rer. nat. Evgeny Zhuravlev (°CALOR)
Steffen Heiland, M.Sc. (LWK)
Richard Grothe (TMC)

WEBSITE

www.uni-due.de/matframe/projects.php

Deutsche Forschungsgemeinschaft
German Research Foundation

Objectives

Reduction of weight corresponding with saving energy. The combination of lightweight materials and laser beam melting (LBM) is well suited to realize new opportunities to achieve lightweight design. Due to difficult to process aluminum alloys such as EN AW-7075 (AlZnMgCu1.5) which tends to pores and hot cracks during additive processing and welding processes, it is not possible to exploit the potential of these materials for efficient application. One opportunity to change that, is a modification of the surface of aluminum particles by inoculation with nanoparticles which shall lead amongst others to grain refinement. This effect reduces or avoids mentioned issues and should improve the processability of aluminum alloys by means of LBM. In addition to the process development and material characterization, another target is the derive of a scalable model for the precise use of grain refinements in the LBM process.

Approach

Previous studies and experiences revealed, an appropriate opportunity to minimize cracking issues in continuous and shape casted wrought aluminum alloys, a commonly used method is adding grain refiner like Al-5Ti-1B into the melt. In this case Al3Ti dissolves in the melt and TiB2 conduce to nucleation. For application in additive manufacturing, TiC or Ti2B are applied to achieve the effect of grain refinement.
Both, pure and inoculated aluminum alloys are investigated. For the modification of aluminum particles, TMC has enhanced a version of adding nanoparticles. As illustrated in figure 1, a stable aquerious dispersion is generated by using high power ultrasonic and adding Polyethylenimine (PEI). After evaporation under low pressure, aluminum powder with covered nanoparticles are merged. Likewise, the capacity for a scalable industrial application of inoculation process will be shown within the project.

With parameter studies, the appropriate adjustments of factors like laser power, scan speed, hatch distance and layer thickness are determined to achieve a high component density. Statistical test series are used to verify a broad range of factors and their variations. The process development is supported by Differential Fast Scanning Calorimetry (DFSC), which makes it possible to investigate the melting and cooling behavior of individual powder particles for extremely high heating and cooling rates.
Specimens are applied to analyze inter alia the mechanical properties, the micro- and nanostructure, grain orientation and corrosion behavior. For this, FE-SEM, TEM, XPS as well as optical spectroscopy and techniques like potentiodynamic polarisation are deployed. Due to expected grain refinement, the improvement of strength and an increase of resistance to corrosive media should occur.
After supply of aluminum powder, first investigations regarding the sphericity by means of SEM, shown in figure 2, and determination of the particle size distribution are already conducted. The latter analysis results a relatively high proportion of fine grains. Whether this will lead to an undesired effect concerning coating process will be apparent during ongoing parameter studies. For the powder bed-based laser beam melting, a machine from SLM Solutions Group AG is used. Currently, the chemical composition is accertain by spark spectroscopy and energy dispersive X-ray spectroscopy.

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.

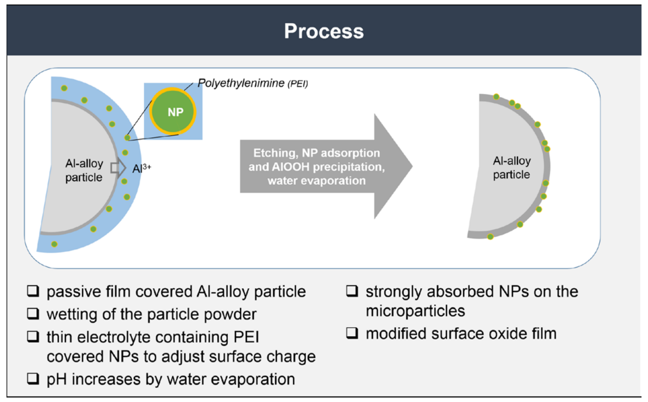

FIGURE 1 Procedure to surface inoculation

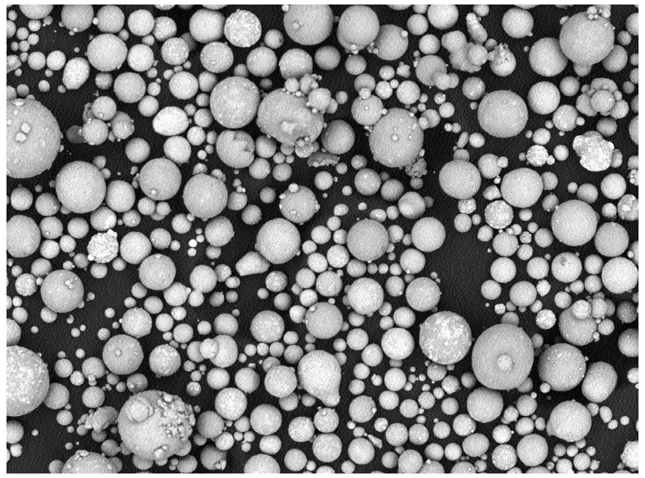

FIGURE 2 SEM image of aluminum alloy Al7075 powder

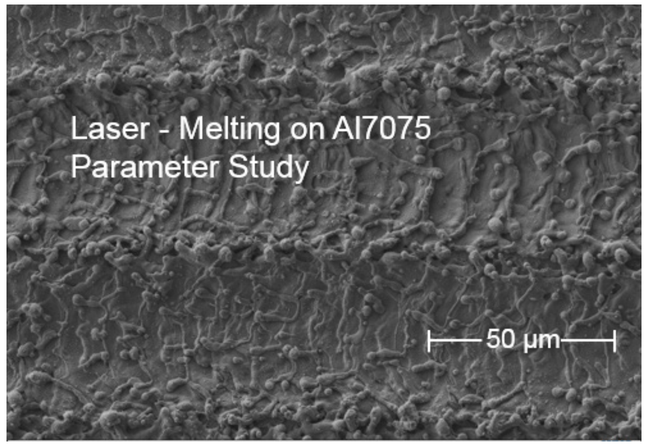

FIGURE 3 SEM image of laser melted surface of AL7075

VERONIKA – EFFICIENT AND INTERCONNECTED PRODUCT AND PRODUCTION DEVELOPMENT FOR AIRCRAFT PASSENGER CABINS (SUBPROJECT OF DMRC: ADDITIVE LIGHTWEIGHT STRUCTURES FOR THE AIRCRAFT CABIN)

Additive Manufacturing enables high innovation and absolutely new possibilities in design und structure for components of the aircraft cabin. The AM relevant work packages of VERONIKA (funded by the BMWi) aim to improve the planning-, design- and manufacturing processes for aircraft cabin parts. Within this project, the DMRC is responsible for analyzing the potentials of additive manufactured parts. Studies on AM processes, material for aircraft industries and design rules were prepared. Based on case studies several parts or assemblies have been selected and were optimized for lightweight, function and assembly integration as well as change in material. Finally, demonstrator parts are build and verified based on performance requirements as well as cost, time and quality.

PROJECT OVERVIEW

DURATION

04/2016 - 06/2019

PARTNER

- Diehl Aviation Hamburg (formerly: Diehl Service Modules GmbH)
- Diehl Aerospace GmbH
- Diehl Aviation Laupheim (formerly: Diehl Aircabin GmbH)
- Diehl Aviation Gilching GmbH (formerly: AOA Gauting GmbH)
- Boeing Research & Technology Europe

FUNDED BY

Federal Ministry of Economic Affairs and Energy (BMWI)

RESEARCHER

Research leader
Prof. Hans-Joachim Schmid

Research assistent
Dennis Menge, M.Sc.
Helge Klippstein, M.Sc.

Supported by:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

Objectives

The main aim of the DMRC work scope in the VERONIKA project is to enhance the understanding of AM for the aircraft cabin industry. AM implies high benefits for components of the aircraft cabin due to its high design freedom and potentially lower costs for small series. The applicability of the AM technologies fused deposition modelling, laser melting and laser sintering for components of the aircraft cabin shall be increased by consideration of several case studies for different objectives and by developing process chain instructions for reproducible manufacturing.

Procedure

The DMRC participates in two work packages of the collaborative project VERONIKA. In the first work package – Process Chain of Rapid Engineering – two different studies were worked out. The first study deals with the different AM processes and their processable materials. The second study is about part selection and design rules for parts generated by AM. Furthermore, material properties are determined and FE models are developed. A production instruction based on quality management will be prepared for the selected aircraft cabin components from WP2. Finally, a validation of the process chain shall be performed. In the second work package – Application of Additive Manufacturing – components of the aircraft cabin are selected by using a trade of methodology after running a specification analysis. These parts shall be transferred into an AM compliant design and optimized regarding material change, weight, part integration or function integration by e.g. topology optimization. Process parameter shall be defined and demonstrators shall be produced. Further, the demonstrators shall be verified and squared with the specification analysis.

Latest results

The latest results after creating the studies and the selection of five cabin components are various optimizations of these components on basis of FE and material models. One component, a housing for a projector unit made of aluminum, is optimized regarding function integration in form of passive cooling (natural convection) using a high surface due to lattice structures (see Figure 1).

Furthermore, an aluminum bracket is optimized concerning weight and part number reduction. The weight can be saved drastically by up to 70 % and the number of parts can be reduced from two to one part (see Figure 2). Hereby, several different optimization parameter were tested. The bracket, which was furthermore successfully simulated in FEM, was manufactured on the DMRC SLM machines. Here a support optimization study was performed to get the optimal serial production parameter for the given design.
Part integration, material change and weight reduction were performed in another case study, handeling an assembly for a drain tube of a tank. The number of parts were reduced from five to one part by topology optimization and a change in material. The former metal tube can be replaced by a design made for SLS in plastic (polyamide 12). The connection of a flange to a surrounding component was achieved using integrated, additively manufactured floating anchor nuts (see Figure 3).
Within the mentioned optimization procedure the manufacturing technology of laser sintering and laser melting were applied. For this reason, the production instruction for this technologies regarding the case study parts were prepared and the process chain highlighted and validated. Various post-processing possibilities were carried out both internally and via external service providers. These include vibratory grinding, machining processes as well as heat treatment. Furthermore, a full catalog of standardized work processes within the variation of AM technology is generated with the deep knowledge and experiences of the DMRC.

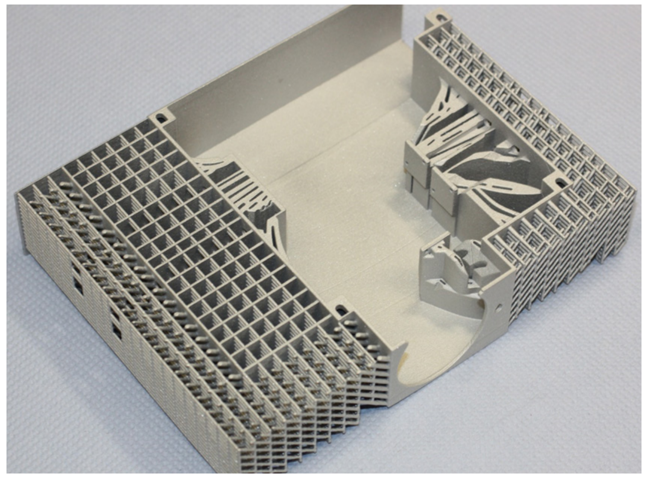

FIGURE 1 Topside of the passively cooled projector housing

FIGURE 2 Bracket

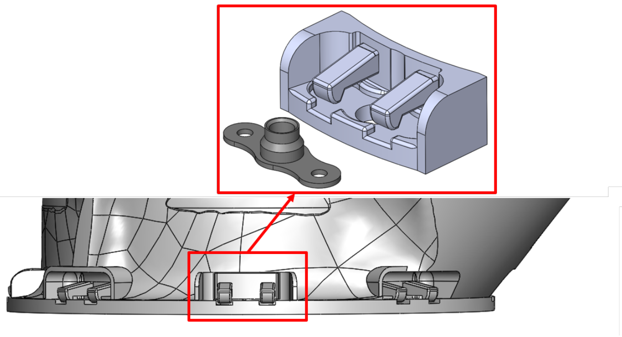

FIGURE 3 Flange with integrated floating anchor nut

INNOVATION

CONTENT

ADDITIVE MARKING – EFFICIENT MARKING OF DIGITAL PRODUCT DATA FOR ADDITIVE MANUFACTURING PROCESSES

PROJECT OVERVIEW

PARTNER

Industrial Consortium of DMRC

RESEARCHER

Research leader
Dr.-Ing. Ulrich Jahnke

INDUSTRIE PREIS 2018
BEST OF

Introduction

Traceability is often mentioned as one fundamental requirement to reach the vision of Industry 4.0, the next industrial revolution. Additive Manufacturing (AM) as a technology with high relevance in the scope of Industry 4.0 offers the potential to directly produce markings for traceability during the manufacturing process. Even industries that are not focusing on products with critical functionality can benefit of markings for quality management and liability exclusion. The identifiability of products is a valuable outcome. Markings can be understood as a kind of individualization of parts. As individualization does not increase production costs when using AM the only effort results from the integration of markings in the digital product data.

Objectives

A solution to mark products individually for AM is highly desired by industry. Using usual CAD software tools it is possible to integrate a marking for traceability manually. Doing the same for a whole batch of products that need an individual marking the effort is not reasonable in relation to the achievable benefits. Therefore the development of a software-driven solution has been focused to allow efficient integration of markings in digital product also for high batch production.

Achievements

Analysing the current workflow from designing a product to the start of the additive manufacturing process digital product data are converted in the STL file format during the preparation phase. Thus the software tool focuses on this format to allow a broad application along different branches using different CAD solutions with proprietary data formats. A pattern defining dimensions of a marking to be generated during AM can be placed in the STL file. Duplications of this pre-marked file inherit the defined pattern so that the effort is no longer depending on a batch size. Now individual markings can be generated based on this pattern following specific rules of creation. Position and orientation of each single part can become part of alphanumeric or machine-readable codes. Compared to existing software tools this is the most time and cost efficient software solution. The pattern can be placed on a surface, in a surface or even under a surface so that obviously visible markings are realizable as well as invisible markings for example for authentication matters.

Promising Applications

- Marking of spare parts e.g. usually manufactured by injection molding so that the products‘ marking has generated by the mould.
- Test specimen with a need of traceability to its position, orientation and process parameters
- Products for safety critical applications with need to traceability following legal regulations

Additive Marking supports industry to be prepared for a potential but still fictive headline of the future:
“New EU directive regulates by law that products made by additive manufacturing have to be marked”.

FIGURE 1 Additive Marking – efficient solutions made by creative minds

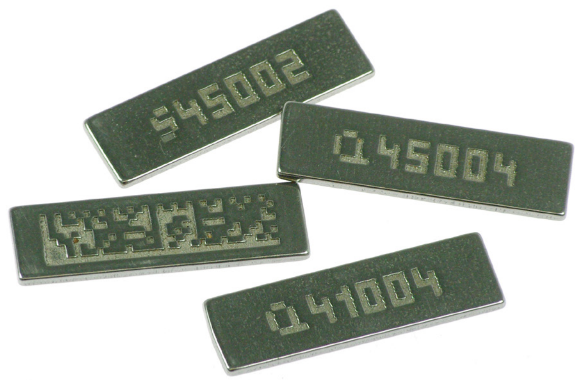

FIGURE 2 Individual markings directly produced during Selective Laser Melting

AIRCRAFT BRACKET CASE STUDY

PROJECT OVERVIEW

PARTNER

H&H

RESEARCHER

Research leader
Prof. Dr.-Ing. Dettmar Zimmer

Research assistent
Dr.-Ing. Guido Adam
Marc Timmer, M.Sc. (H&H)

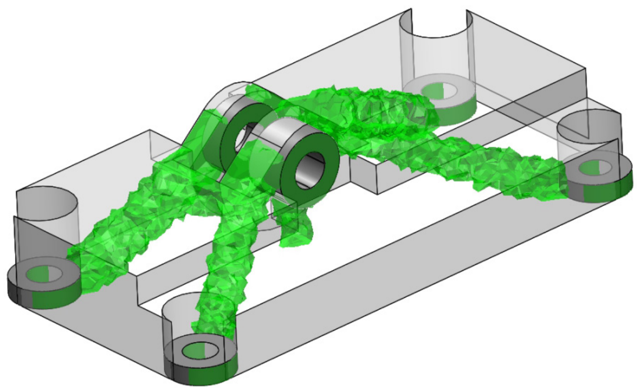

FIGURE 1 Topology Optimization of the bracket

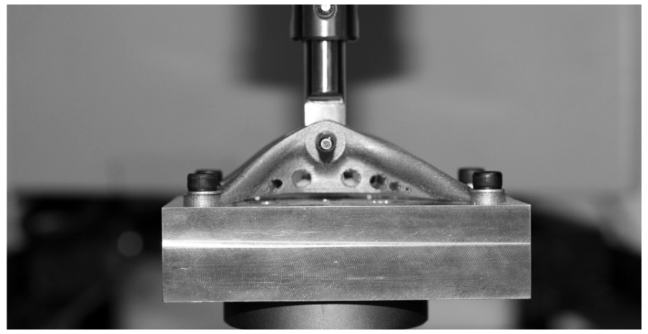

FIGURE 2 Testing of the manufactured bracket

Partner

The Company H&H GmbH – partner of the DMRC since 2013 – offers all the development services required to transform an idea into a series product. Thereby, H&H develops and builds prototypes and then simulates, tests and produces the idea that has taken shape in series volumes.

Objectives

The main purpose of this case study was to demonstrate the potential of Laser Melting for the development of brackets for the aircraft industry. Therefore, a given bracket should be redesigned, technical and economic benefits should be analyzed.

Procedure

For this case study a bracket was considered that mounts the luggage compartment damper to the aircraft structure and that is fabricated by milling. In order to foster a lightweight design, topology-optimization was used to define the geometry. Under consideration of design rules from the Direct Manufacturing Design Rules project, the bracket was further designed in order to stick to manufacturing constrains and to minimize post-process operations. The bracket was manufactured and tested with several different loading conditions in order to prove the computer-simulated results practically.

Achievements

Generally, the case study proofed that additive manufacturing can provide great advantages for the fabrication of brackets. In this particular case, the following achievements could be obtained:
Weight reduction of -46.2% (16.13 g) compared to the milling part (29.98 g).
Manufacturing cost increase of 39.47% (92.19 €) compared to the milling part (66.11 €)

AM FOR SATELLITES: REACTION WHEEL BRACKET

Partner

The Reaction Wheel Bracket was used as a sample part in the Project NewStructure, funded by the European Space Agency (ESA).

Objectives

Main aim of the study was to determine whether direct manufacturing of structure elements for satellites is feasible. High complex mission-customized parts with a high buy-to-fly ratio had to be examined to show the potential for reducing weight, waste, cost and time during production and use.

Procedure

After a profound analysis of many satellite parts a huge bracket was chosen. It is used four times per satellite for holding a mechanism where a mass is set into rotation to use the moment of inertia for adjusting satellites orientation in space without using propellant. As a computer-aided geometry creation topology optimization was used in a multi-step optimization procedure. For the retransition of calculation results a voxel-based approach is used to cover the high complex geometries with biologic seeming shapes.

Achievements

During the study a new highly time efficient semi-automatic voxel-based methodology for geometry retransition of topology optimization results was found. This enables a fast and stress optimal design. Furthermore the product related key figures show the remarkable potential of additive manufacturing for huge structural parts, even with regard to costs:

- Weight reduction: -60 % (1100g -> 450g)
- Waste reduction: - 98 % (56kg -> 0.8kg)
- Cost reduction: - 53 % (8000€ -> 3800€)
- Time reduction: - 32 % (59h -> 40h)
- Max. Displacement: - 37 %
- 1st Eigen frequency: + 20 %

PROJECT OVERVIEW

PARTNER

Industrial Consortium of DMRC

RESEARCHER

Research leader
Prof. Dr.-Ing. Rainer Koch

Research assistent
Dr.-Ing. Thomas Reiher

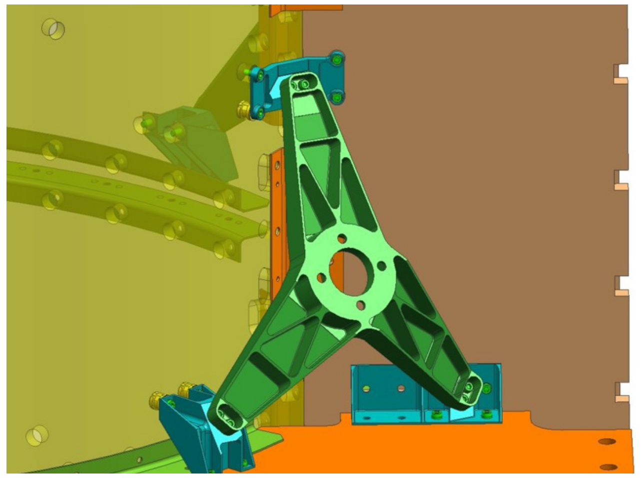

FIGURE 1 Traditional design of Reaction Wheel Bracket mounted in Exo Mars satellite

FIGURE 2 AM Designed Reaction Wheel Bracket

AMendate – INNOVATIVE AM OPTIMIZATION

PROJECT OVERVIEW

PARTNER
AMendate

RESEARCHER
Research assistent
Dr.-Ing. Thomas Reiher
Dr.-Ing. Gereon Deppe

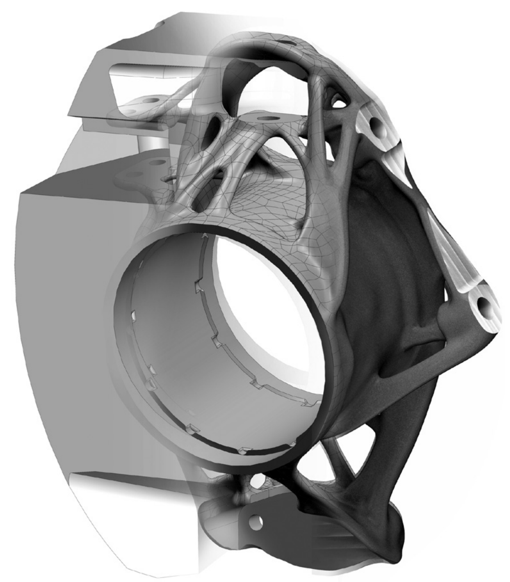

FIGURE 2 Optimization from CAD to CAD in 6 hours combined in one automated software

Objectives

In order to save resources and adapt parts better to their requirements, companies are focusing on part optimization for lightweight design. Unfortunately, the existing software for topology optimization is characterized by several shortcomings: Modeling is a lengthy, labor-intensive process, the computing time is long and extensive expertise and manual reworking is required. Usually several software tools are needed to achieve a satisfying result. However, these software tools are not aligned to an AM-specific design and the transition between the various tools results in errors and reduces the quality of results.
The aim was therefore to develop a dedicated software solution for automated topology optimization with integrated retransition into proper, additive manufacturable geometries. The result is a software called AMendate, which will soon be available on the market and offers topology optimization, automated in one single solution, from CAD to CAD.

Procedure and Achievements

Instead of a polygon-based approach, the software is based on an innovative voxel grid, which enables a multitude of unique selling points: The model is created automatically, a high resolution can be achieved and the resolution can be varied within the optimization calculation. This results in highly complex, optimal structures. An intelligent smoothing algorithm automatically transfers the voxel result to smooth surfaces. The result requires neither further interpretation nor further engineering. The optimization algorithm automatically takes into account all relevant design rules for additive manufacturing for a directly printable result. This gives the user a better result much faster and more cost-effectively. Time savings of up to 80% can be achieved by eliminating and automating several time-consuming process steps. The automated and integrated topology optimization enables an optimization from CAD to CAD within hours instead of days. The newly developed software and its innovative approach enable considerable speed growth. This is driven by a software architecture that fully utilizes the computing power of current high-tech graphics cards and the seamless, automatic workflow. Another significant advantage is the direct stress oriented optimization, which provides better optimization results and a balanced stress distribution over the entire component.
This makes AMendate a significant step towards the automated design of optimized parts, which will promote the introduction of additive manufacturing in other industries.

BIPOLARPLATES USING FDM-MOLD

Partner

This Innovation was developed together with Eisenhuth GmbH & Co. KG. Eisenhuth. Eisenhuth is SME located in Germany, Osterode am Harz, and has three main competencies: Mold making, small and medium series of thermoplastics, rubber, silicone and thermoset components and the production of bipolarplates from graphite compound materials. In this place the DMRC want to thank Eisenhuth for the great contribution.

Objectives

The aim was to investigate, if the FDM-Process is suitable for the production of tool inserts (negative molds), which enables the production of finely textured metallic bipolar plates (BPP) to realize the efficient production of fuel cells.

Procedure

The first part of the project was to define and design the finely structured hydrogen channel, taking the requirements of the subsequent production steps into account. There, the limitations of the FDM-Process in this area of application and the resulting mechanical properties and geometrical characteristics were investigated.

Achievements

Finely textured mold with good surface quality and sufficient mechanical properties for a small series production of metallic bipolarplates. Identification of suitable materials for this application using the FDM-Process and investigations of orientation angles for optimal canal depths and shapes.

Highlights

- Performance: up to 62% higher
- Speed: 5 times faster
- Space: up to 50% thinner

PROJECT OVERVIEW

PARTNER
Eisenhuth GmbH & Co. KG

RESEARCHER
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Prof. Dr. rer. nat. Thomas Tröster
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Research assistent
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Dr.-Ing. Matthias Fischer
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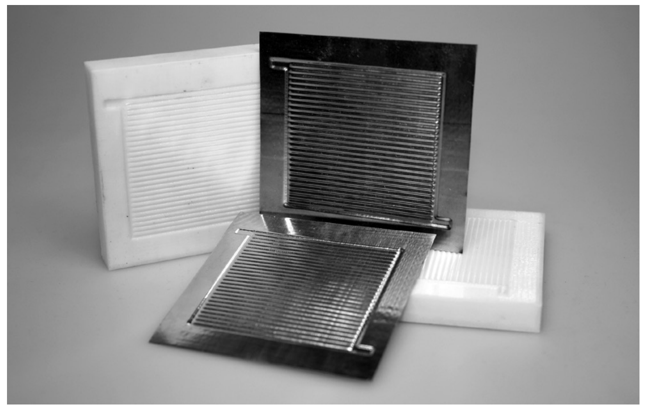

FIGURE 1 Pressed sheet metal

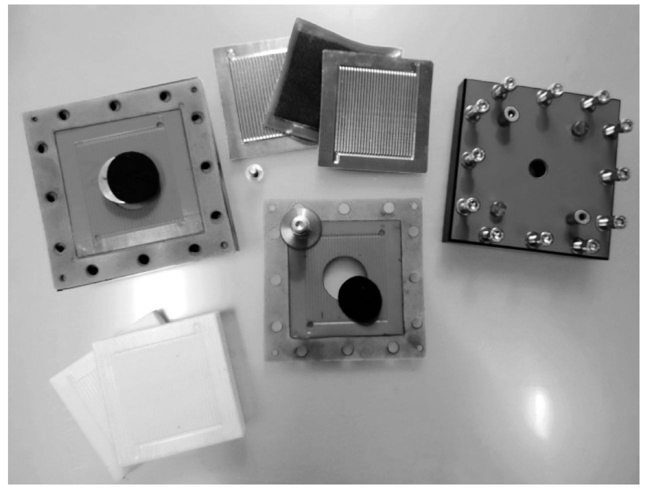

FIGURE 2 Experimental setup of the fuel cell

DIRECT DAMPING OF AN ARMATURE PLATE USED IN A SPRING-LOADED BRAKE

PROJECT OVERVIEW

RESEARCHER

Research leader
Prof. Dr.-Ing. Detmar Zimmer

Research assistent
Thomas Künneke, M.Sc.

FIGURE 1 Test rig used for sound pressure level tests

FIGURE 2 Sectional view of the cavities inside the damped armature plate

Objectives

In drive systems, spring-loaded brakes are commonly used to slow down, stop and lock the drive system. They are located at the B-side of electric motors. While braking, the armature plate is pressed against the rotating friction lining by spring elements. To release the brake, an electro magnet rescinds the spring forces. The fast movement of the armature plate leads to strong impacts with the friction lining and the housing of the electric motor. This results in a vibration of the brake-system and the emission of perceivable noise.

Procedure

Using the results of the AMFIDS-project, AM technologies have been used to integrate damping structures into the armature plate of a spring-loaded break. A segmented, ring shaped cavity was integrated into the armature plate consisting of eight single cavities. The powder was left inside the cavities to act as a particle damper. Further, lattice structures were integrated into the cavities to support the manufacturing process as well as to allow thinner walls. The cavity is divided into segments to achieve a better absorption of the impact forces. After manufacturing, the armature plate by laser melting process and a following turning operation experimental tests were carried out to evaluate the effect of the integrated damping structure. Therefore, the sound pressure level was measured and compared for the shift operation of the brake system.

Achievements

By integrating damping structures the mean sound pressure level could be reduced by 7.86 dB(C). This is a significant reduction in the emitted noise of the brake system and shows the tremendous potential of direct manufactured function integrated damping structures.

KOBFS - LuFo

Objectives

The reduction of process times in additive manufacturing is a major focus of research. The aim of the investigation was to reduce the time, required for a process route, of the additive manufacturing process for the Ti6Al4V titanium alloy with subsequent HIP process.

Procedure

Therefore, this study pursues comprehensive investigations on the mechanical properties of the titanium alloy TiAl6V4, which was processed in an optimized process chain. By optimizing the process parameters, the production speed is drastically increased, the process-induced defects are adjusted in a controlled manner and eliminated by thermal post-treatment (HIP). The result is a faster processability of the titanium alloy and thus better economic efficiency.

A HighSpeed parameter window was determined during singletrack tests. Subsequently, mechanical characteristic values of the specimens are determined in tensile tests and fatigue tests. Both static and dynamic measurement results are very sufficient in comparison to the conventional route.

Achievements

The exposure time during the additive manufacturing process was reduced to 50%. The subsequent HIP treatment also reduces pores up to approx. 6%. Compared to samples that were not generated with high-speed parameters, the mechanical characteristics are identical. In addition, the HighSpeed parameter does not generate any increased residual stresses in the component. This leads to a process time reduction of around 25%. These were validated with a gimbal specimen whose process time could be reduced from 49 hours to 38 hours.

PROJECT OVERVIEW

RESEARCHER

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Research assistent
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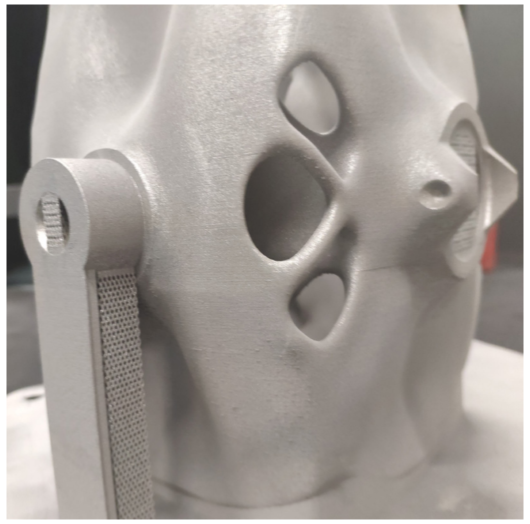


FIGURE 1 Gimbal built with HighSpeed Parameter

FIGURE 2 Inner surfaces of HighSpeed build job

LIGHTWEIGHT CONSTRUCTION OF HYDRAULIC CLAMPING DEVICES PROCESSED BY SLM

PROJECT OVERVIEW

PARTNER

ELHA-MASCHINENBAU Liemke KG

RESEARCHER

Research leader
Prof. Dr. rer. nat. Thomas Tröster
Prof. Dr.-Ing. Rainer Koch

Research assistant
Peter Koppa, M.Sc.
Dr.-Ing. Thomas Reiher

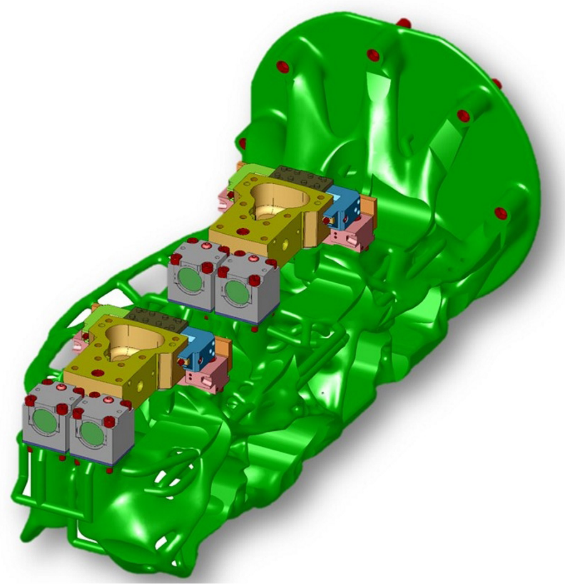


FIGURE 1 Topology optimized clamping device

Partner

ELHA-MASCHINENBAU – a company with a long tradition – stands for technical innovation with customized machine tools providing individual manufacturing processes for advanced machining requirements. Our divisions PRODUCTION MOD-ULES and XL MANUFACTURING SYSTEMS stand for different machine concepts and machin-ing solutions for various industry sectors.

Objectives

The project is about a technical and economic study for the feasibility of a base body for a hy-draulic clamping fixture by using the advantages of the SLM process. So far the fixture is made in several machining steps out of one solid piece of steel.

Procedure

To achieve the advantage of weight reduction and higher stiffness of the clamping system, the com-plete part had to be redesigned. Several iterative topology optimization steps had to be calculated considering geometry, stiffness and collision re-strictions. In addition, the production costs of the fixture system made by SLM process were com-pared with the conventional process.

Achievements

Due to the fact the clamping device lost after the optimization around 58% of weight, the dynamic and inertial forces on the milling machine de-crease significantly. That has a positive effect on the weight and stiffness of the whole milling module.

- Weight reduction:- 58 %

LIGHTWEIGHT ROTOR SHAFT FOR PMSM

Partner

The project was funded by the Forschungsvereinigung Antriebstechnik (FVA, engl.: Research Association Drive Technology). Specific the work group “Geregelte Elektroantriebe” (GEA, engl.: Controlled Electric drives) with its industrial members like Siemens, Wittenstein, Porsche, VW, Wilo. The scientifc partners were the chairs IAL (University of Hanover) and the IAM (Karlsruher Institute of Technology).

Objectives

The aim of the project was the identification of benefits of Additive Manufacturing (AM) in electric engineering and especially the implementation of this benefits in a Permanent Magnet Synchronous Motor (PMSM)

Procedure

An optimal material was determined (H13) and its mechanical and electromagnetic properties were investigated and improved by a heat treatment. A suitable PMSM was selected and its rotor shaft design was optimized for AM. The rotor shaft was built out of H13 and mounted into a given stator. Finally the motor characteristics were determined.

Achievements

The promising results of the motor characteristic determinations showed that the weight of the rotor shaft could be reduced by 25,1%. This leads to a reduction of the moment of inertia of 23% and an reduction of the acceleration time of 23,2 %. The Investigations were performed at 71,98 Nm and 3000 rpm. Moreover the permeability of the material H13 could be improved through a heat treatment. So the permeability could be enhanced from 32 to 480 and the coercivity could be reduced from 5600 A/m to 1300 A/m. This lead to an obvious enhanced soft magnetic behavior.

PROJECT OVERVIEW

PARTNER

- Siemens
- Wittenstein
- Porsche
- VW
- Wilo
- IAL (University of Hanover)
- IAM (Karlsruher Institute of Technology)

RESEARCHER

Research leader
Prof. Dr.-Ing. Detmar Zimmer

Research assistant
Stefan Lammers, M.Sc.

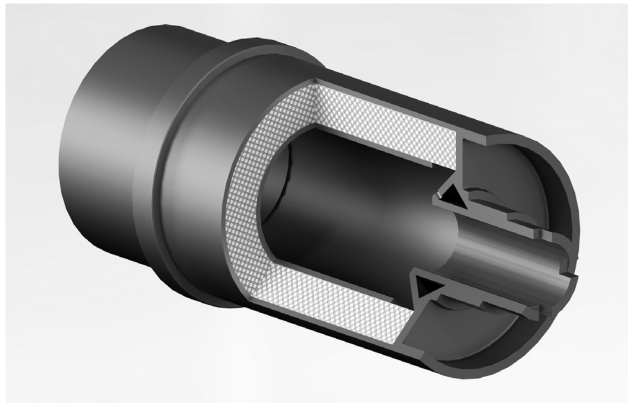


FIGURE 1 Optimized rotor shaft with lattice structures for a lightweight design

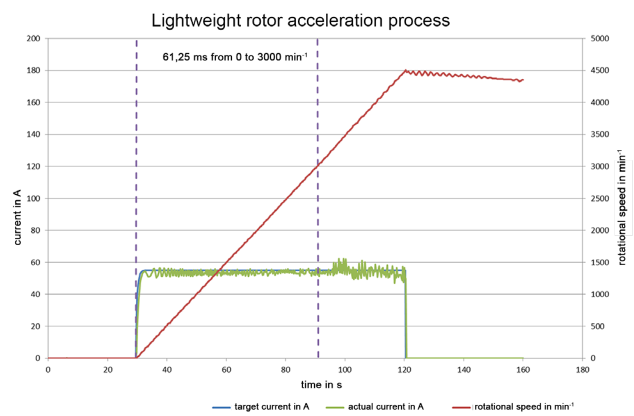


FIGURE 2 Results of the motor characteristics investigations.

MODELLING OF TEMPERATURES AND HEAT FLOW WITHIN LASER SINTERED PART CAKE

PROJECT OVERVIEW

PARTNER

Indian Institute of Technology Bombay, Powai, Mumbai, India

RESEARCHER

Research leader
Prof. Dr.-Ing. Hans-Joachim Schmid

Research assistent
Dr.-Ing. Stefan Josupeit
Lavish Ordiac

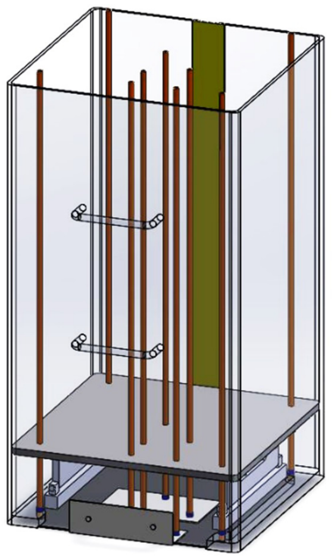


FIGURE 1 EOS P395 Frame with installed temperature measurement system

Objectives
Temperature effects in the polymer laser sintering process are an important aspect regarding the process reproducibility and part quality. Depending on the job layout and position within the part cake, individual temperature histories occur during the process. Temperature history dependent effects are for example part warpage, the crystallization rate and powder ageing effects. This work focuses on temperatures and heat flow within laser sintered part cakes.

Procedure
Therefore, a thermal Finite Element (FE) model of a part cake is developed based on experimental temperature in situ measurements (Figure 1). Determining of the heat flow within laser sintered part cakes requires experimental information about the three-dimensional temperature distribution and history within the powder as a reference for the model development. Since the size of the part cake increases continuously during the build phase, here only the cooling phase is selected for the model development. Experimental temperature measurements are used to specify the temperature distribution and determine the starting of the cooling phase on the one hand and to validate and check the accuracy of the model on the other hand. Thermal boundary conditions and properties of the used bulk polymer powder are analyzed and relevant parameters are identified. The FE model is validated and optimized considering different job heights and ambient conditions during the cooling phase.

Achievements
A model to simulate the temperature history and heat flow within laser sintered part cakes during the cooling phase has been set up. Thermal boundary conditions of a polymer laser sintering system were analyzed. Modelled data has been compared to experimental data obtained with 48 thermocouples inside the part cake. The outer heat transfer coefficient (thermal powder contact and convection) and the thermal conductivity of the part cake were determined in a parameter study. A parameter set has been validated with an accuracy of about 6 K for all sensor positions during the whole cooling process. To improve the model, possible disturbance variables were figured out. A consideration of time and location dependent heat transfer coefficients lead to an improved model with an accuracy of 3 K. Further aspects are for example cracks within the part cake or the influence of the powder bed density on its thermal conductivity. It is finally possible to predict position-dependent temperature histories as a function of significant job parameters. The model allows a transfer of the results for varied boundary conditions during cooling. In combination with an implementation of built parts, this model will be an important tool for the development of optimized process controls and cooling strategies.

OPTIMIZATION OF MATERIAL PROPERTIES OF SELECTIVE LASER-MELTED ALUMINUM ALLOY 7075

Objectives
Experience from conventional manufacturing shows a good performance of the high-strength aluminum alloy EN AW 7075 which leads to frequent use in automotive and aerospace sector. Scientific investigations on the processability of this alloy in the SLM process shows that prepared samples have anisotropic behavior due to process-induced hot cracks (Figure 1). Furthermore, it was not possible to determine solid results regarding the fracture mechanical characterization. Due to its chemical composition, aluminum alloy EN AW 7075 has a high solidification interval. As a result, the melting and solidification of the material results in a high affinity for the formation of hot cracks. For industrial use, these hot cracks must be avoided.

Procedure
An investigation documented in literature shows that addition of 4 Wt.-% Silicon avoids hot cracking. This is due to a reduction of the thermal expansion coefficient. Furthermore another investigation shows that an increase of the pre-heating temperature of the building platform reduces the number of hot cracks in selective laser melted EN AW 7075. In practice, pure silicon is not always available for the modification of the powder, which is why a practice-oriented approach to the production of a mixed alloy made of high-strength EN AW-7075 and silica-rich AlSi10Mg is pursued in this context.

Achievements
The production of a mixed aluminum alloy based on the high-strength alloy EN AW-7075 led to process-reliable processing using SLM. When using an adequate process parameter set, the samples produced have an almost pore-free appearance without detectable hot cracks (Figure 2). A subsequent heat treatment leads to an increase in the mechanical and fracture mechanical characteristics of the mixed aluminum alloy.
The approach of mixing two available powders makes it possible to compensate for negative mechanical and fracture mechanical properties and to generate additively processable material.

PROJECT OVERVIEW

RESEARCHER

Research leader
Prof. Dr.-Ing. Gunter Kullmer

Research assistent
Dr.-Ing. Jan-Peter Brüggemann

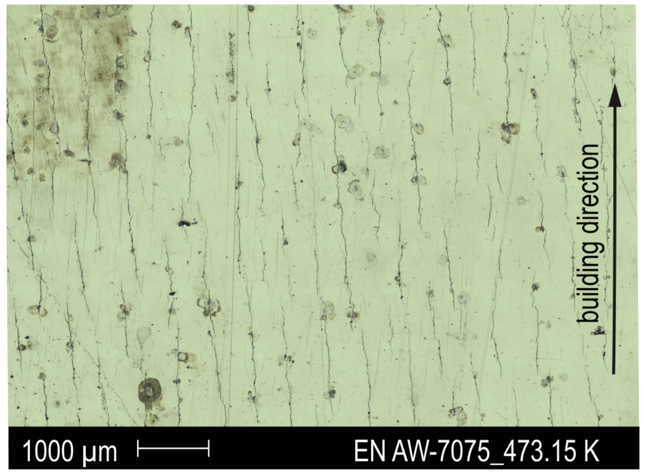


FIGURE 1 Optical micrographs of the specimen after SLM processing EN AW-7075 manufactured with a 473.15 K pre-heated building platform

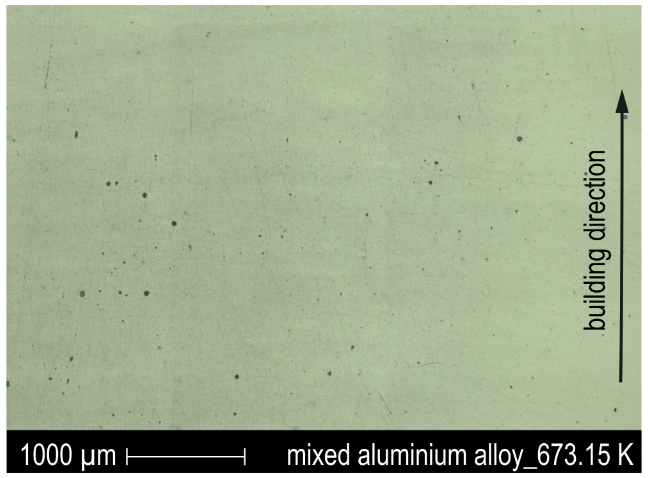


FIGURE 2 Optical micrographs of the specimen after SLM processing mixed aluminum alloy manufactured with a 673.15 K pre-heated building platform

PLASTIC FREEFORMING OF LIQUID-TIGHT MICROFLUIDIC COMPONENTS

PROJECT OVERVIEW

PARTNER
- Kunststofftechnik Paderborn, Paderborn University
- Institute of Manufacturing Technology, Technische Universität Dresden
- Fraunhofer Institute for Material and Beam Technology IWS

RESEARCHER

Research leader
Prof. Dr.-Ing. Elmar Moritzer

Research assistant
Andre Hirsch, M.Sc.

Introduction and Objectives

The Plastic Freeforming (PF) enables the successful construction of application-specific reservoirs and cell culture segments directly on a universal micromachining platform (polymer chip). The cell culture reservoirs were manufactured from the copolymer ABS. The focus was on the optimization of the process parameter concerning the fluid tightness and the bonding on the polymer chip made of PC. A design adjustment of the inner structure minimizes the floating overhangs in the range of the flow channels. Due to this adjustment, the use of any kind of support material can be avoided. In this way it can be ensured that no residues of water soluble or non-biocompatible material remain in the system. Apart from avoiding support material, the aim was to apply the cell culture reservoir on the polymer chip without the need for any adhesives. In the PF-process, polymer chips can be inserted into the build chamber so that an additive structure can be directly applied in the next step. The deposition of the molten polymer droplets on the thermoplastic basic chips is similar to the welding process of polymers.
The cell culture reservoirs have the purpose to absorb, store and pass the microfluidic into micro physiological systems. Therefore, the tightness of the whole system is crucial to ensure the functionality. The structure is generated by applying single polymer droplets, so that cavities are formed between the droplets. The optimization of the process parameters aimed to minimize the porosity of the cell culture reservoirs to ensure the fluid tightness. The cell culture reservoirs were produced with a 0.2 mm nozzle and the layer thickness is about 0.15 mm.

Procedure

By adjusting the form factor (FF), the degree of filling and thus the pore volume can be varied. Besides the impact of the form factor, the impact of the processing temperatures (material preparation and build chamber temperature) are investigated as well. These process parameters affect the mass temperature of the molten polymer droplets. A temperature increase results in a decrease of the viscosity. Expectably, a decrease of the viscosity improves the wettability of the droplets, so that less cavities are generated. The lower viscosity, therefore, is expected to result in a reduction of the pore volume. The setting behavior of the polymer droplets immediately after the deposition is mainly affected by the temperature of the build chamber.

Achievements

The figure shows the three-dimensional view of three cell culture reservoirs. The yellow colored areas mark the pores in the test samples. The integrated structures are clearly recognizable in the middle of the figure. It is clear to see that a low form factor and a high temperature in the build chamber result in a decrease of the pore volume.

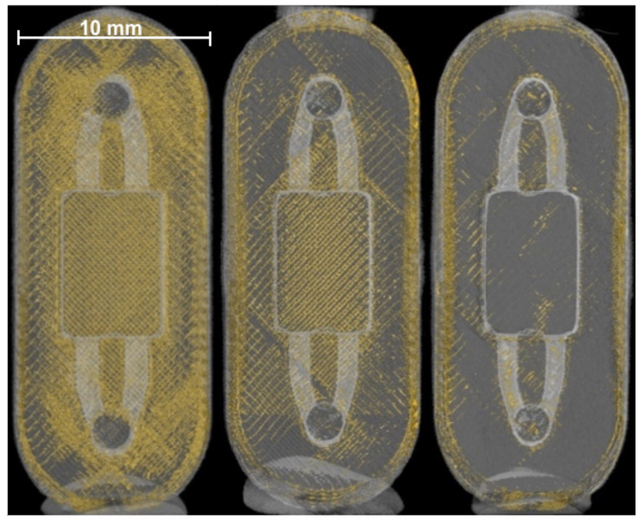


FIGURE 1 Computer tomographic pore volume analysis with varied form factors (FF) and build chamber temperatures (BT)

SURFACE FINISHING

Partner

This post processing study was realized in cooperation with Walther Trowal GmbH & Co. KG, a company specializing in grinding technology based in Haan.

Objectives

The surfaces of additive components are not as smooth as for conventional machined parts due to the manufacturing process. Therefore, AM manufactured components require a surface post treatment. Due to the complex geometries of AM components with undercut and difficult to reach areas, conventional machining like drilling or milling are not suitable as overall surface treatments. Even sand blasting often does not meet the requirements. In cooperation with Walther Trowal the vibratory finishing technique was investigated as a surface treatment for additive manufactured components. This offers attractive possibilities for improving the surface.

Procedure

Walther Trowal has developed various processes and special machines for subsequent surface treatment. The Direct Manufacturing Research Center at Paderborn University has provided various components with hard-to-reach areas and narrow cross-sections. These are treated by vibratory grinding for a period of around 24 hours. The polishing and treatment additives developed at Walther Trowal are specially selected for the materials to be prepared.

Archievements

After the treatment, the surface quality of the components is outstanding. Even very narrow and hard to reach areas have a smooth surface. The process is also used by many well-known companies for difficult-to-machine materials such as titanium and cobald chromium alloys. The process is characterized by high quality and reproducibility, which makes it attractive for other applications.

WALTHER TROWAL!
Oberflächentechnik

PROJECT OVERVIEW

PARTNER
Walther Trowal Gmbh & Co. KG

RESEARCHER

Research leader
Prof. Dr. rer. nat. Thomas Tröster
Prof. Dr.-Ing. Mirko Scharper

Research assistent
Dominik Ahlers, M.Sc.
Florian Hengsbach M.Sc.

FIGURE 1 Component on building plate after sand blasting

FIGURE 2 Component after final surface finish through vibratory grinding

SURFACE ROUGHNESS OPTIMIZATION BY SIMULATION AND PART ORIENTATION

PROJECT OVERVIEW

PARTNER

Industrial Consortium of DMRC

RESEARCHER

Research leader
Prof. Dr.-Ing. Hans-Joachim Schmid

Research assistent
Patrick Delfs, M.Sc.

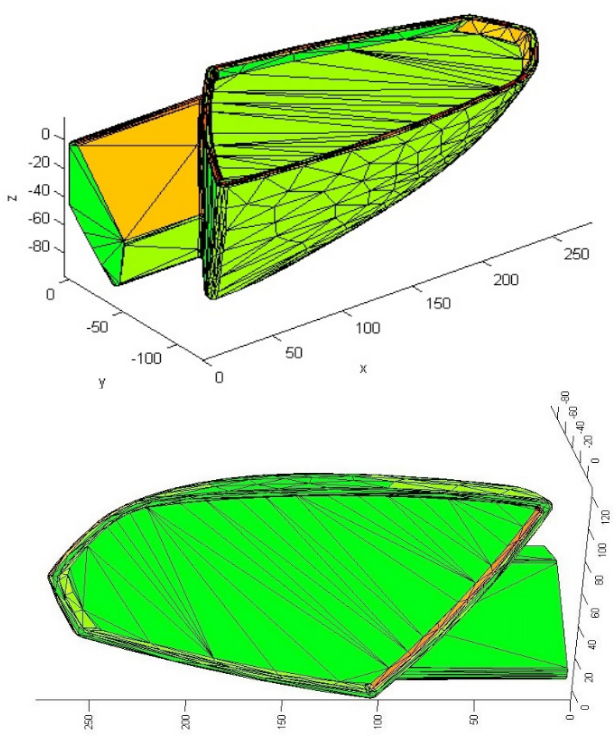


FIGURE 1 EOS P395 Frame with installed temperature measurement system

Objectives

The layered structure of Additive Manufacturing processes results in a stair-stepping effect of the surface topographies. In general, the impact of this effect strongly depends on the build angle of a surface whereas the overall surface roughness is caused by the resolution of the specific AM process.
The aim of this work is the prediction of surface quality in dependence of the part building orientation. Furthermore, these results can be used to optimize the orientation of the part to get a desired surface quality for functional areas or an overall optimum.
In AM the build height is most often a cost factor, therefore the part orientation tool takes not only the predicted surface quality into account. The job height is an optimization objective for this tool as well.

Procedure

Based on experiments a surface roughness database was generated. To support this database an additional surface roughness Rz simulation tool was developed (Figure 1).
Usually not every area of a part can be optimized, as the surface quality is highly dependent on the build angle. Therefore, a pre-assignment of functional or important areas takes place for the orientation simulation. The selected surfaces get an increased weighting factor for the preferred build alignment.
The model uses the digital STL format of a part as this is essential for all AM machines. Each triangle is assigned with a roughness value and by testing different orientations an optimized position can be found. Even if this tool is validated and build on the LS process, this method can be applied to all AM technologies.

Achievements

With the alignment optimization tool for AM processes, which uses a surface roughness database and build height as optimization objectives, it is possible to validate the part orientation for AM parts.

EDUCATION

CONTENT

DMRC - AM LESSONS

Additive Manufacturing technologies and applications are becoming more and more mature. The DMRC is supporting this progress on different levels. Doing fundamental and applied research along different disciplines, technologies and research fields on the one hand. On the other hand, there is an increasing need of standardization and the DMRC is actively participating in different standardization committees to foster this process.
It plays an important role in the 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).
Furthermore, the DMRC is part of the VDMA Additive Manufacturing – Automation. The superordinate committee targets at the whole chain of production and brings together industry and research institutes. The overall goal is to develop standards and technical requirements to support the ongoing extension of Additive Manufacturing application. DMRC activities are focused on aspects regarding the automation of Additive Manufacturing processes.
Another standardization committee the DMRC is part of is the FVA AK Geregelter Elektroantrieb and FVA AK Additive Manufacturing. It aims at uncover new application potentials of Additive Manufacturing in the field of drive train applications. FVA AKGEA is focused on applications regarding controlled electric drives, while FVA AKAM has a broader perspective and targets
The DVS FA 13 is a committee concerned about Additive Manufacturing based on 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.

DMRC - SEMINARS FOR INDUSTRY

Besides the scholar teaching, the DMRC was active in industrial teaching 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. The certificate course is technically coordinated by Dr.-Ing. Stefan Bindl (AM Ventures Holding GmbH) and Dr.-Ing. Christian Lindemann (DMRC) and VDI WF. First courses will start in 2018. Within the seminar series the DMRC will educate in the area "Design for additive Manufacturing"

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.

https://www.vdi-wissensforum.de/lehrgaenge/fachingenieur-additive-fertigung-vdi/

UPBRACING TEAM

The UPBracing Team had one, big primary goal for their new car, the PX219. Save as much weight as possible and retain its reliability. To achieve this goal, additive manufacturing was a vital part of the overall concept.

As was the case in all cars since 2013, the uprights were manufactured by using SLM. Since SLM does not put any constraints on a parts geometry, the parts could be topology optimized with AMendate. The resulting bionic structures are a perfect fit for the load cases the uprights are confronted with, without carrying any unnecessary weight. After meticulous analysis of all load cases and closely working together with the DMRC the team was able to achieve optimal uprights, which are perfectly suited for the PX219.

Going further, the team analyzed other parts of the car to find out, which parts would be suitable and could be improved by additive manufacturing. They found that especially the junctions from two titanium exhaust pipes into one could be improved. The main advantage of additive manufacturing in this case is the easier manufacturing, since welding these juctions is very complex and their dimensional accuracy is not as good, as it would need to be, to fit in the very tight package in the rear frame. Another important improvement that additive manufacturing enables, is a better exhaust flow, as no welds are in the way of the exhaust coming from the engine.
Especially the last bend would not hat been possible to manufacture by bending and widening, since it is a 90-degree piece going from a 40mm diameter fitting the exhaust system to a 60mm diameter to fit the muffler of choice.

What's more, members of the team had the chance to gain theoretical as well as practical knowledge in additive manufacturing. They were taken along on many steps of the manufacturing process, i.e. retooling the SLM machines, removing the manufactured parts from the machines or removing the support.
Additionally, the UPBracing Team profited from the extensive knowledge and advice of the staff regarding the after-treatment of the parts.

With the uprights and the components for the exhaust system, the cooperation with the DMRC played an important part in realizing the teams mission and building the lightest race car in the teams history.

STUDENTLAB3D - STUDENT LABORATORY

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), the Chair of Technical and Macromolecular Chemistry (TMC) 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.

Started in 2014

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". With this financial support, three affordable 3D printers and a handheld 3D scanner have been purchased. In the meantime the equipment was extended by additional 3D printers, 3D scanners and software.

Teaching and workshops

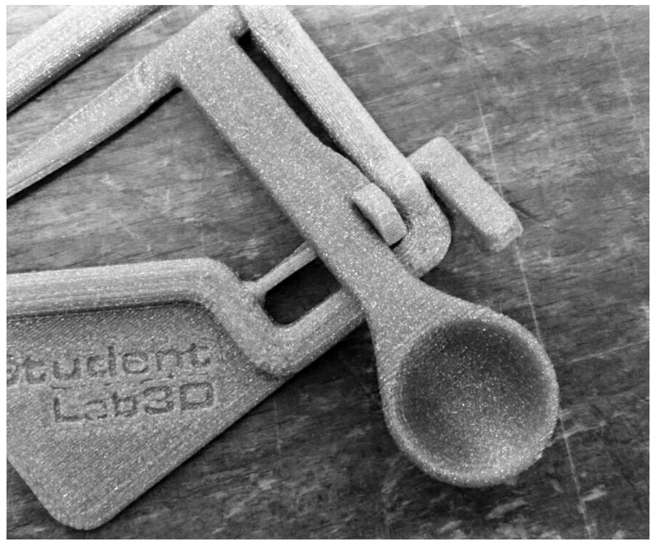
All students and the stuff of the Paderborn University are invited to visit and use the StudentLab3D. It is a great opportunity to get to know the world of 3D printing in reality and not only in theory. While providing a 3D printing and 3D scanning service, the StudentLab3D offers three different workshops. One workshop covers the basics of the major procedures that are used in 3D printing technologies. Another workshops covers the basics of 3D scanning technologies and in the last workshop the basics of computer aided design (CAD) are taught.
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.

Achievements

In 2017 the printers of the StudentLab3D have produced more than 1000 individual parts for students and staff-members of various faculties of the Paderborn University. Furthermore, over 100 students obtained a certificate of completion for successfully attending all three workshops offered by the StudentLab3D.

PROJECT OVERVIEW

PARTNER	University Paderborn
RESEARCHER	Research leader Prof. Dr.-Ing. Hans-Joachim Schmid) Research assistent Christian Schumacher, M.Sc. Dennis Menge, M.Sc.
WEBSITE	https://dmrc.uni-paderborn.de/de/inhalt/lehre/studentlab3d/



CHAIRS AND INSTITUTES

CONTENT

COMPUTER APPLICATION AND INTEGRATION IN DESIGN AND PLANING (C.I.K.)

> Additive Manufacturing will influence industrial processes in a similar way as before CAD affected design activities. Due consideration of potential applications for AM is essential.
>
> Prof. Dr.- Ing. Rainer Koch

INTRODUCTION

The research group Computer Application and Integration in Design and Planning (C.I.K.) takes advantage of basic technologies and innovative IT concepts and applications together with related methodologies. Specific research and work priorities are applications of software engineering methods from conceptual design to implementation of information systems and evaluation of research results and quality management in product development with focus on usability of software solutions.

Bridging the gap between science and industry

In collaborative research projects the C.I.K. bridges the gap between science, industry and user. This is emphasized by close connections with manufacturing and service companies including small and medium sized enterprises as well as global players. The focus on requirements and goals of human stakeholders supports the transfer of research results into practice. The IT-based collection, processing and target oriented provision of information is studied with respect to pragmatic aspects. In this regard, business process management methods and semantic technologies have a major priority in current projects.

The projects of the C.I.K. cover a broad spectrum of relevant topics in the field of Design and Planning. Specific goals are given by the knowledge management, the integration of expert knowledge into product and process models, the identification and utilization of hidden knowledge as well as IT support in complex environments.

Civil safety and Additive Manufacturing projects

The research group C.I.K. is one of the leading German institutes for research on public safety and security. Within numerous projects the research group is building the bridge between civil rescue organisations, additional end user groups and other project partners from industry and science. The experience in industry research has been enhanced with the beginning of scientific projects in the field of Additive Manufacturing. The gained expertise is the base for our ideas, systems and technologies in the context of planning, coordination support, training and decision support. Today nine research assistants and up to fifteen student assistants are working for the C.I.K. bringing in knowledge from the fields of engineering, computer science, economics and mathematics.

ADDITIONAL EQUIPMENT OF THE CHAIR

Software

- 3D Systems - Geomagic Freeform incl. 3D Systems touch haptic device

Hardware

- Ultimaker 3 incl. Dual Extruder
- Prusa MKi3

STAFF

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Integration of AM as a serial production process

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CURRENT RESEARCH PROJECTS

OptiAMix - Multi-target optimized Product Development for Additive Manufacturing

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MORE INFORMATION: page 76

FUNDED BY: Federal Ministry of Education and Research

proDruck - 3D printing – Technology of industry 4.0 – as a medium for inclusion of people with disabilities in the work world

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MORE INFORMATION: page 78

FUNDED BY: Federal Ministry of Education and Research

iBUS - an integrated business model for customer driven custom product supply chains

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MORE INFORMATION: page 66

FUNDED BY: (EU)

FINISHED RESEARCH PROJECTS (2015-2018)

RepAIR - Future RepAir and Maintenance for Aerospace industry

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ASSISTENT: Dr.-Ing. Gereon Deppe
Dr. -Ing. Christian Lindemann
Dipl. -Ing. Marco Plaß

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FUNDED BY: (EU)

Know AM - Knowledge about Additive Manufacturing

RESEARCH LEADER: Prof. Dr.-Ing. Detmar Zimmer

ASSISTENT: Dr. -Ing. Christian Lindemann

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FUNDED BY: DMRC – Direct Manufacturing Research Center – Research, Innovation, Education

NewStructure - Direct Manufacturing of structure elements for the next generation platform

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FUNDED BY: esa

It's OWL 3P - Prevention of Product Piracy - protect innovations

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FUNDED BY: Federal Ministry of Education and Research

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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AM in medical technologies

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CURRENT RESEARCH PROJECTS

Changes of stainless steel powder

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MORE INFORMATION	page 28
FUNDED BY	

FINISHED RESEARCH PROJECTS (2015-2018)

Fatigue strength properties of SLM components

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FUNDED BY	

Fatigue Life Manipulation

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FUNDED BY	

Influence of different powder properties on the material characteristics

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CHAIR OF FLUID PROCESS ENGINEERING (FVT)

> Our sound expertise with the methods of computational thermofluiddynamics is essential for designing thermally optimal geometry of additively manufactured devices.
>
> Prof. Dr.-Ing. Kenig

INTRODUCTION

A successful optimization and intensification of industrial processes depends on the predictability and robustness of the developed process models and simulation tools. In this regard, the Chair of Fluid Process Engineering (FVT) applies a particular approach denoted complementary modeling. This approach is based on an efficient combination of models with different rigor and detailization degree.

Complementary modeling comprises the following three main modelling methods:
The CFD (Computational Fluid Dynamics) provides velocity, temperature, pressure and concentration fields in continuous phases and allows a detailed insight into the transport phenomena in industrial equipment. This enables optimization of fluid flow and unit geometry.
Modeling of large-scaled separation units is accomplished with the rate-based approach. Here, stage models, which discretize column equipment and involve the process kinetics (e.g. mass transfer, heat transfer, chemical reactions), are employed. Furthermore, the rate-based approach includes a reasonable consideration of column internals and design.
A third modelling approach to describe transport processes in structured equipment units is based on hydrodynamic analogies (HA) between real complex fluid flows and geometrically simplified flow patterns.

All three approaches can be applied either individually or in a complementary way.

The main research topics of the Chair are:
- Process intensification
- Investigation, optimization and development of column internals
- Real and virtual experiments towards determination of process parameters in packed columns and fixed-bed reactors
- Investigation of transport phenomena in multiphase flows
- Investigation and optimization of heat exchangers
- Cooling and/or heating of electrical and mechanical engineering system elements

Currently, application of additive manufacturing (AM) in the fluid process engineering is expanding. It covers a broad application spectrum including optimized heat exchangers, micro-process engineering and efficient separation column internals. Above all, creation of completely new geometries, which would be even out of imagination because of manufacturing limitations, could be realized with the AM technique. This is where our Chair can contribute.

ADDITIONAL EQUIPMENT OF THE CHAIR

Equipment
- Pilot plant for absorption and desorption
- Pilot plant for investigation of single-phase convective heat transfer, pressure loss and evaporation in pillow-plate heat exchangers
- Experimental setup for investigation of condensation
- Experimental setup for investigation of heat exchangers
- Setup for investigation of exhaust gas recirculation (EGR) coolers

Software
- AspenONE®
- STAR-CCM+
- ANSYS Fluent
- Abaqus
- LabVIEW
- COMSOL Multiphysics®
- DeltaV

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Multiphase flows in complex geometries

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CFD simulation of heat transfer in complex geometry

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FINISHED RESEARCH PROJECTS (2015-2018)

Concept and Case Studies 2017 (CaCS 2017)

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DMRC DIRECT MANUFACTURING RESEARCH CENTER – RESEARCH INNOVATION EDUCATION

HEINZ NIXDORF INSTITUTE (HNI) - PRODUCT CREATION

HEINZ NIXDORF INSTITUT
UNIVERSITÄT PADERBORN

> Successful innovation requires a holistic approach in product creation – from strategic planning to digitalization of the entire process chain.
>
> Univ.-Prof. Dr.-Ing. Iris Gräßler

INTRODUCTION

The chair for Product Creation at Heinz Nixdorf Institute applies a holistic research approach in the context of AM.

Strategic Planning and Innovation Management

Synergies in entrepreneurial skills, product programs and customer structures are best developed if business policy is oriented towards a holistic entrepreneurial vision. We use and further develop methods such as the scenario technique in order to anticipate possible future developments. Our perspective covers aspects like business, political and social environment, industrial players, relevant key technologies and competitive situations. Taking future scenarios into account, we define search fields for product innovations. Thus, promising product ideas meet a high demand at market entry. Future implicit wishes of untapped customer groups will be anticipated in addition to articulated customer requirements. Our product understanding includes both material core product and related services.

Systems Engineering and Engineering Management

In order to convince end-users with a product innovation, one has to learn about the nature of product use, the prevailing conditions, and the profile of the targeted buyer group. One approach is to use application scenarios. These application scenarios are provided as inputs to product development. Once assumed boundary conditions as well as target costs and market entry date are regularly subjected to a premise controlling, the necessary changes are identified and taken into account at an early stage. With Systems Engineering and Engineering Management, we provide tools for the functional realisation and manufacturability of complex technical systems. We link the various disciplines with development methodologies such as V-model for mechatronic systems and INCOSE processes. We focus on effectiveness and efficiency of development and production processes.

Production Management

At the same time, we pay attention to the early consideration of manufacturability, for example, location and degree of automation. In our Smart Automation Lab, we validate prototypical "Industrie 4.0" implementations (i.e., "Factory of the Future" or "Smart Factory applications") with the help of communication networks, adaptivity and configurability.

Digital and Virtual Engineering

Methods and tools for Digitalisation and Virtualisation are key enabling technologies in the field of Product Creation. A holistic digitalization of the AM process chain is one aspect in focus of our research. In addition, Virtual and Augmented Reality serve as a tool for design and planning of modern, complex products of tomorrow.

ADDITIONAL EQUIPMENT OF THE CHAIR

Smart Automation Lab

- Decentralized production system (incl. agent-based scheduling)
- 5-axis machining centre, milling and turning machine
- Robotics (5-axis industrial robot, collaborative robot)
- Self-organizing logistics and transport system

Equipment for Digitalization (incl. VR/AR devices)

- VR equipment (Oculus Rift, HTC Vive)
- AR equipment (Microsoft Hollowlens)

Software Tools

- CAX (CATIA, Matlab,...)
- Modelling (MagicDraw,...)
- Management (PDM/PLM, ERP/MES,...)

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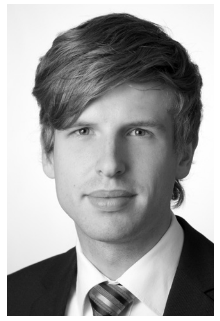

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Strategic Planning and Innovation Management

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Digitalization of Process Chain, incl. VR/AR

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CURRENT RESEARCH PROJECTS

OptiAMix - Multi-target optimized Product Development for Additive Manufacturing

RESEARCH LEADER — Univ.-Prof. Dr.-Ing. Iris Grässler

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Christian Oleff, M.Sc.

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MORE INFORMATION — page 76

FUNDED BY — Federal Ministry of Education and Research

FINISHED RESEARCH PROJECTS (2015-2018)

FOCUS – Active Strategy Implementation and Advancement

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MORE INFORMATION — page 36

FUNDED BY — DMRC Direct Manufacturing Research Center (Research, Innovation, Education)

DynAMiCS - Development of an Additive Manufacturing Potential Check System

RESEARCH LEADER — Univ.-Prof. Dr.-Ing. Iris Grässler

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FUNDED BY — DMRC Direct Manufacturing Research Center (Research, Innovation, Education)

University of Paderborn
Design and Drive Technology

DESIGN AND DRIVE TECHNOLOGY (KAt)

> It is important that we consider the fascinating possibilities and the relevant restrictions of additive manufacturing [...] consistently and systematically.
>
> Prof. Dr.-Ing. Detmar Zimmer

INTRODUCTION

The Chair of Design and Drive Technology is lead by Prof. Dr.-Ing. Detmar Zimmer. He received his doctorate in 1989 from the Institute of Machine Design and Gear Building at the University of Stuttgart. During his subsequent eleven years of industrial work at Lenze GmbH & Co. KG, Prof. Zimmer was initially responsible for development and later for the business unit geared motors, until he started working at the University of Paderborn in July 2001.

Focal points of the chairs work are theoretical and experimental investigations in the fields:

- electromechanical drive technology and
- additive manufacturing from a design perspective.

Key aspects in the field of electromechanical drive technology are the:

- reduction of the resources needed for the operation of drive systems, and their
- modularity against the background of intelligent variant management.

In the field of additive manufacturing we have the following goals:

- Systematic development of rules for a production-oriented design including post-processing aspects
- Design for tolerances
- Integration of additional functions , such as damping or cooling
- Adaptation of the design methodology with regard to design freedoms caused by additive manufacturing
- Optimization of drive 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

STAFF

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Field of Research
Design for Additive Manufacturing: Design rules

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Field of Research
Design for Additive Manufacturing: Electromagnetic flux

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Thorsten Koers, M.Sc.

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Design for Additive Manufacturing: Technology shuttle

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CURRENT RESEARCH PROJECTS

Additive Manufacturing of electric machines: Research on the potential of additive manufacturing in PM synchronous machine rotors

RESEARCH LEADER: Prof. Dr.-Ing. Bernd Ponick
Prof. Dr.-Ing. Mirko Schaper
Prof. Dr.-Ing. Detmar Zimmer

ASSISTENT: Sebastian Magerkohl, M.Sc.
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MORE INFORMATION: page 46

FUNDED BY: Deutsche Forschungsgemeinschaft – German Research Foundation

Concept and Case Studies 2017, 2018 and 2019

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MORE INFORMATION: page 30

FUNDED BY: DMRC – Direct Manufacturing Research Center (Research, Innovation, Education)

DMDR 3.0 - Updated and Extended DMRC Design Rule Catalog

RESEARCH LEADER: Prof. Dr.-Ing. Detmar Zimmer

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MORE INFORMATION: page 32

FUNDED BY: DMRC – Direct Manufacturing Research Center (Research, Innovation, Education)

OptiAMix - Multi-target-optimized product design for additive manufacturing

RESEARCH LEADER: Prof. Dr.-Ing. Rainer Koch
Prof. Dr.-Ing. Detmar Zimmer
Prof. Dr.-Ing. Iris Gräßler
Prof. Dr.-Ing. Thomas Tröster

ASSISTENT: Klaas Tuschen, M.Sc
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MORE INFORMATION: page 76

FUNDED BY: Federal Ministry of Education and Research

Combination and integration of established technologies with additive manufacturing processes in a single process chain (KitkAdd)

RESEARCH LEADER: Prof. Dr.-Ing. Detmar Zimmer
Prof. Dr.-Ing. Gisela Lanza

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MORE INFORMATION: page 52

FUNDED BY: Federal Ministry of Education and Research

FINISHED RESEARCH PROJECTS (2015-2018)

Dimensional Tolerances for Additive Manufacturing (DT-AM)

RESEARCH LEADER
Prof. Dr.-Ing. Detmar Zimmer
Prof. Dr.-Ing. Volker Schöppner
Prof. Dr.-Ing. H.-J. Schmid
Prof. Dr.-Ing. Thomas Tröster

ASSISTENT
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Dr.-Ing. Guido A. O. Adam
Frederick Knoop, M.Sc.
Dipl.-Wirt.-Ing Stefan Leuders
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FUNDED BY
DMRC – Direct Manufacturing Research Center

Additive Manufactured Function Integrated Damping Structures (AMFIDS)

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DMRC – Direct Manufacturing Research Center

Direct Manufacturing Design Rules 2.0 (DMDR 2.0)

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FUNDED BY
DMRC – Direct Manufacturing Research Center

Direct Manufacturing Design Rules (DMDR)

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FUNDED BY
DMRC – Direct Manufacturing Research Center

Lightweight construction of hydraulic clamping devices processed by SLM

RESEARCH LEADER
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Prof. Dr.-Ing. Detmar Zimmer

ASSISTENT
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FUNDED BY
FVA – Forschungsvereinigung Antriebstechnik e.V.

Soft magnet 3D-Print (FVA 731II) - Softmagnetic materials for additive manufacturing of electric drives

RESEARCH LEADER
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Prof. Dr.-Ing. Detmar Zimmer

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FUNDED BY
FVA – Forschungsvereinigung Antriebstechnik e.V.

Feasibility study 3D printing electric motors (FVA 731I)

RESEARCH LEADER
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FUNDED BY
FVA – Forschungsvereinigung Antriebstechnik e.V.

KUNSTSTOFFTECHNIK PADERBORN (KTP)

> The new Freeformer technology gives us the chance to create innovative milestones in new products and new opportunities.
>
> Prof. Dr.-Ing. Elmar Moritzer

> 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 thirty 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) and ARBURG Plastic Freeforming (APF).

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: Pendulum impact tester (HIT5.5P);
- Zwick Roell: Universal Testing Machine ProLine Z010 (10 kN, climatic chamber with elastic modulus);
- Zwick Roell: Universal Testing Machine 1446 (10 kN);
- ....further equipment see *page 138*

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Julian Wächter, M.Sc.

Field of Research
Fused Deposition Modeling (FDM): Fatigue Behavior and Material Development

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CURRENT RESEARCH PROJECTS

Processing of alternative FDM materials

RESEARCH LEADER: Prof. Dr.-Ing. Volker Schöppner, Prof. Dr.-Ing. Elmar Moritzer

ASSISTENT: Julian Wächter, M.Sc..

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MORE INFORMATION: page 40

FUNDED BY: DMRC

Fused Deposition Modeling with Metal Powder Filled Filaments

RESEARCH LEADER: Prof. Dr.-Ing. Elmar Moritzer

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MORE INFORMATION: page 26

FUNDED BY: DMRC

Development of Design and Manufacturing Guidelines for Arburg Plastic Freeforming

RESEARCH LEADER: Prof. Dr.-Ing. Elmar Moritzer

ASSISTENT: Andre Hirsch, M.Sc..

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MORE INFORMATION: page 60

FUNDED BY: DFG Deutsche Forschungsgemeinschaft – German Research Foundation

Research of Innovative and Breakthrough Additive Manufactured Leading-edge Concept

RESEARCH LEADER: Prof. Dr.-Ing. Elmar Moritzer

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MORE INFORMATION: page 80

FUNDED BY: Clean Sky 2

FINISHED RESEARCH PROJECTS (2015-2018)

FDM-structures for the partial reinforcement of hybrid structures

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ASSISTENT: Andre Hirsch, M.Sc..

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FUNDED BY: DMRC

Long-term Properties of High Temperature FDM Material

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FUNDED BY: DMRC

Development and Optimization of Additively Manufactured Tool Components for a High-Speed Forming Process

RESEARCH LEADER: Prof. Dr.-Ing. Volker Schöppner

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MORE INFORMATION: page 58

FUNDED BY:

Material development of non-reinforced and fiber-reinforced polymers for Fused Deposition Modeling

RESEARCH LEADER: Prof. Dr.-Ing. Volker Schöppner

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MORE INFORMATION: page 74

FUNDED BY: Ministerium für Wirtschaft, Innovation, Digitalisierung und Energie des Landes Nordrhein-Westfalen

Fatigue Behavior of FDM and LS Parts

RESEARCH LEADER	Prof. Dr.-Ing. Volker Schöppner
ASSISTENT	Dr.-Ing. Matthias Fischer
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FUNDED BY	

DMRC DIRECT MANUFACTURING RESEARCH CENTER RESEARCH INNOVATION EDUCATION

ADDITIONAL EQUIPMENT OF THE CHAIR

Equipment

- Zwick Roell: Universal Testing Machine 1474 (50 kN);
- 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)

AUTOMOTIVE LIGHTWEIGHT CONSTRUCTION (LiA)

www.Leichtbau-im-Automobil.de

> Die Additive Fertigung hat in den letzten Jahren stark an Fahrt aufgenommen und die ersten Serienanwendungen stehen in den Startlöchern. Gerade durch die Anwendungen in der Automobilbranche, wird sich die additive Fertigung weiter in der Industrie verankern. Es ist schön zu sehen, dass Deutschland hier als Technologieführer diese Entwicklung mit bestimmt.
>
> Prof. Dr.-Ing. Volker Schöppner

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

Regarding the technical 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. 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

- Matlap 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)
- 3D Optical measurement for elongation- and deformation analysis (Aramis GOM)
- High Speed tensile test equipment – Zwick HTM8020
- 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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SLM Parameter Development

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CURRENT RESEARCH PROJECTS

Additive manufactured lightweight structures for civil aircraft components

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MORE INFORMATION page 48

FUNDED BY

Federal Ministry
for Economic Affairs
and Energy

OptiAMix - Multi-target optimized Product Development for Additive Manufacturing

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MORE INFORMATION page 76

FUNDED BY

Federal Ministry
of Education
and Research

Effect of defect

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MORE INFORMATION page 34

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DMRC DIRECT MANUFACTURING RESEARCH CENTER RESEARCH INNOVATION EDUCATION

MatCharact

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DMRC DIRECT MANUFACTURING RESEARCH CENTER RESEARCH INNOVATION EDUCATION

FINISHED RESEARCH PROJECTS (2015-2018)

Meltpool Monitoring

RESEARCH LEADER Prof. Dr. Thomas Tröster

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HighTemp SLM

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DMRC DIRECT MANUFACTURING RESEARCH CENTER RESEARCH INNOVATION EDUCATION

Medium Carbon Steels

RESEARCH LEADER Prof. Dr.-Ing. Mirko Scharper

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DMRC DIRECT MANUFACTURING RESEARCH CENTER RESEARCH INNOVATION EDUCATION

Fatigue strength properties of SLM components

RESEARCH LEADER Prof. Dr. Thomas Tröster
Prof. Dr. Hans Albert Richard

ASSISTENT Prof. Dr. Thomas Tröster
Dr.-Ing. Andre Riemer

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FUNDED BY

Ministerium für
Kultur und Wissenschaft
des Landes Nordrhein-Westfalen

LWK
Lehrstuhl
für Werkstoffkunde

CHAIR OF MATERIAL SCIENCE (LWK)

> 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 dis-equilibrium conditions and transitions between different phases and alloys, like iron-silver alloys - to elements that are immiscible with conventional casting processes - are investigated. Using selective laser melting both metals are processable which results in a new alloy where small silver islands are embedded stochastically in the iron matrix. This alloy might be applicable in biomedical applications, such as stents, intramedullary nails, screws or osteosynthesis plate.
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

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)
- ....further equipment see *page 149*

STAFF

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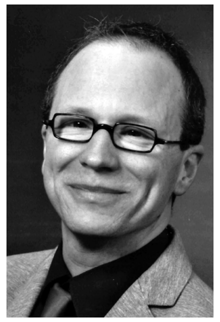

Dr.-Ing. Kay-Peter Hoyer

Field of Research
Alloy development,
AM for biomedical applications

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RESEARCH ASSISTENTS

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Material characterization

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AM alloys for lightweight applications

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Maxwell Hein, M.Sc.

Field of Research
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Alloy Development

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AM alloy development, Material characterization, Hybrid materials

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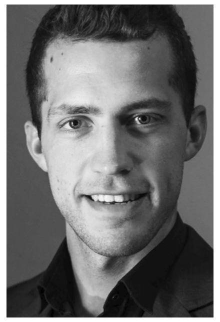

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AM implementation in electromobility,
Soft magnetic materials

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CURRENT RESEARCH PROJECTS

Investigation of the effect of residual stresses and roughness of additive manufactured components on the coatability and fatigue strength of the composite system

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MORE INFORMATION page 70

FUNDED BY

Deutsche Forschungsgemeinschaft
German Research Foundation

Surface Inoculation of Aluminium Powders for Additive manufacturing guided by Differential Fast Scanning Calorimetry

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MORE INFORMATION page 82

FUNDED BY

Deutsche Forschungsgemeinschaft
German Research Foundation

Additive Manufacturing of electric machines: Research on the potential of additive manufacturing in PM synchronous machine rotors

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MORE INFORMATION page 46

FUNDED BY

Deutsche Forschungsgemeinschaft
German Research Foundation

Development and characterization of biodegradable FeMnAg-materials used for the SLM-process

RESEARCH LEADER Prof. Dr.-Ing. Mirko Schaper

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MORE INFORMATION page 62

FUNDED BY

Deutsche Forschungsgemeinschaft
German Research Foundation

Coating of Near-Net Shaped Additively Manufactured Components with Biocompatible Properties

RESEARCH LEADER Prof. Dr.-Ing. Mirko Schaper

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MORE INFORMATION page 50

FUNDED BY

Deutsche Forschungsgemeinschaft
German Research Foundation

Innovative Alloying Concepts for Additive Manufacturing

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EUROPEAN UNION
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EFRE.NRW
Investitionen in Wachstum und Beschäftigung

Ministerium für Wirtschaft, Innovation, Digitalisierung und Energie des Landes Nordrhein-Westfalen

Material characterization – mechanical and corrosive performance of SLM parts

RESEARCH LEADER Prof. Dr.-Ing. Mirko Schaper

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FUNDED BY

DMRC
DIRECT MANUFACTURING RESEARCH CENTER
RESEARCH INNOVATION EDUCATION

FINISHED RESEARCH PROJECTS (2015-2018)

Additive manufacturing of medium carbon steels and a CoCr-alloy

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DMRC – DIRECT MANUFACTURING RESEARCH CENTER – RESEARCH INNOVATION EDUCATION

High Temperature Processing of Metallic SLM Powders

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DMRC – DIRECT MANUFACTURING RESEARCH CENTER – RESEARCH INNOVATION EDUCATION

Light-weight construction: Robust simulation of complex loaded cellular structures

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DMRC – DIRECT MANUFACTURING RESEARCH CENTER – RESEARCH INNOVATION EDUCATION

Ministerium für Innovation, Wissenschaft und Forschung des Landes Nordrhein-Westfalen

Adhesive and Corrosion Properties of Laser Molten Fe-alloy Moulds for Polymer Proceeding

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DMRC – DIRECT MANUFACTURING RESEARCH CENTER – RESEARCH INNOVATION EDUCATION

Ministerium für Innovation, Wissenschaft und Forschung des Landes Nordrhein-Westfalen

Soft magnetic alloys for additive manufacturing of electric motors

RESEARCH LEADER Prof. Dr.-Ing. Mirko Schaper

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FUNDED BY

FVA Forschungsvereinigung Antriebstechnik e.V.

High Temperature Fatigue Behavior of Nickel based Superalloys Manufactured by Selective Laser Melting

RESEARCH LEADER Prof. Dr.-Ing. Mirko Schaper

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DFG Deutsche Forschungsgemeinschaft – German Research Foundation

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, Infra-Tec)
- 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 (PVT)

PVT

> 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 of particulate systems, the production, conditioning and manipulation of those 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 of gaseous or liquid. These systems show a complex behavior, sometimes called the 'fourth state of aggregation'. In particular, for very small particles, the particle-particle interactions become dominant for the the behavior of such systems.

The Particle Technology Group is involved in both fundamental and applied research. We have a strong focus on understanding the behavior of particulate systems and to learn how to produce requested particulate property in a final product. Therefore, doing fundamental, publicly funded research is considered to be equally important as cooperation's 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:

- Particle synthesis
- Aerosol particle formation
- Characterization of particles and dispersed systems
- Polymere Laser Sintering process analysis
- Quality management systems for LS processes
- Qualification of polymer material for LS production
- Precipitation / crystallization in liquids
- Analysis of particle size distribution and particle structure
- Analysis of powder properties, e.g. bulk flow properties, bulk density
- Rheology of suspensions
- Analysis of multi-phase flows, e.g. measuring velocity fields
- Handling and manipulation of particulate systems and products
- Production of composite materials
- Filtration and separation
- Dispersion and mixing technology
- Interface phenomena and nano-particulate systems like carbon coatings

ADDITIONAL EQUIPMENT OF THE CHAIR

Dispersion

- Multi Frequency-Ultrasonic Bath - Elma Transsonic TI-H5

Interfacial properties

- Drop Volume Tensiometer - Krüss DVT50
- Bubble Pressure Tensiometer - Krüss BP2
- Ring- or Plate Tensiometer - Lauda TE1C

Material properties

- Pycnometer – Multivolume Micromeritics 1305
- Jenike Shear Tester
- Instron 5569 EH Universal Testing System

Particle size analysis

- Laser Diffraction Spectrometer - Malvern Mastersizer 2000 and Sympatec Helos Vario F
- 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
- Sieve analysis
- Sedimentation Balance
- Scanning Mobility Particle Sizer (SMPS) - TSI
- Goniometer (Combined Static-Dynamic Light Scattering) – ALV-GmbH – ALV/CGS3
- 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

Crushing

- Cutting Mill - Retsch SM2000
- Stone Mill - Fritsch Pulverisette
- Stirring Ball Mill - Netzsch LabSta
- ....further equipment on our homepage: *https://mb.uni-paderborn.de/pvt/*

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CURRENT RESEARCH PROJECTS

VERONIKA - Efficient and Interconnected Product and Production Development for Aircraft Passenger Cabins

(Subproject: Additive Lightweight Structures for the Aircraft Cabin)

RESEARCH LEADER: Prof. Dr.-Ing. H.-J. Schmid

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FUNDED BY: Federal Ministry for Economic Affairs and Energy

LS Polyamide for High Temperature Applications – Long term behavior of PA613 / PA613 3.0

RESEARCH LEADER: Prof. Dr.-Ing. H.-J. Schmid

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FUNDED BY: DMRC – Direct Manufacturing Research Center (Research, Innovation, Education)

TPE-A Laser Sintering Material and Part Properties – Qualification for New Applications

RESEARCH LEADER: Prof. Dr.-Ing. H.-J. Schmid

ASSISTENT: Christina Kummert, M.Sc.

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FUNDED BY: Federal Ministry for Economic Affairs and Energy

Manufacturing Technology – Additive Manufacturing for the production of polymeric components

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FUNDED BY: FVA Forschungsvereinigung Antriebstechnik e.V.

FINISHED RESEARCH PROJECTS (2015-2018)

LS Polyamide for High Temperature Applications – Potentials of PA613/ PA613 2.0

RESEARCH LEADER: Prof. Dr.-Ing. H.-J. Schmid

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FUNDED BY: DMRC – Direct Manufacturing Research Center (Research, Innovation, Education)

Surface Topography Analysis and Enhancement of Laser Sintered Parts (STEP)

RESEARCH LEADER: Prof. Dr.-Ing. H.-J. Schmid

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FUNDED BY: DMRC – Direct Manufacturing Research Center (Research, Innovation, Education)

QuLS: Qualification of Laser Sintering Serial Production

RESEARCH LEADER: Prof. Dr.-Ing. H.-J. Schmid; Prof. Dr.-Ing. Rainer Koch

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MORE INFORMATION: page 42

FUNDED BY: DMRC – Direct Manufacturing Research Center (Research, Innovation, Education)

D-TAM: Dimensional tolerances for additive manufacturing

RESEARCH LEADER: Prof. Dr.-Ing. Detmar Zimmer

ASSISTENT: Tobias Lieneke, M.Sc.; Frederick Knoop, M.Sc.; Dr.-Ing. Stefan Josupeit

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FUNDED BY: DMRC – Direct Manufacturing Research Center (Research, Innovation, Education)

TECHNICAL AND MACROMOLECULAR CHEMISTRY (TMC)

INTRODUCTION

The chair is divided into the research areas

- „Adhesion and Corrosion Science“
- „Interfacial Engineering of Advanced Materials“
- „Nanotechnology and Nanomaterials“
- „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 analysis of interfacial processes and measurement of molecular forces at interfaces as well as molecular and macromolecular nanostructuring. In addition, new chemical and electrochemical film-forming processes for highly resistant interfaces of composite materials and composites are being developed, and plasma technology supported by the adjustment of adjacent solid surfaces. Research in the field of biomaterials and nanobiomaterials focuses on issues of biocompatibility, corrosion, protein adsorption and nanostructuring.
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 the years 2017 to 2018, the working group published fundamental findings on the growth and defect formation in plasma coatings on polymeric substrates as well as on the adhesion behavior of highly abrasion-resistant ternary nitride coatings as part of SFB TRR87. In addition, atomic force microscopy was successfully used to elucidate dispersion forces and coordinate bonds to technically relevant oxides. The Nanobiomaterials research area focused on various aspects of biomolecular self-assembly in 2017 and 2018. These include, in particular, fundamental studies of the stability of DNA origami nanostructures in application-specific media, surface-catalyzed amyloid aggregation, and pharmaceutically-relevant protein-ligand interactions. Another field of research is the hierarchical assembly of DNA origami masks for molecular lithography.

In addition to publicly funded research projects, the Laboratory for Material and Corrosion Analysis is available for direct cooperation between industry and professors.
The aim is to provide the project partners with as comprehensive information as possible, which goes well beyond the usual pure analytical services. Thus, the solution of the question is always in the center of the investigations. The data are evaluated at the TMC against the background of the respective industrial question and the conclusions and conclusions are developed in cooperation with the client.

In the field of teaching, events are offered for the faculties of mechanical engineering and natural sciences in the fields of technical chemistry, electrochemistry, interfacial chemistry, surface analysis and biomaterials

ADDITIONAL EQUIPMENT OF THE CHAIR

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

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Dr. Juan Carlos Calderón Gómez

Field of Research
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Richard Grothe, M.Sc.

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CURRENT RESEARCH PROJECTS

SFB-TR87: Pulsed high power plasmas for the synthesis of nanostructured functional layers

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SFB-TR 87

SPP 2122: Materials for Additive Manufacturing

RESEARCH LEADER	Prof. Dr.-Ing. Guido Grundmeier
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FUNDED BY	

MATframe SPP 2122 Materials for Additive Manufacturing

Design of microstructure and degradation behavior of oxide-particle modified Fe-based alloys processed by selective electron beam melting

RESEARCH LEADER	Prof. Dr.-Ing. Thomas Niendorf Prof. Dr. Hans Jürgen Maier Dr. Florian Nürnberger Prof. Dr. Guido Grundmeier
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DFG Deutsche Forschungsgemeinschaft German Research Foundation

FINISHED RESEARCH PROJECTS (2015-2018)

Development and qualification of a test for electrochemical rapid testing of corrosion-stressed adhesive bonds

RESEARCH LEADER	Prof. Dr.-Ing. Guido Grundmeier
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Federal Ministry for Economic Affairs and Energy

DATABASE AND INFORMATION SYSTEMS (DBIS)

> We do research on model-based software development and quality assurance methods that are precise and applicable in practice for the innovative software systems & services of tomorrow!
>
> Prof. Dr. Gregor Engels

INTRODUCTION

The great challenge of modern software development is to systematically implement the diverse requirements of users in complex software systems. To overcome this challenge, models on different levels of abstraction are used on the way from the problem definition to the software product. This modelling makes the complexity of the development task controllable and allows for a systematization of the development process. Models for software development are therefore central research topics of the database and information systems group.

The spectrum of our research ranges from the formal basis of visual and domain-specific modelling languages to analytical approaches for quality assurance of models and software and their practical application in current technology areas such as web services, software product lines, socio-technical systems, and service-oriented architectures. Based on established industry standards such as UML, SysML, and XML, we develop modelling techniques, concepts and methods for future software generations. By analysing models with formal techniques, we can detect, visualize and correct errors early on. Our development tools thus provide an active contribution for quality improvement in software development. Following a holistic approach of quality software engineering, we link model-based and generative software development with requirements engineering and management, domain modelling, human-centred design methods, software architecture management and evolution, adaptive systems technology, data analytics and quality models.

Within the collaboration of the DMRC, we are expanding the cooperation between mechanical engineering and informatics. By applying the methods for analysis and modelling of problems, the processes in additive manufacturing can be further optimized.

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PUBLICATIONS

CONTENT

BOOKS AND JOURNALS

2019

Gräßler, I.; Oleff, C.; Scholle, P. (2019): Priorisierung von Anforderungen für die Entwicklung mechatronischer Systeme. In: Fachtagung Mechatronik 2019: Paderborn, 1-6.

Moritzer, E.; Bürenhaus, F.; Hirsch, A. (2019): Advancing into New Dimensions. In: Kunststoffe international, Volume 109, Issue 3, 48-52.

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Moritzer, E.; Hirsch, A.; Heim, H.-P.; Cherif, C.; Truemper, W. (2019): Plastic droplet welding: bond strength between plastic freeforming structures and continuous fiber-reinforced thermoplastic composites. In: Welding in the World, Volume 63, Issue 3, 867–873.

2018

Alexander, J.; Künneke, T.; Lieneke, T.; Baumann, T.; Stricker, N.; Zimmer, D.; Lanza, G. (2018): Iterative Produktentwicklung und Produktionsplanung für die Additive Fertigung. In: ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb 113(11), 742-745.

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Brüggemann, J.-P.; Risse, L.; Grübel, A.; Richard, H. A.; Kullmer, G. (2018): Validierung der strukturmechanischen Funktionsfähigkeit durch experimentelle Bauteilprüfungen additiv gefertigter Leichtbaustrukturen. In: DVM-Bericht 250, Arbeitskreis: Bruchmechanische Werkstoff- und Bauteilbewertung: Beanspruchungsanalyse, Prüfmethoden und Anwendungen, Paderborn, 89-98.

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Brüggemann, J.-P.; Risse, L.; Kullmer, G.; Schramm, B. Richard, H. A. (2018): Optimization of the fracture mechanical properties of additively manufactured EN AW-7075. In: Procedia Structural Integrity, Volume 13, 311-316.

Brüggemann, J.-P.; Risse, L.; Richard, H. A.; Kullmer, G. (2018): Einflussfaktoren auf Bauteilgüte lasergeschmolzener Strukturen. In: DVM-Bericht 251, Arbeitskreis: Bruchmechanische Werkstoff- und Bauteilbewertung: Beanspruchungsanalyse, Prüfmethoden und Anwendungen, Deutscher Verband für Materialforschung und -prüfung e.V., Paderborn, 207-218.

Dsuban, A.; Lohn, J.; Brüggemann, J.-P.; Kullmer, G. (2018): Entwicklung und Umsetzung eines Qualitätssicherungskonzeptes für die additive Fertigung. In: DVM-Bericht 403, Arbeitskreis: Additiv gefertigte Bauteile und Strukturen: Berlin.

Joy, T.D.; Brüggemann, J.-P.; Kullmer, G. (2018): Crack growth simulation with Adapcrack3D in 3D structures under the influence of temperature. In: Procedia Structural Integrity, Volume 13, 328-333.

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Knoop, F.; Lieneke, T.; Schöppner, V.; Zimmer, D. (2018): Additive Fertigung nach Maß. In: Kunststoffe, 06/2018, 70-73.

Kummert, C.; Josupeit, S.; Schmid, H.-J. (2018): Thermoplastic Elastomer Part Color as Function of Temperature Histories and Oxygen Atmosphere During Selective Laser Sintering. In: The Journal of The Minerals, Metals & Materials Society (TMS), March 2018, Volume 70, Issue 3, 425–430

Risse, L.; Schramm, B.; Brüggemann, J.-P.; Woodcock, S. C.; Kullmer, G.; Richard, H.A. (2018): CAE-gestützte Optimierung eines Hüftimplantats durch Ausnutzung der Potentiale additiver Fertigungsverfahren. In: DVM-Bericht 403, Arbeitskreis: Additiv gefertigte Bauteile und Strukturen, Berlin, 89-100.

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2017

Brüggemann, J.-P.; Risse, L.; Riemer,A.; Reschetnik, W.; Kullmer,G.; Richard, H.A. (2017): Entwicklung von Fahrradtretkurbelsystemen mittels additiver Fertigung. In: Richard H., Schramm B., Zipsner T. (Hrsg.): Additive Fertigung von Bauteilen und Strukturen. Springer Vieweg, Wiesbaden.

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Menge, D.; Josupeit, S.; Schmid, H.J. (2017): Herstellbarkeit und mechanische Charakterisierung von lasergesinterten Gitterstrukturen. In: Richard H., Schramm B., Zipsner T. (Hrsg.): Additive Fertigung von Bauteilen und Strukturen. Springer Vieweg, Wiesbaden,105-120.

Reiher, T.; Lindemann, C.; Jahnke, U. et al. (2017): Holistic approach for industrializing AM technology: from part selection to test and verification. In: Progress in Additive Manufacturing. June 2017, Volume 2, Issue 1–2, Heidelberg, 43–55.

Taube, A.; Reschetnik, W.; Pauli, L.; Hoyer, K.-P.; Kullmer, G.; Schaper, M. (2017): Numerische und mechanische Untersuchung additiv gefertigter TiAl6V4 Gitterstrukturen. In: Richard H., Schramm B., Zipsner T. (Hrsg.): Additive Fertigung von Bauteilen und Strukturen. Springer Vieweg, Wiesbaden. 201-214.

Schöppner, V.; Schumacher, C.; Guntermann, J. (2017): Beurteilung der Schweißnahtfestigkeiten verschiedener Kunststoffe im FDM-Prozess. In: Jahresmagazin Kunststofftechnik, 2017, 108-114.

2016

Aydinöz, M.E.;Brenne, F.;Schaper, M.;Schaake, C.; W. Tillmann; Nellesen, J.; Niendorf, T. (2016): On the microstructural and mechanical properties of post-treated additively manufactured Inconel 718 superalloy under quasi-static and cyclic loading. In: Materials Science and Engineering: A, Volume 669, 246-258.

Delfs P.; Tows M.; Schmid, H.J. (2016): Optimized build orientation of additive manufactured parts for improved surface quality and build time. In: Additive Manufacturing, Volume 12, Part B, 314-320.

Hickmann, T.; Ahlers, D.; Fulland, N. (2016): Neue Prototypen-Werkzeugtechnologie für Bipolarplatten und Batteriekomponenten. In: Der Stahlformenbauer: Velbert.

Josupeit, S.;Delfs, P.; Menge, D.; Schmid, H.J. (2016): Herstellbarkeit und mechanische Charakterisierung von lasergesinterten Gitterstrukturen. In: Richard, H.A.; Schramm, B.; Zipsner, T. (Hrsg.): Additive Fertigung von Bauteilen und Strukturen, Springer Vieweg: Wiesbaden, 105-120.

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DISSERTATIONS

2019

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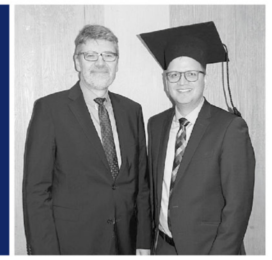
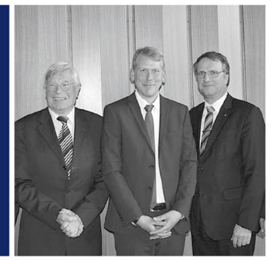
THE DMRC CONGRATULATES THE FOLLOWING COLLEAGUES ON THEIR DOCTORAL EXAMINATION.....

Dr.-Ing.
Stefan Josupeit
(April 2019)



Dr.-Ing.
Matthias Fischer
(April 2019)

Dr.-Ing.
J.-P. Brüggemann
(April 2019)



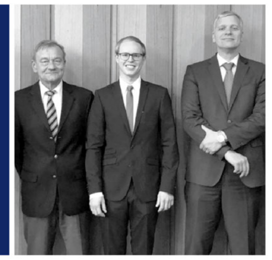
Dr.-Ing.
Ulrich Jahnke
(March 2019)

2019

Dr.-Ing.
Mehmet E. Aydinöz
(Nov. 2018)

Dr.-Ing.
Thomas Reiher
(Oct. 2018)

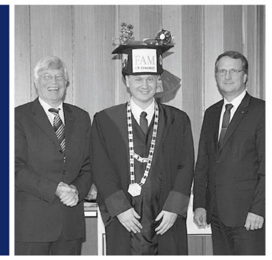
Dr.-Ing.
Gereon Deppe
(Oct. 2018)



2018

Dr.-Ing.
Chr. Lindemann
(Oct. 2017)

Dr.-Ing.
Wadim Reschetnik
(Oct. 2017)



2017

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