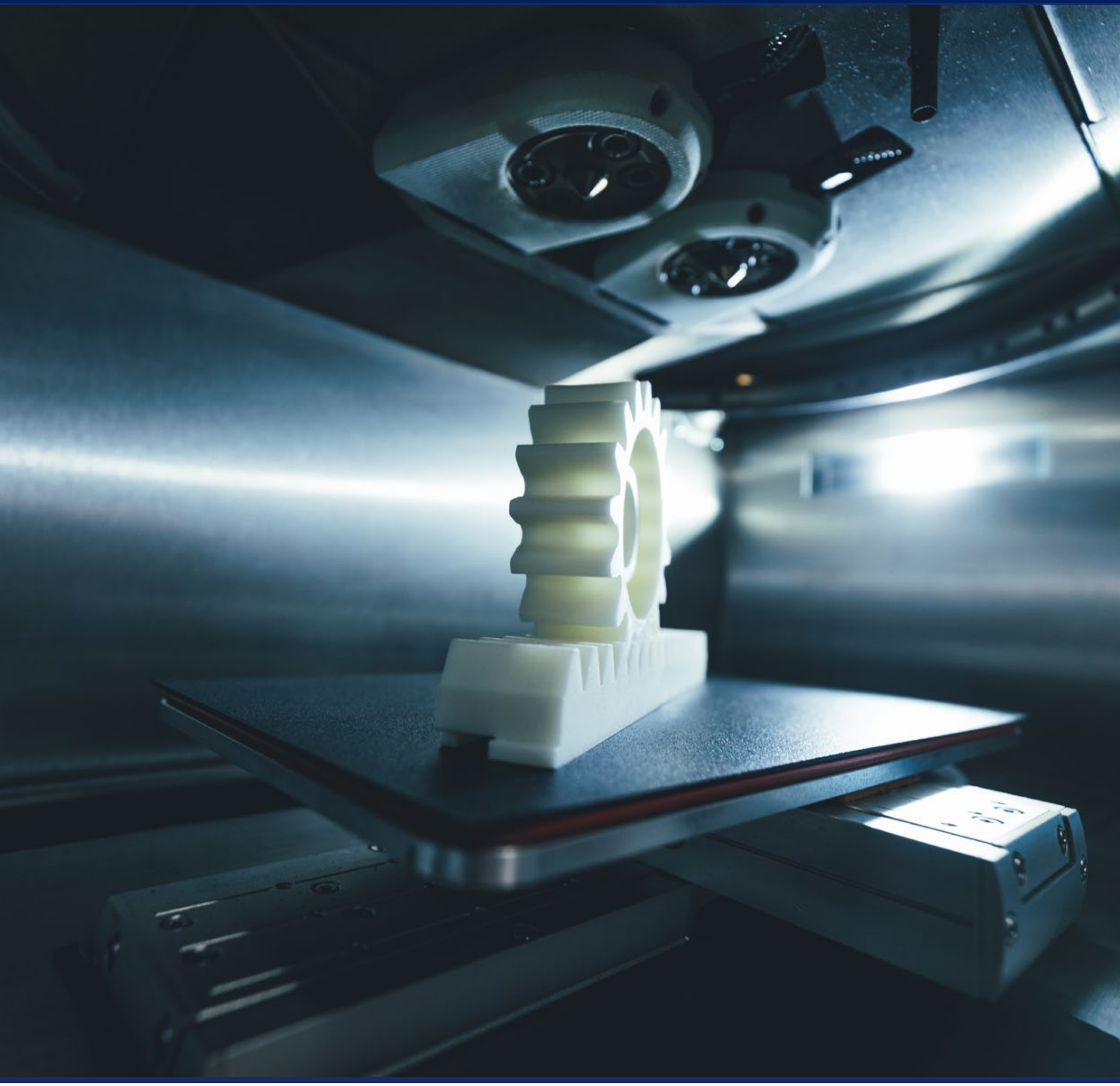
DMRC

DIRECT MANUFACTURING RESEARCH CENTER

RESEARCH
INNOVATION
EDUCATION

Report 20/21



PADERBORN UNIVERSITY
The University for the Information Society

PIAF
PADERBORN INSTITUTE FOR ADDITIVE FABRICATION

© 2021 Direct Manufacturing Research Center (DMRC)
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Text
DMRC staff and members

Sources
Page 4, 33, 129, 160, 166, 192 - Designed by pikisuperstar/ Freepik”

FOREWORD

Dear members and friends of the DMRC,

once again, a year in the fast-evolving world of additive manufacturing has passed by. In the last year the way we work, the way we collaborate and the way we interconnect has changed in a major way. Going hand in hand with these challenges, we could see a global push in terms of digitalization by which we were affected in in all parts of our life.

Additive manufacturing itself has moved in the public spotlight during the pandemic. The technology was able to demonstrate how we can bridge the gap in shortages of global supply chains. The DMRC started a collaboration to support local hospitals based their requirements. Due to the donations of EOS and Evonik and the involvement of multiple local companies (e.g., Condor Group, LST, Centroplast) we were able to donate 4.700 laser sintered faceshields to local medical institutions for free in the last year.

In summary one can say the past month have been on the sign of change. We believe that the AM community will benefit from a more digitized world, where the benefits of the technology can be utilized in a better way. Some of the DMRC highlights of the last year:

We were able to install multiple new production and post processing technologies:
- Post processing unit Multivibrator AM 2 from Walther Trowal
- Base material production in SLM / LS / FDM

We have introduced new manufacturing technology at the Paderborn University:
- DED - Powder Nozzle Lasertech 65
- DLP Process

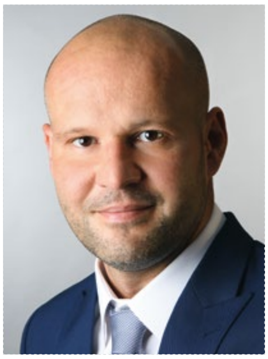
We were able to welcome two new partners in our consortium:
- The Condor Group and one of our very own startup companies, Additive Marking

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

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ABOUT THE DMRC

CONTENT

THE DIRECT MANUFACTURING RESEARCH CENTER

MOTIVATION AND AIM

Additive manufacturing processes create parts in layers and without using formative tools. In many industries this technology may have a highly 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.
- **Economic freedom:** Additive manufacturing decouples the part manufacturing costs from the part quantity and the part complexity.

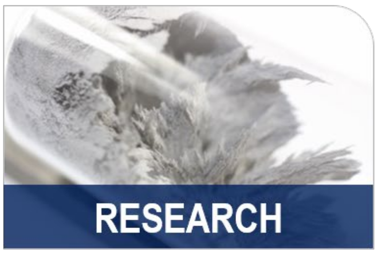
Because these freedoms often exceed the freedoms provided by established manufacturing technologies, additive manufacturing can create various and great benefits to its users. Contrary to this, it is recognized that the technology is mainly used at technology leading companies and research institutes. 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.

AIM

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



INVOLVED CHAIRS AND INSTITUTES

FACULTY OF MECHANICAL ENGINEERING

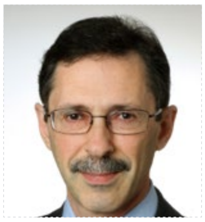
Automotive Lightweight Construction

Prof. Dr. rer.nat
T. Tröster

Chair of Materials Science

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

Chair of Fluid Process Engineering



Prof. Dr.-Ing.
E. Kenig

Computer Application in Design & Planing

Prof. Dr. -Ing.
R. Koch

Design an Drive Technology

Prof. Dr.-Ing.
D. Zimmer

Heinz Nixdorf Institute (HNI)

Prof. Dr.-Ing.
I. Gräßler

Institute of Applied Mechanics

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

Institute of Applied Mechanics

Prof. Dr.-Ing. habil.
H. A. Richard

Particle Technology Group

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

Kunstofftechnik Paderborn

Prof. Dr.-Ing.
E. Moritzer

Kunststofftechnik Paderborn

Prof. Dr.-Ing.
V. Schöppner

FACULTY OF SCIENCE

Technical & Macro Molecular Chemistry

Prof. Dr.-Ing.
G. Grundmeierr

FACULTY OF COMPUTER SCIENCE

Chair of Database & Information Systems

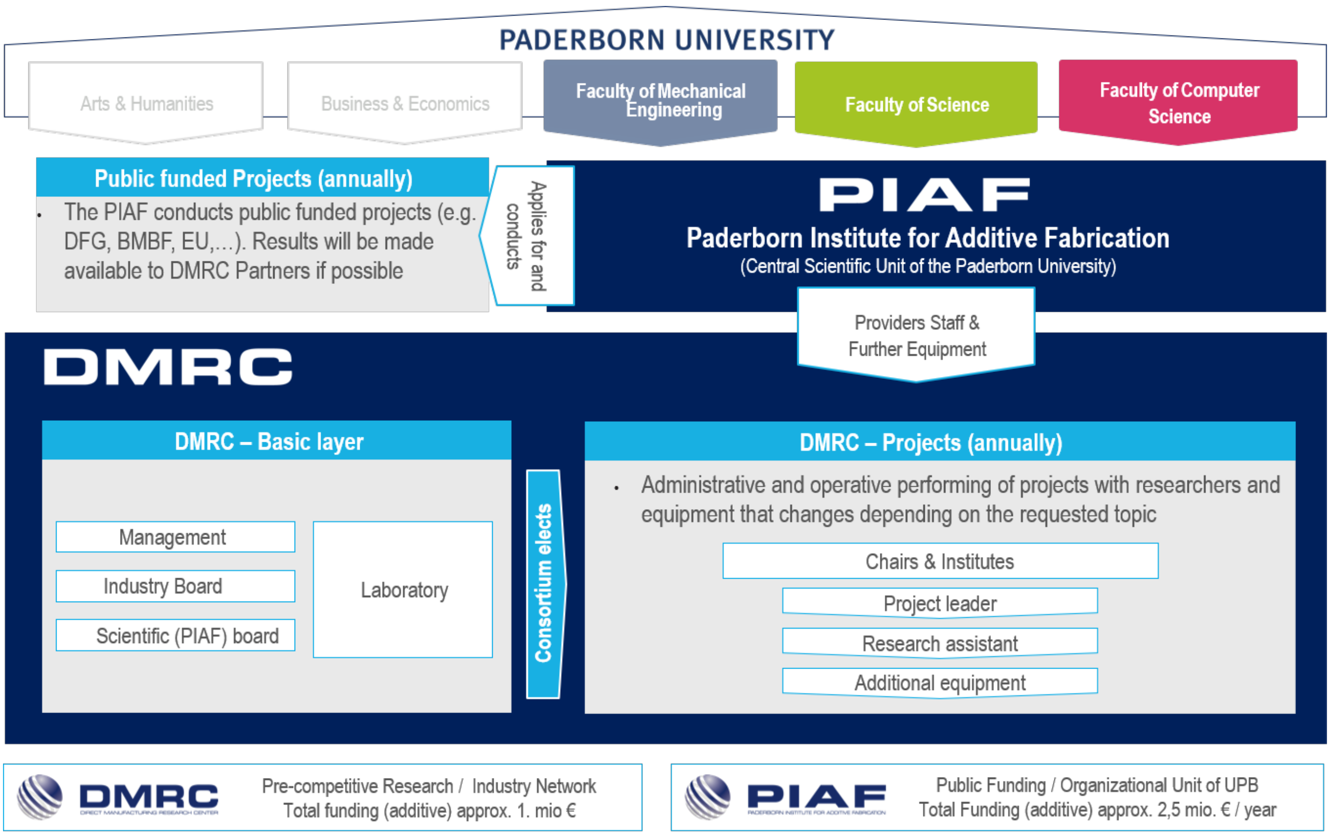
Prof. Dr.
G. Engels

STRUCTURE OF THE DMRC & THE PIAF

The additive manufacturing technology implies that needs to be handled comprehensively. This goes along with the fact that several very different disciplines need to be covered: materials science, particle technology, process understanding, mechanics, applications, design, software support and business, just to name some examples.

In addition, the research and development focus will change over time from one discipline to another. In Paderborn we wanted to meet the following goals:

- Our structure needs to be interdisciplinary
- Our structure needs to be flexible



Dr. Christian Lindemann, Prof. Dr. Hans-Joachim Schmid, Vice President Simone Probst, Dominik Schulte (Condor), Klaus-Peter Jansen (it's OWL) and Dr. Gereon Deppe (Amendate) informed the public about AM at the PIAF foundation meeting

To fulfill these requirements, we are structured in different layers and into two different organizational units organized around the Paderborn University. The Paderborn University with over 20,000 students and its five faculties builds the Basis for all additive manufacturing related activities with the two different organizational units: the **DMRC** and the **PIAF**.

The DMRC represents the industrial community in the setup. Stakeholders from the whole AM process chain have united here and define a strategic research agenda. From the DMRC membership fees, the industry network defines common research projects mainly in the field of precompetitive research. The projects and the project goals are defined by the industrial consortium. The additive manufacturing research projects are carried out at the Paderborn University, coordinated by the Paderborn Institute for Additive Manufacturing. Due to the strong industrial background these projects are mainly application-oriented research projects. The companies driving these projects are often enabled to directly utilize these results in their commercial activities.

The Paderborn Institute for Additive Fabrication (PIAF) is a central scientific unit at the Paderborn University. Based on the knowledge that access to transdisciplinary research and innovation has become an indispensable competitive factor in additive manufacturing, the Paderborn Institute for Additive Manufacturing participates in innovation projects with partners from science and industry. The tasks of the PIAF consist of interfaculty and interdisciplinary cooperation, especially in research, teaching, the qualification of young scientists and the transfer of knowledge and technology in the field of additive manufacturing processes. In addition, the transfer of knowledge and technology between science and industry is also part of the tasks. Research at PIAF is characterized by the fact that research results are achieved through intensive cooperation between the chairs, institutes, and other research centers. The PIAF represents the AM related academic part of the Paderborn University. Public funded research projects are conducted by this organizational unit. The research activities range from basic research to application-oriented research projects. Furthermore, the PIAF carries out the projects defined by the DMRC consortium based on contractual research.


picture: H&H

WORKING GROUPS & COMMITEES

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

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

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

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

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

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

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

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

WORKING GROUPS

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

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

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

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

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

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

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

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

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

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

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

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

PARTNER & NETWORKS

Being part of a network often provides benefits and possibilities that cannot be obtained individually. We believe that therefore – besides fundamental and applied research – the DMRC provides an excellent network.
At its core, this network is formed by a research community that is comprised of technology leading industrial partners representing all disciplines along the value chain of Additive Manufacturing. That way our research results are based on the needs of experienced AM users. The results then are utilized or commercialized by the industry partners. The network furthermore 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 finding sand innovations are just a few points our partners benefit from.

ADVANTAGES OF A DMRC MEMBERSHIP

- Benefit from collaboratively financed research and leverage you own research funds (short- to mid-term goals)
- Collaborate in publicly funded research projects (long term goals)
- Cooperate with recognised AM-Experts from industry and academia
- Get access to our state of the art of production & test equipment - use the DMRC as „extended workbench“
- All our partners can promote student theses over the DMRC. These will be supervised by the DMRC staff.
- Recruit qualified employees which are experts in additive manufacturing (Students / Scientific Staff / PHD‘s)
- We are a solution provider offering a flexible and interdisciplinary structure
- Benefit from over 10 years of experience in additive manufacturing & get access to our knowledge base

RESEARCH

- PADERBORN UNIVERSITY – The University for the Information Society
- Mobility goes Additive
- VDMA
- it's owl
- BDLI
- VDI

DESIGN & MATERIAL

- EVONIK – POWER TO CREATE
- Heraeus
- BASF
- AME
- HEXAGON | MSC Software
- ADDITIVE MARKING

PRODUCTION

- eos – e-Manufacturing Solutions
- SLM SOLUTIONS
- bigrep
- assonic
- AMPROVED – SMART SOLUTIONS FOR ADDITIVE MANUFACTURING

SERVICE PROVIDERS & END-USERS

- AKG
- Centroplast – Engineering Plastics GmbH
- JOHN DEERE
- METTLER TOLEDO
- rembe
- Baker Hughes
- CONDOR GROUP
- PORSCHE
- SAC FS Stükerjürgen
- VOITH
- BOEING
- KRAUSE DiMaTec
- PROTIQ – A Phoenix Contact Company
- SIEMENS
- WALTHER TROWAL

Partner 2021

Associated networks

DMRC Spin-Offs

EQUIPMENT

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

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

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

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


PMRC

Powder Bed Fusion

picture: SLM

LASER SINTERING LS

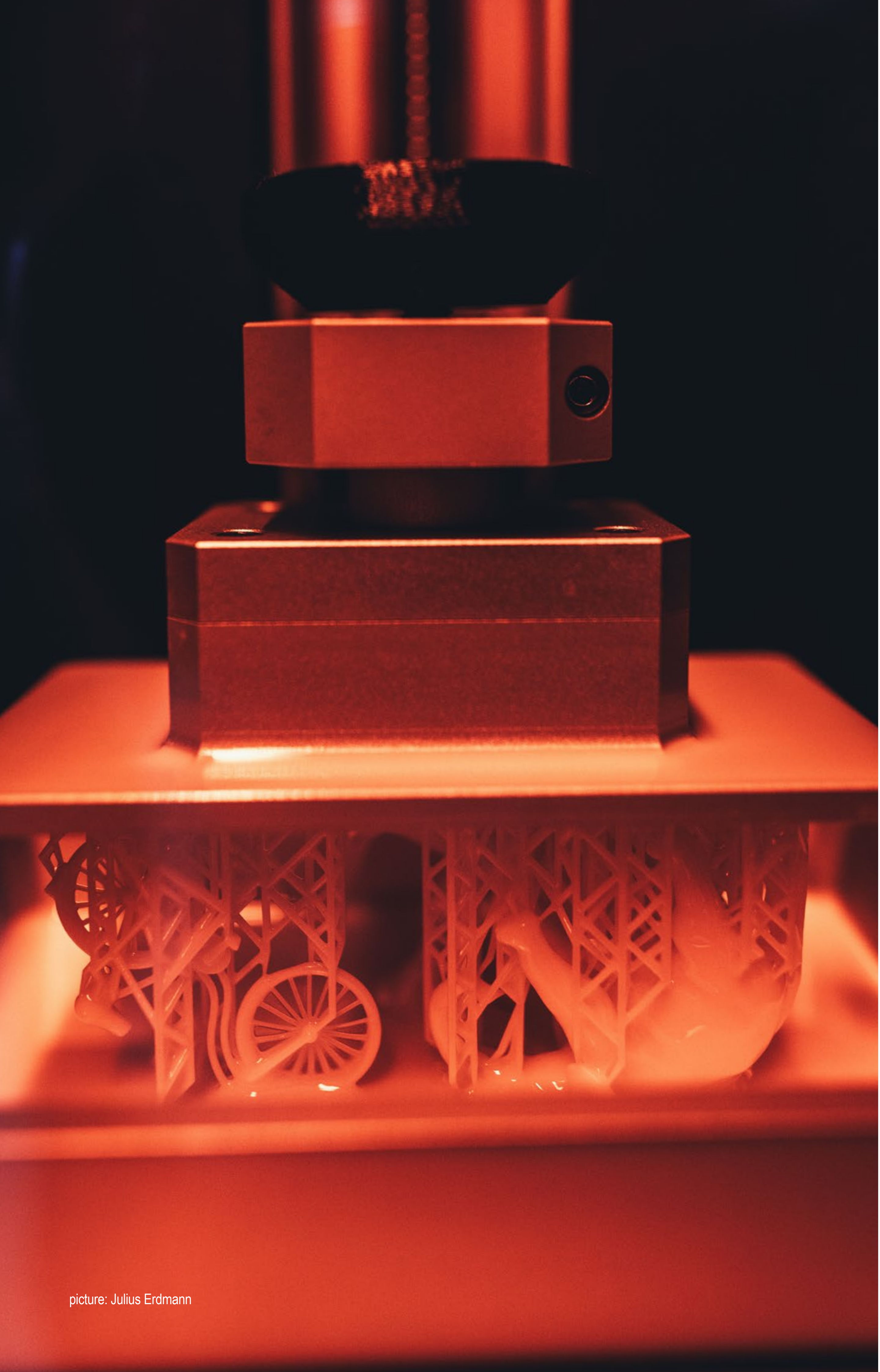
EOISINT P395
EOISINT P396
EOISINT P396 HIGH TEMP.
SINTERIT

picture: EOS

LASER MELTING

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

picture: Matthias Groppe



picture: Julius Erdmann

Material Extrusion and Vat Photopolymerisation

picture: BigRep

picture: Gewo3D

FUSED DEPOSITION MODELING

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

picture: Arburg

ARBURG PLASTIC FREEFORMING

ARBURG FREEFORMER (2x)

picture: Henkel

DIGITAL LIGTH PROCESSING

EQ PR10 PRINTER
EQ CL36 CURE CHAMBER
EQ WASHER DW11

Measurement

picture: Zwick

PHYSICAL AND CHEMICAL ANALYSIS

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

MECHANICAL ANALYSIS

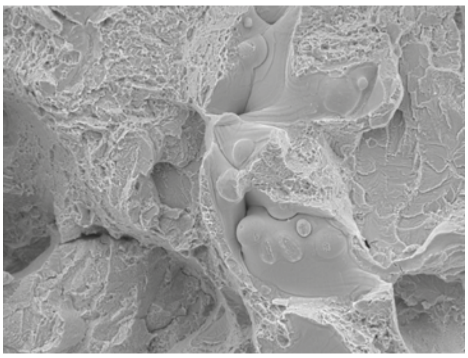
INSTRON 5569
TEST RIG FOR BENDING VIBRATIONS
ZWICK HB 250
ZWICK HC 10

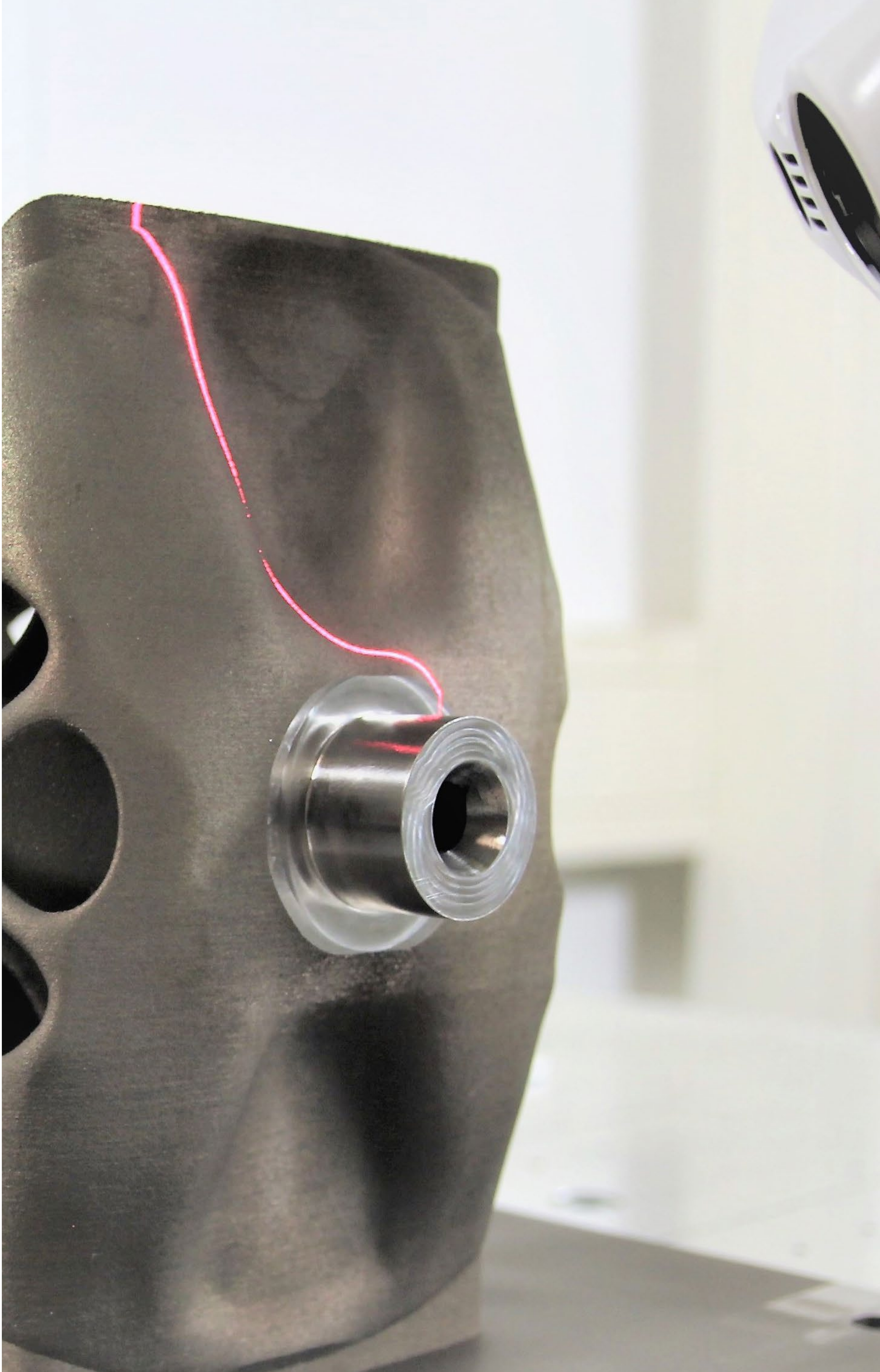
GEOMETRICAL ANALYSIS

HOMMEL ETAMIC T80000
NIKON ALTERA 8.7.6

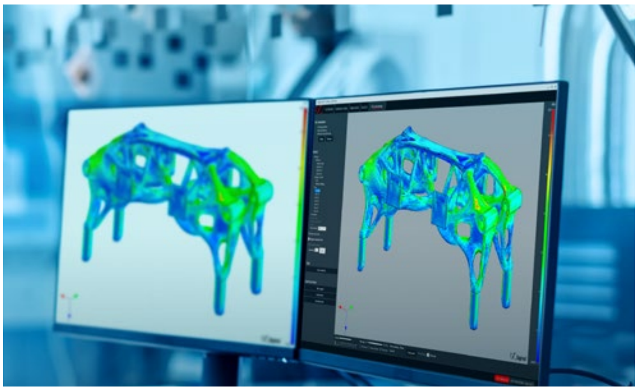
OPTICAL ANALYSIS

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





AM Related Software Solutions



DESIGN

SOLIDWORKS

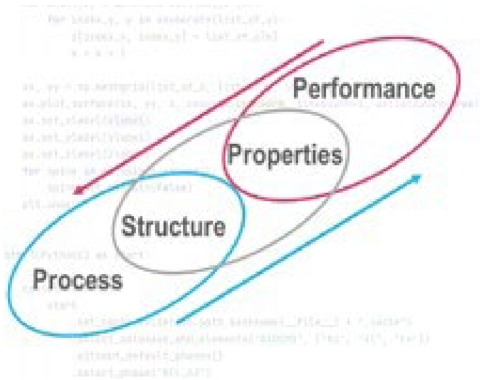
GENERATIVE DESIGN

APEX GENERATIVE DESIGN

picture: Additive Marking

DIGITAL IDENTITY

ADDITIVE MARKING SUITE



SIMULATION TOOLS

ANSYS
ABAQUS
THERMOCALC

Material Production & AM-Specific Post Processing

SLM POWDER

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

LS POWDER

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

picture: Thermo Fisher

FILAMENT EXTRUSION

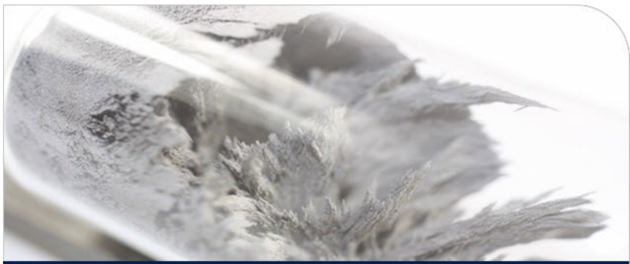
EXTRUSION OF ADVANCED POLYMERS
EQUIPMENT:
• MINI TWIN-SCREW EXTRUDER
• MELTING PUMP
• HAUL-OFF BELT
• MEASURING UNIT
• WINDER

picture: Walter Trowal

SURFACE FINISHING

PWALTER TROWAL AM 2 MULTIVIBRATOR

DIRECT MANUFACTURING RESEARCH CENTER (DMRC)



MATERIALS AND PROCESS

DESIGN – METHODOLOGIES

APPLICATIONS

INDUSTRIALIZATION & EDUCATION

» 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

Fields of research

As 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 chairs help 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 utilising 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).

STAFF

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Prof. Dr. Hans-Joachim Schmid

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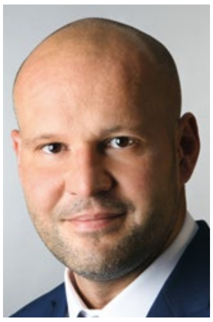
MANAGING DIRECTOR



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START UP'S

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

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

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

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

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

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

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

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

STATEMENTS

VOITH

We appreciate the DMRC as a group of strong partners who tackle and solve common challenges in additive manufacturing. The annual project cycle ensures that tangible research results are always achieved in the near future.

Robin Hohe
Master of ScienceJ.M. Voith SE & Co. KG
Innovation Manager
Additive Manufacturing

SIEMENS

To the question "what is the DMRC?" I once answered: "The DMRC is the preferred research center for Additive Manufacturing of Boeing, Porsche and Siemens."

I am still convinced of the advantages of the DMRC:
Nowhere else can we cover such an extensive research spectrum in such depth and speed and, due to the interdisciplinary collaboration approach, with the economic efficiency at hand.

Maximilian Kunkel
Doctor of Engineering (TUT; ZA)
Siemens Mobility GmbH
R&D Project Manager &
Senior Key Expert AM Technologies

BASF We create chemistry | FORWARD AM

For us as a material suppliers, the DMRC consortium is very important to get feedback on our new materials and suggestions for new developments. With its broad spectrum of machine manufacturers, material producers and end users in additive manufacturing, it is the perfect forum for developing new applications and processes under industrial criteria. In doing so, we very much appreciate the open and direct exchange between all partners.

Florian Fischer
Doctor of chemistryBASF 3D Printing Solutions
Business Developent Manager &Industry
Manager Consumer

With its consistent focus on establishing industrial production with additive manufacturing, the DMRC fills a gap in the global research landscape. Since its founding in 2009, it has become a much respected institution, both numerically and figuratively; in particular, its proximity to industrial partners leads to practical results, exciting lectures, and graduates who are highly sought after in industry. A well-rounded success story!

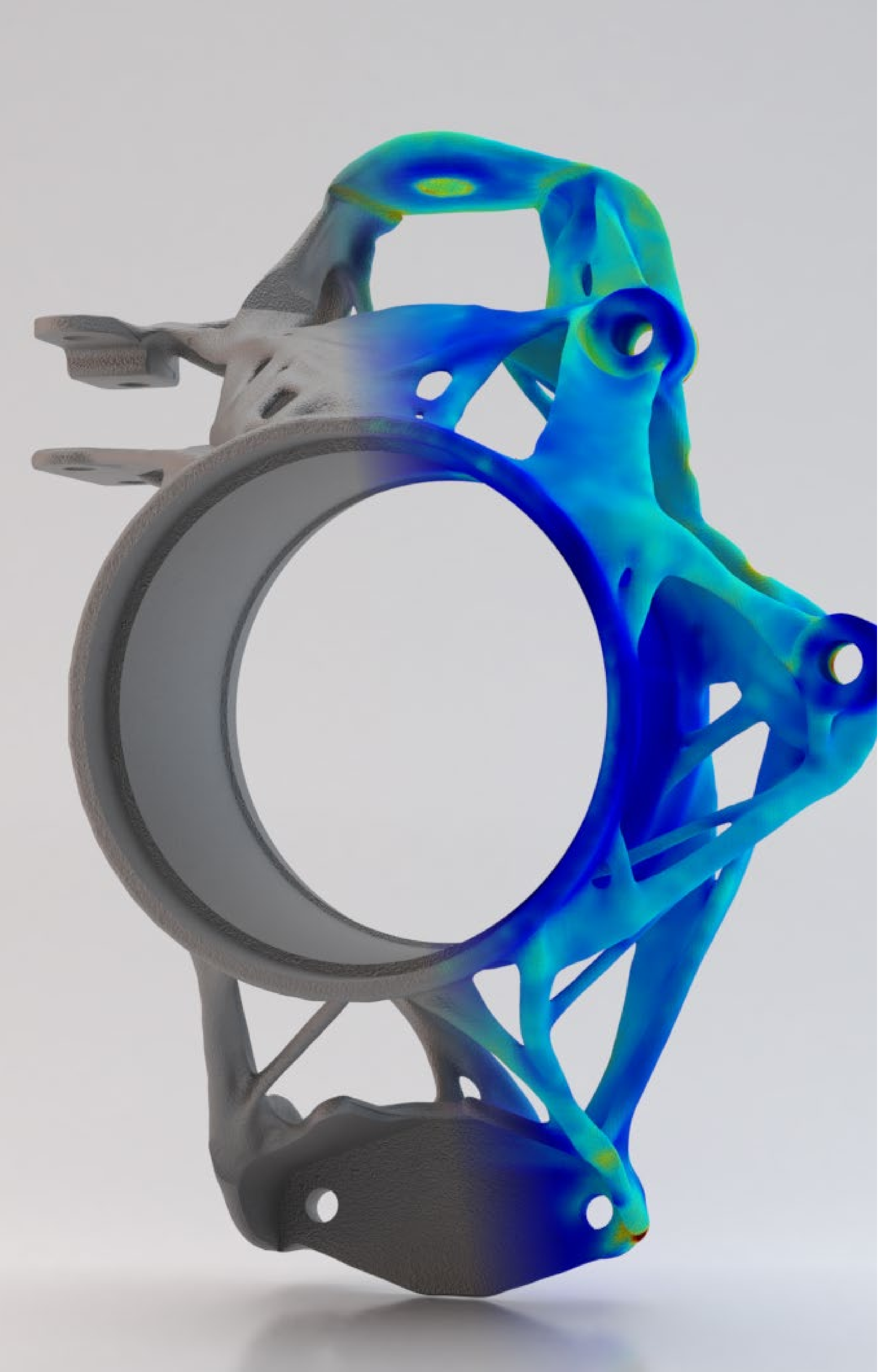
Sylvia Monsheimer
Evonik Operations GmbH
Head of Industrial Printing & N3D

Since we are primarily concerned with the opportunities and challenges of the technologies in relation to our products and processes, it is essential for us to work out the basics and the outlook together with partners.

The DMRC offers a consortium that is very strongly positioned with all relevant partners such as material manufacturers, machine manufacturers and post-processing, both in plastics and metal. Furthermore, access to the institutes relevant to us, such as materials technology or design, opens up the development of complex interrelationships.

Thanks to the open and agile collaboration in overarching cooperation projects or also bilaterally, we can develop the basic principles necessary for us and incorporate them into our projects. Access to publicly funded projects also gives us the opportunity to put the foundations on a broad basis. We also use the knowledge we gain for the internal training of our staff.

Falk Heilfort
Dr. Ing. h.c. F. Porsche AG
Entwicklungsingenieur Entwicklung Antrieb
Vorentwicklung Triebstrang und Elektrifizierung



RESEARCH

CONTENT

DMRC FUNDED PROJECTS

ASSESSMENT AND ENHANCEMENT OF THE PROCESSABILITY OF TPU IN FDM

The processing of soft materials in the FDM process brings new challanges for the process execution. Studies have already shown that the definition of the process parameters and, above all, the existing design limitations do not necessarily correspond to those of the processing of typical FDM polymers. Reasons for this are the soft elastic behavior of the deposited strands as well as the material behavior before and inside the extrusion head. This project identifies and improves the process limitations by selecting suitable geometries. At the same time, the process parameters are also adapted to the processing of a soft FDM material. Based on this, a procedure will be developed with which a material- and machine-independent improvement of the processing of TPU in FDM can be achieved.

PROJECT OVERVIEW

DURATION

05/2021 – 12/2021

PARTNER

Industrial Consortium of DMRC

FUNDED BY

Industrial Consortium of DMRC

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DMRC DIRECT MANUFACTURING RESEARCH CENTER – RESEARCH INNOVATION EDUCATION

Motivation

For the design process as well as for the dimensioning of an additively manufactured component it is important to know the underlying process limits and ideally the design guidelines. In order to support users of additive manufacturing technologies in the design process, a number of research activities have been carried out at the DMRC in the last years. Initially, hard materials such as ABS-M30 and Ultem 9085 were in the focus of the investigations regarding Fused Deposition Modeling (FDM). However, the ongoing developments in the field of additive manufacturing also lead to the expansion of available materials and machines. Thus, the demand for materials with specific properties is also constantly increasing. One of these materials are Thermoplastic Polyurethanes (TPU), which have a soft elastic material behavior. Possible fields of application include their use as sealing inserts. For this purpose, the FDM process must be mastered when processing these soft materials, and the limitations of the processing must be known.
In this context, investigations have shown that the already developed and existing procedure for determining the design guidelines cannot be transferred to soft TPUs without adaptions. One issue is that some of the test specimens from the investigations for hard materials cannot be manufactured without restrictions using soft materials. Furthermore, the investigations have revealed that the potential of TPUs in FDM cannot be fully exploited with the standard process parameters used for processing soft materials.

Aim

Due to the partly special material behavior of soft thermoplastics, new process limits arise in the FDM. These process limits are to be determined and extended in this research project by simultaneously optimizing the FDM process parameters. The optimization of the process parameters is carried out for a selected soft material on only one machine. However, since the variety of materials and machines in FDM is increasing, the development of a method for parameter optimization and determination of design limits of soft materials is the focus of this research project. This should guarantee a high transferability to other machines and soft materials for the users of the technology. The overall objective of this research

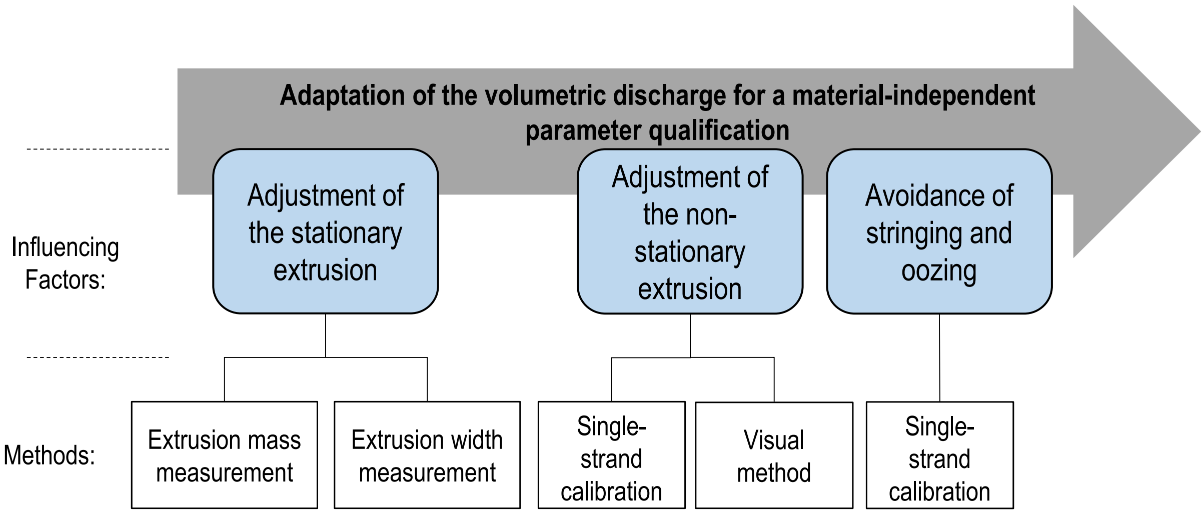

FIGURE 1 Procedure for the qualification of relevant process parameters

project is to develop a new method for optimizing the processability of soft materials in FDM with respect to process limits and design guidelines.

Determination of design limitations

The basis for the investigations is the selection of a suitable TPU material. Here, a TPU with a Shore hardness of 85A is selected. This material, which is considerably soft with regard to the FDM process, is expected to allow the procedure developed to be transferred to other, harder materials.

On that basis, the existing procedure for determining process limits and design guidelines is used first. For this purpose, the already existing test specimen geometries (e.g. for overhang angles, minimum wall thicknesses, unsupported construction height, etc.) are produced using the standard parameters available for the selected material. The analysis of the results focuses on the difficulties in processing soft materials. In addition, parallel to this, approaches are being developed to counteract these process limits and difficulties in processing in the FDM process. Test specimens, which do not seem to be useful for the processing of soft materials, will be adapted and further developed.

Optimization of process parameters

The optimization of the processing parameters is necessary to improve and extend the existing process limitations. When adjusting the parameters, the experience gained by the DMRC in recent years is applied and, if necessary, adapted to the special needs of the soft material. Thereby, the stationary and non-stationary movement of the FDM head as well as the movement of the FDM head without material discharge are considered. The result is a homogeneous strand geometry in a reliable manufacturing process which demonstrates and expands the possible areas of application for processing TPU in FDM. The optimization steps are performed by an iterative procedure with continuous validation of the results.

Derivation of a procedure for the processing of TPU in FDM

Based on the improved processing of the soft material, a methodology can be derived. The aim is to obtain a guideline for the processing of generally soft materials in FDM, with which a transfer to other materials and machines is possible. This should enable the users of the FDM-technology to rapidly improve the processing of other soft materials on the specific machines.

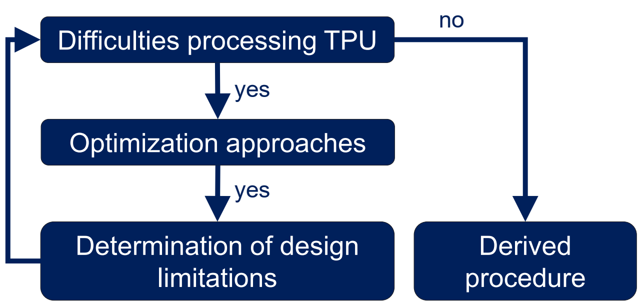

FIGURE 2 Project approach to develop a procedure for processing TPU materials in FDM

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 focus is on "Embedded Sensors" to implement certain sensors within components that are manufactured in the Laser Beam Melting process (LBM).

PROJECT OVERVIEW

DURATION

2017 / 2018 / 2019
(one year each)

PARTNER

Industrial Consortium of DMRC

FUNDED BY

Industrial Consortium of DMRC

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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 the potentials of AM 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. With a focus on

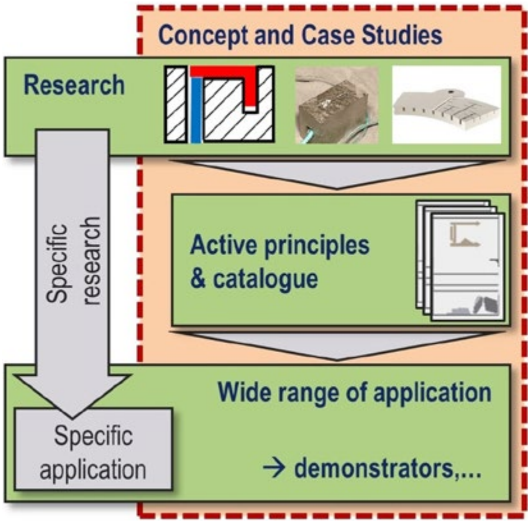

FIGURE 1 Project concept and process phases

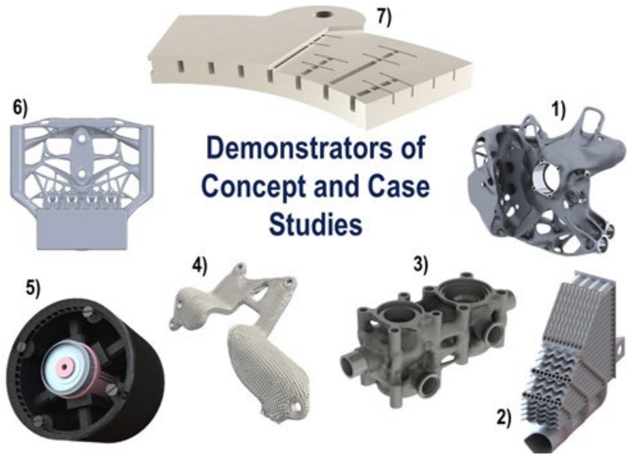

FIGURE 2 Selection of demonstrators developed in CaCS

the application in the design process, a clear and uniform form of presentation is 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 general 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 gain that experience for the corresponding subject area, industrial demonstrator components are optimized and analysed using a design for AM ( ). 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), structural optimization (3) and combinations of both topics (1 & 6). In the following year the topics magnetic flux guidance (5) and structure damping (4) were investigated. Due to the generic approach and the use of function-orientated active principles, the application of the active principles is not limited to the demonstrators. They have a broad applicability and can be used in various components and application fields.

Results in 2019

In the field of sensor embedding, it was shown in 2019 that the three-dimensional freedom of design and the layer-by-layer build-up of additive manufacturing can be used specifically to integrate sensors within components. For this purpose, geometric and thermal boundary conditions were defined for the selection of sensors in order to provide the necessary sensor characteristics for a target-oriented embedding. The location and shape of the cavities must be taken into account in the design to insert the sensor at a specific location and with a specific orientation. Experimental tests have shown that various aspects have to be considered when designing the cavities and channels of the sensor cables in order to be able to perform the embedding process reliably and easily. The possibilities for the integration of further functions, such as cable strain relief, are taken into account. Additional challenges during implementation are the removal of powder, the embedding process in the build chamber and the process-related temperatures during manufacturing. Furthermore, temperature measurements of embedded sensors during the manufacturing process have been recorded in order to be able to make predictions about the minimum temperature resistance of the sensors and actuators which have to be embedded.

As a demonstrator a thrust washer of a brake was designed (7). During operation, the thrust washer is in contact with rotating friction linings. The occurring friction leads to a heating of the thrust washer. By embedding a large number of thermocouples, distributed underneath the entire friction surface, it was possible to implement a temperature monitoring system which can detect local temperature peaks.

Based on these findings, active principles and design guidelines were identified which support the user in embedding sensors during the LBM manufacturing process.

HYDRAULIC -, PNEUMATIC COMPONENTS

Additive Manufacturing (AM) is a technology enabling the engineers to increase the function and efficiency of designs. The idea of this project is to develop generic design studies that are relevant to the members´ application needs, run analysis, collect performance data and report the benefits. Thus, the project idea is adapted year by year with facing new challenges or harnessing further potentials of AM. This year the project considers hydraulic- and pneumatic powder bed AM parts and assemblies. General feasibility and limitations in design and manufacturing for hydraulic or pneumatic parts shall be analyzed for Polymer Laser Sintering and Selective Laser Melting as well.

PROJECT OVERVIEW

DURATION

01/2020 – 12/2020

PARTNER

Industrial Consortium of DMRC

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Industrial Consortium of DMRC

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Introduction

Limits of applications should be clarified for the adaptation and utilization of additive manufacturing technologies for hydraulic or pneumatic components. AM can be used for pressurized, storage and distributing applications. The use of metal AM technologies is hereby most prominent for pressurized applications, whereby polymer parts show promising performance and cost benefits for storage and distributing use cases. Especially for polymers the influences of environmental interaction as media exposure has to be analyzed in more detail. Thus, for the implementation of polymer laser sinter parts in fluid contact applications, the material behavior in the given environment need to be analyzed in more detail. The here obtained information will be used for a case study part, which shall demonstrate the benefit of additive manufacturing and utilize the obtained information of the investigated material properties and post processing methods.

Experimental approach

First of all, information on general requirements from conventional manufacturing should be analyzed in order to incorporate these into the development of AM hydraulic components. Further, suitable test procedures are selected.

As all laser sintering materials are well known from conventional manufacturing methods, the chemical resistance and stress crack resistance is known as well. However, laser sinter parts have a higher crystallinity, rougher surfaces and some porosity. Therefore, the knowledge of conventional chemical material resistance should be validated. For the validation different LS materials are exposed to different substances and changes in especially the physical properties (mechanical, thermal, optical, etc.) immediately after immersion storage for different dwell times and temperatures are investigated. In addition, the effect on the manufacturing specific part structure is examined more in detail in dependence of different manufacturing parameters and design aspects.
These might be the microstructure or the part surface as well and will be compared to injection molding parts. Ideally, some processing guidelines for improved stability can be derived.

Design guidelines

Although the great design freedom of AM manufacturing offers new potential and some design rules already exist for the processes under investigation, certain limitations must be taken into account. For helping designers, some guidance for fluid transmitting parts shall be developed. For laser sintering, at a minimum the minimal wall thickness at fluid tightness are analyzed and determined. Furthermore, post processing methods for powder cleaning are considered for those investigations. For selective laser melting, samples are manufactured in different diameters and orientations to test the component in a destroying pipe test by internal pressure, as well as to identify the minimal thickness for fluid tightness.

Case study

The information of the previous investigations will be evaluated and shall be used for a case study part. Hereby, the material restrictions as well as the new and general design guidelines for polymer LS parts will be applied and utilized in a laser sintering technology part, e.g. fluid distribution, transfer or storage. For the SLM technology a pressurized part will be developed, as well emphasizing the benefits of AM design for hydraulic parts. Thus, the case study part will be a fictive part combining multiple benefits of the AM technology for the given application.

Overall aim

The overall aim, is to find limitations of additive manufacturing in hydraulic or pneumatic components and to create processing and design guidelines for these applications.

FIGURE 1 Storage test on the functional behaviour towards different media

DMDR 3.0 – UPDATED AND EXTENDED DMRC DESIGN RULE CATALOGUE

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 "Updated and Extended DMRC Design Rule Catalogue – DMDR 3.0" is aimed to extend the exisiting DMRC Design rule catalogue by six machine-material-parameter-combinations of the participating industry partners.

PROJECT OVERVIEW

DURATION

01/2019 – 12/2019

PARTNER

Industrial Consortium of DMRC

FUNDED BY

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Objectives

The aim of the projects "Direct Manufacturing Design Rules" (DMDR 1.0 and 2.0) is to develop 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. Because of their dependance on these parameters, 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 rules 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, the range of validity is extended by new combinations of material, manufacturing machines and parameters. Thus, the DMRC Design Rule Catalogue is enhanced by six further pillars of the project DMDR 3.0 (Figure 1).To extend the range of validity, the following work packages are defined:

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

The DMRC selects the most relevant design rules from the method of DMDR 1.0. The industrial partners select on free choice six preferred combinations, which they frequently use in their companies or intend to use in the future.
After the definition of all boundary conditions the process specific CAD-Files and a description of the manufacturing of the test specimens are sent to the participating industry partners, in order

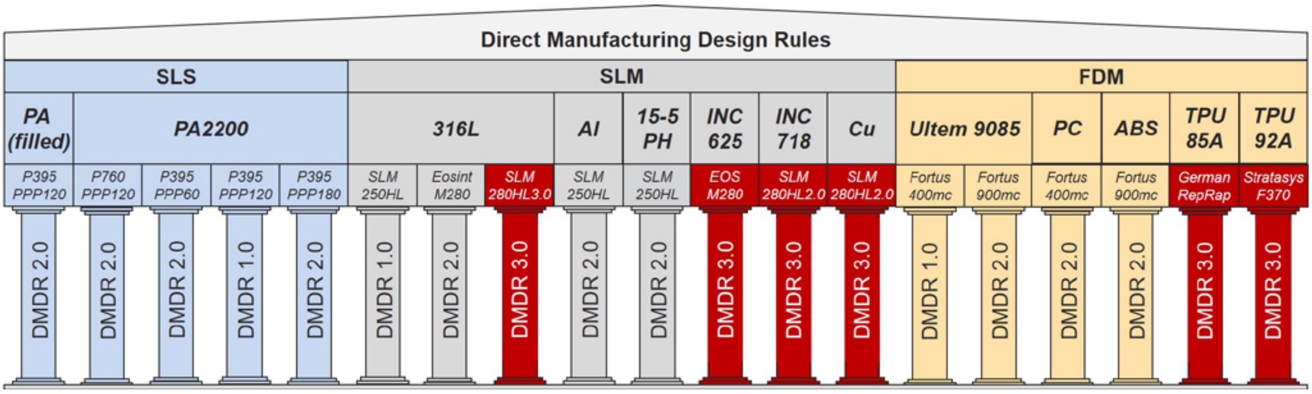

FIGURE 1 Schematic display of the range of validity for the design rules developed in projects DMDR 1.0 and DMDR 2.0, enhanced by the design rules of project DMDR 3.0

to guarantee the same methodical procedure for manufacturing. Thus the selected test specimen are ranked into uncritical and critical. Taking this differentiation into account, two build jobs are created and the related test specimens are placed on the building platforms. This allows failure-free manufacturing of the non-critical test specimens and simultaneous monitoring of all critical test specimens.

In order to enable a statistical evaluation and to increase the significance of the results, the test specimens are build 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 catalogue

As part of the second work package, the DMRC design design rule catalogue developed in DMDR 1.0 and 2.0 is adapted to the results of the DMDR 3.0 project. The results of work package 1 are integrated into the respective design rules with a note on the respective combination. This process is accompanied by the analysis whether the respective design rule is relevant for the examined boundary conditions. If necessary, the previous design rule catalogue is also extended by further design rules for required combinations.

The result of the project DMDR 3.0 is a design rule catalogue with an extended range of validity (Figure 1). With the design rules and the specific limit values it is possible to realize a robust component design for a multitude of combinations. The catalogue 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 catalogue. Furthermore, this offers the possibility to reduce time and therefore costs by the conscious approach during the component design.

Machine-material-parameter-combinations

The six machine-material-parameter-combinations of the participating industry partners in DMDR 3.0 are listed below. Both metallic materials and plastics are investigated.

Laser Beam Melting

- 316L / SLM 280 HL 3.0 / 60 µm
- Copper / EOS M290 / 50 µm
- Inconel 625 / EOS M280 / 50 µm
- Inconel 718 / SLM 280 HL 2.0 / 60 µm

Fused Deposition Modeling

- TPU 92A / Stratasys F370 / 250 µm
- Ultrafuse TPU 85A / German RepRap / 200 µm

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

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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.

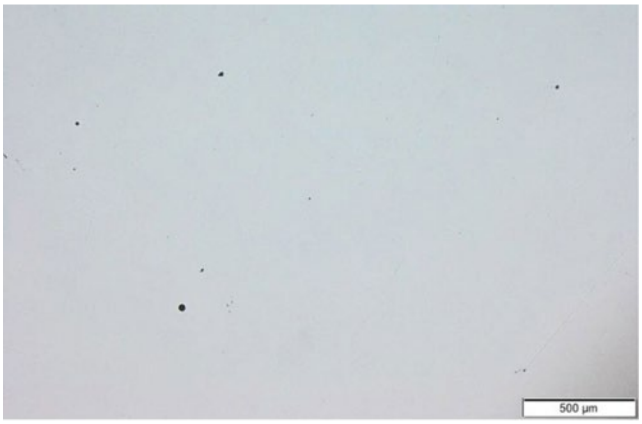

FIGURE 1 Spherical gas porosity

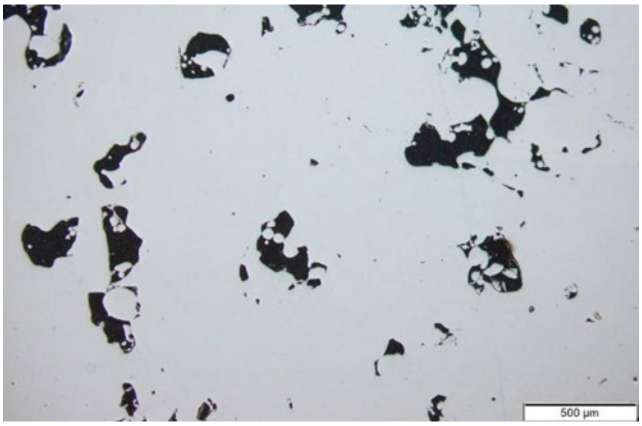

FIGURE 2 Selcetion of demonstrators developed in CaCS

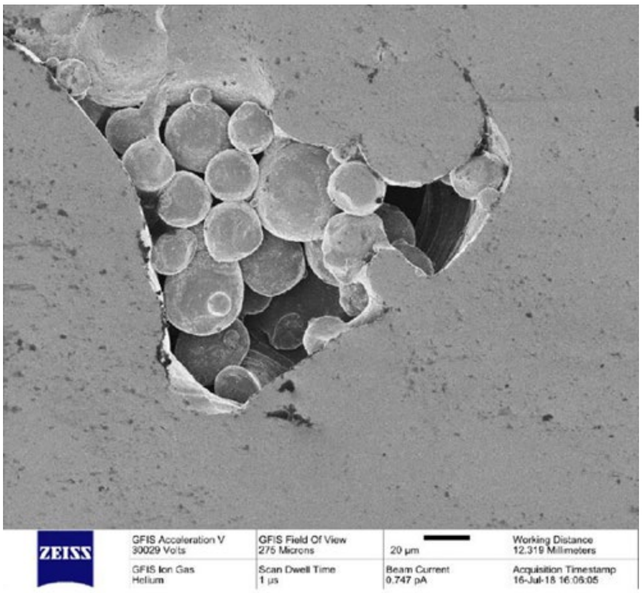

FIGURE 3 Selcetion of demonstrators developed in CaCS

EFFECT OF DEFECT 2.0

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 PBF-LB/M 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 PBF-LB/M process, and categorizing the critical defect types, sizes and distributions is critical for establishing acceptance criteria.

PROJECT OVERVIEW

DURATION

01/2021 – 12/2021

PARTNER

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Aim

In the 2019 DMRC project "Effect of Defect for SLM" a strategy was successfully developed in which a specific type of defect (gas pores, keyhole pores and lack of fusion) could be locally introduced into samples in a reproductible way. In extensive tests, the effects of these three defect types on static and cyclic mechanical properties of Ti6Al4V were investigated. Based on the defect type, diameter and location, a model for predicting the lifetime of the defect was developed. The current project builds on these results and expands the existing investigations in various areas. The method is to be improved and transferred to other materials. In this case, the material INC718 will be further investigated. Furthermore, a modelling of the results by a computer-aided simulation and component tests are planned.

Experimental Procedure

The strategy developed for Ti6Al4V must be adapted to the new materials through a preliminary study. The aim is to achieve locally introduced defects while maintaining a high density in the rest of the sample. Material-specific parameters for INC718 to create those defects will be evaluated with the powderbed based laser additive manufacturing system from SLM Solutions type 280HL stationed at the DMRC. In case of lack of fusion defects, work will also be carried out on reducing the defect radius to be able to model even smaller bonding defects. Therefore, density cubes will be printed to select the parameters in which the desired types of defects can be specifically generated.
After the required parameters and building conditions are developed, the samples for determining the mechanical parameters (static/cyclic) will be manufactured and the defects will be measured by CT scans. In addition, an investigation of the fracture surface (e.g. SEM, light microcopy) will help to determine the cause of failure. Thus, the defect diameter and the surface can be measured, which are the input variables of the lifetime model. While not only the type and size of the defect are important also the internal location in the part has a significant influence. As in the preceded project, machined tensile specimens will be used.

A further examination will introduce the defects locally in a few layers or small volumes in the tensile specimen to account for the distribution as well as the frequency.

The results of the tensile and fatigue tests, fracture surface analyses and CT scans will be evaluated to establish a correlation of the defects and to achieve a systematic evaluation of these. As in the first Effect of Defect project, analogous models will be applied to describe the service life to present the specific results in a transferable way. Since nowadays the lifetime and strength verification is carried out by FEM-Models, the defects should be able to be represented with the relevant influencing factors. Based on this evaluation a classification of the defects will be conducted by taking the position, the material, etc. into account and organize them into permissible and inadmissible defects.

Expected Outcome

The performance and quality of AM parts are significantly influenced by the material characteristics and process parameters. As in the study of Ti6Al4V, local defects were successfully and reproducibly introduced into the samples. It is to be expected that characterizing defects and their effect on mechanical performance for further materials with the already developed strategy is applicable. This would help fill gaps related to the acceptance criteria for AM parts.

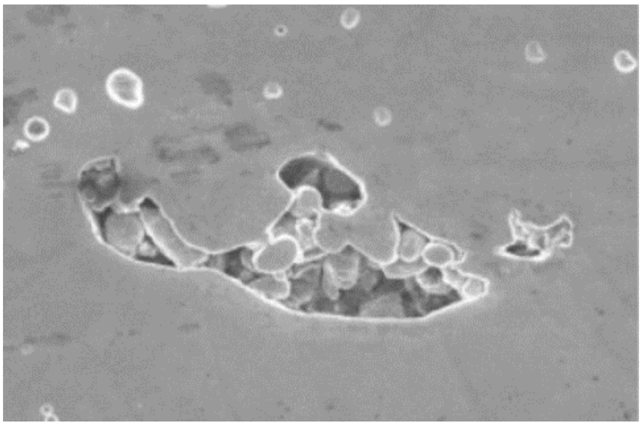

FIGURE 1 Lack of fusion pores

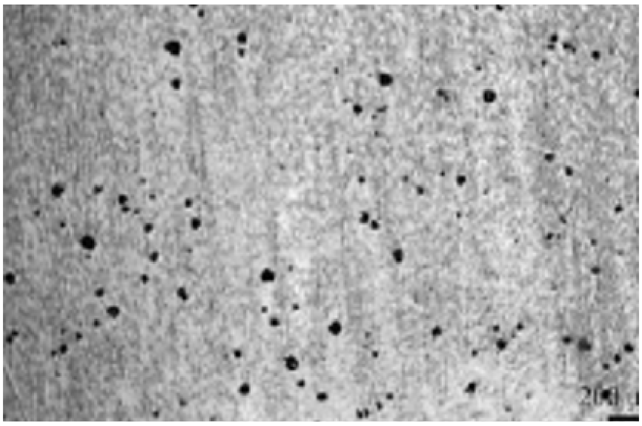

FIGURE 2 Spherical gas pores

FIGURE 3 Computed tomography scan of Ti6Al4V sample

FILLED MATERIALS

In recent years, selective laser sintering has evolved from a rapid prototyping technology to a process for the direct series production of sophisticated plastic components. In this context, the functional and mechanical properties of additively manufactured components are becoming increasingly important. However, there currently is only a limited selection of LS materials available, meaning that not all customer-specific requirements can be met. Particularly in the automotive and aerospace industries, filled plastics represent standard materials, as they can exhibit better mechanical properties, higher heat resistance or improved wear properties, depending on the filler.

PROJECT OVERVIEW

DURATION

05/2021 – 12/2021

PARTNER

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Project Goals

Although some filled laser sintering materials are already commercially available, for example filled variants of PA12 or PA6, these materials have not yet achieved a wide acceptance on the market. Currently, about 90% of LS components are still manufactured from unfilled PA12. In order to create new fields of application for selective laser sintering, the material variety should be extended by filled variants (dry blends) of polypropylene and polyamide 613 within this project. For this purpose, the influence of different fillers and the filler content on the mechanical properties will be analyzed, thus enabling application specific tailoring of material properties.

Experimental Investigations

Based on the experience of DMRC partners, polymer dry blends with different spherical fillers are investigated within the project. Spherical fillers tend to have a better processability than fibers or mineral fillers and exhibit less anisotropy. Fibers can reduce the powder flowability and tend to align in the recoating direction if they are not incorporated within the polymer particles. Within the project, glass beads (Silibeads), hollow glass beads (iM16k) and artificial quartz sand (Cerabeads#1700) are mixed with Untrasint PP 01 nat and Vestosint PA613 (3D 8754 HT1) polymer powders in a drum hoop mixer in different mixing ratios. In contrast to so-called compounds, the fillers are not incorporated within the polymer particles, but are present loosely in powder form in the resulting dry blends.

In the first step, the powder properties of the dry blends are considered. Particle size distributions and the flowability of the powder mixtures are determined. Furthermore, the influence on the melting behavior is quantified by means of DSC investigations and the melt viscosity of different blends is determined by MVR measurements. The fillers could have a nucleating effect, which could influence the recrystallization behavior and change the sintering process window.

After completion of the basic powder characterization, the processing properties of the dry blends will be investigated on an EOS P3 laser sintering system. It is expected that processing parame-

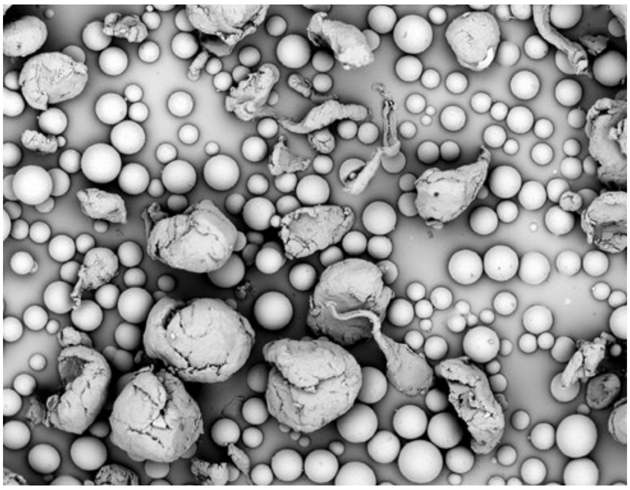

FIGURE 1 Dry-blended Ultrasint PP 01 nat with glass bubbles iM16k

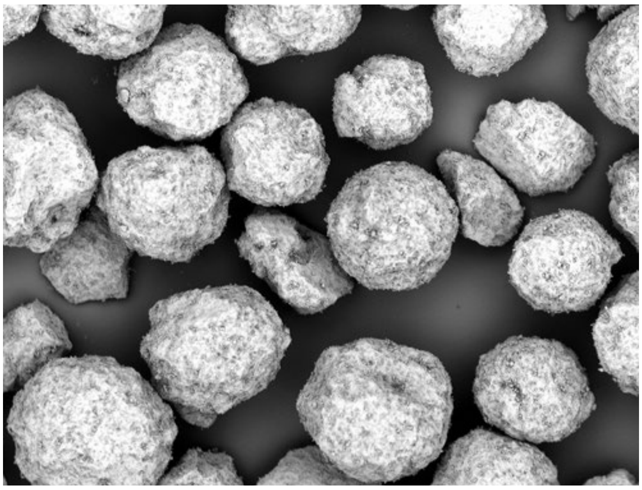

FIGURE 2 Artificial sand (Cerabeads#1700)

ters such as laser power, scanning speed, hatch distance and build temperature will need to be adjusted compared to unfilled material. The altered flow properties of the dry blended powder may necessitate changes in recoater blade geometry to ensure a good powder bed surface. Furthermore, shrinkage factors may need to be adjusted to compensate for the effect of the fillers.

Special attention is paid during processing to possible segregation of the different particles inside the dry blend (polymer and filler). In the feed tanks of EOS P3 laser sintering systems, the powder is fluidized with compressed air in order to dissolve agglomerates and to achieve the best possible coating. However, depending on the density and particle morphology of the fillers, a segregation of polymer powder and filler may occur. This process must be prevented at all costs, as otherwise it is not possible to achieve constant material properties over the entire build height. Even if no segregation should occur in the feed tanks, the distribution of the fillers within the component volume is a critical factor. It must be checked whether the filler is evenly distributed by the mixing process, or whether filler agglomerates are formed which are not surrounded by plastic melt in the subsequent laser sintering process and thus form a defect.

After suitable processing parameters for the dry blends have been determined, the achievable mechanical properties are to be investigated at the end of the project. For this purpose, tensile test specimens made from dry blends with different fillers and filling ratios will be produced in the laser sintering process and tested according to DIN 527. An important target parameter is an increased Young's modulus compared to unfilled polymers. Furthermore, the heat deflection temperature of the components is to be improved by incorporating the fillers. Previous investigations have shown that the bonding of the fillers to the polymer matrix is of particular importance for the mechanical properties. Against this background, the effect of a silane coating on the fillers is investigated. As a failure mechanism, it is aimed that the components fail in the base material and not at the interface between fillers and polymer. At the end of the project, the DMRC partners will have formulations available for dry blends of PP and PA613 with spherical fillers, together with the corresponding material and processing properties.

FUNCTIONALLY GRADED MATERIAL FOR HIGH-SPEED SLM PROCESSING

Laser Powder Bed Fusion (LPBF) is a technology that is utilized to increase function and efficiency of metallic components. However, LPBF cost drivers can be identified in powder material, manual post-processing, and comparable to other AM technologies, lower built-rates. In order to increase the built rate during LPBF processing various startgies cn be exploited. Within this context, many LPBF machine manufacturer have integrated multiple laser sources to increase productivity. Moodifying the scan strategy is another approach to drastically increase the built-rate. Particularly, adjusting the layer thickness represents a key role to reduce LPBF processing time. In fact by modifying the layer thickness multiple parameters have to be modified to ensure a stable processing. In addition to high buit rates

PROJECT OVERVIEW

DURATION

05/2021 – 12/2021

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Motivation

Laser powder bed fusion (LPBF) enables the manufacturing of highly complex metallic structures that cannot be produced using conventional formative or subtractive processes. LPBF processed components are materialized by locally melting the deposited powdery particles, which then solidify as bulk material. As a result, densities close to 100% and surface roughness up to 5 µm (Ra) can be achieved. The latter aspect is related to the thin powder layer thicknesses typically ranging between 30 µm to 50 µm. However, these thin layers simultaneously result in high LPBF processing durations, somehow impeding LPBF in industrial production. Therefore, increasing the layer thickness represents a high potential to increase the economic efficiency of the process. This work addresses the increase of LPBF built-rate by modifying the process parameters, particularly increasing the layer thickness. However, the higher layer thickness is probably at the expense of reduced surface roughness and reduced mechanical properties. These hypotheses will be verified for IN718 within this project.

Proceeding

Thus, LPBF process parameter studies are carried out at layer thicknesses of 120 µm, 150 µm, 180 µm, and 200 µm in which 35 samples each are produced, varying the process parameters laser power, scanning speed, and hatch distance. Subsequently, the samples manufactured are analyzed relative density via light microscopy and µCT, as shown in Figure 1. These samples are then subjected to microstructural, mechanical, and surface roughness investigations to deduce the material's properties. Moreover, the tested specimens are analyzed to elucidate the failure mechanism, exemplarily demonstrated in Figure 2 In particular, the influence on density in correlation with the volume buildup rate, surface roughness, hardness will be analyzed and discussed.

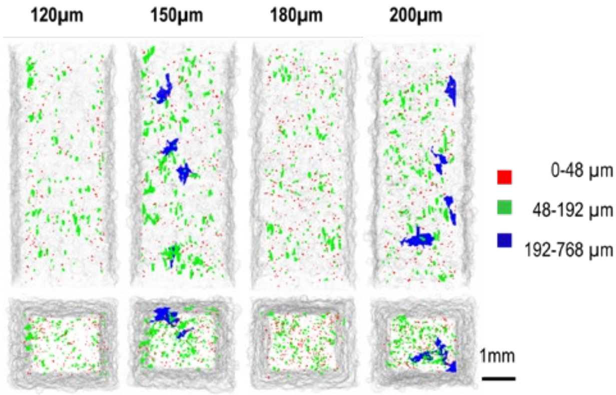

FIGURE 1 Micro-CT scan revealing the gauge section miniaturized tensile test specimens fabricated each at a different layer thickness.

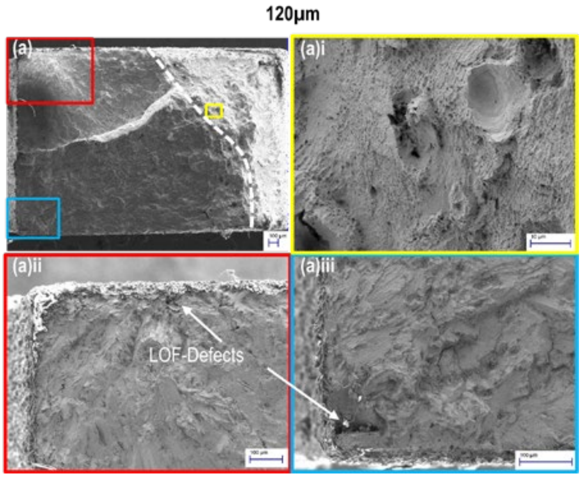

FIGURE 2 Scanning electron microscopy image depicting the fracture surface of a fatigued specimen fabricated utilizing a layer thickness of 120 µm

FUSED DEPOSITION MODELING WITH METAL POWDER FILLED FILAMENTS (METAL-FDM)

Metallic additive manufactured components can be produced with the Fused Deposition Modeling (FDM) process using polymer filaments that are filled with metal particles. In accordance to the conventional MIM (Metal Injection Molding) process, the FDM process is used to manufacture green parts. The polymer is then removed from these green parts in post-treatment steps to create brown parts. Finally, the brown parts with the metal particles are sintered to create the final components. This project deals with this topic and investigates necessary processing parameters along the process chain and demonstrates achievable component properties.

PROJECT OVERVIEW

DURATION

10/2019 – 12/2019
01/2020 – 12/2020

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Introduction

According to the current state of the art, additive manufactured metallic end-use-parts can be produced with Selective Laser Melting (SLM) or Electron Beam Melting (EBM). Due to the high design freedom in the field of additive manufacturing (AM), these processes are increasingly used for complex parts, small series or individualized products. Disadvantages of the SLM 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. A further disadvantage is the handling of metal powder, which places high demands on work safety.

The process chain

Another possibility for the production of metallic AM parts is the use of the Fused Deposition Modeling (FDM) process based on polymer filaments filled with metal powder (Metal-FDM). In accordance to the conventional Metal Injection Molding (MIM) process, the finished FDM parts (green parts) are cleared from polymer in post-treatment steps (brown part). Afterwards the metal particles are sintered to generate the metallic part (white part).
A major challenge in this Metal-FDM process is the large shrinkage of 15 to 20 % in every direction in space due to debinding and sintering. This shrinkage must be considered when designing parts for this process. Since the filament contains a polymer and metal particles, it can be processed with conventional FDM machines that are available on the market.

Applications and advantages

Possible fields of application could be the manufacturing of parts with internal structures that do not require external accessibility. Furthermore, the Metal-FDM process might be used to produce multi-material parts or parts with otherwise incompatible materials in the future, which is not possible in the SLM- or EBM-process. Another major advantage of the FDM process is that material is only used for the actual part and there is no need to fill the entire

FIGURE 1 Specimens manufactured in the Metal-FDM process

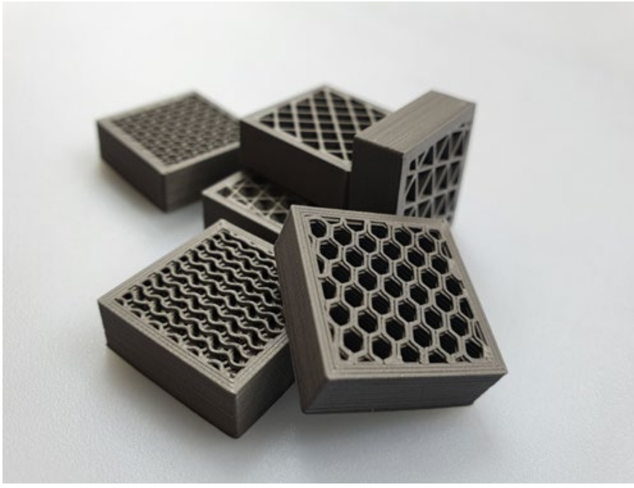

FIGURE 2 Components manufactured with different infill strategies

build chamber with the material to be processed.
In addition, 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 costs for these AM process chains due to the large production amounts coming from MIM.

Approach

In order to build up basic knowledge in this area, a small three-month preliminary project was carried out at the DMRC in 2019. Figure 1 shows some specimens that were produced during the project. On basis of the experience gained, a one year project for 2020 was then conceived and is currently being carried out.

Objectives and Aim

The aim of this project is to generate know-how for FDM with metal filled filaments to introduce it as a further AM process in the DMRC and thus also for the industrial partners. The mechanical characterization and basic design guidelines along the whole process chain should allow a comparison with the established SLM process.

Of course, the process specific challenges must also be considered. One thing to mention here is that the design freedom of Metal-FDM components is not only subject to certain limits in the FDM process but is further limited by the debinding and sintering process. For example, only a certain weight can be supported by a parts structure. If an upper structure of a part is too heavy the component might collapse during the debinding and sintering process.

Furthermore important material-dependent processing parameters are being investigated in this project. The effects on the green parts but also on the white parts are considered. In addition to general process parameters such as the strand deposition strategy and the strand-geometry. Different filling strategies are considered with which, for example, partially filled part areas can be created (cf. Figure 2).

Finally, the investigation of some exemplary use cases that might be provided by the dmrc partners should show the possibilities of the Metal-FDM process. In particular, the aim is to show which component geometries can be realized with the process and what needs to be taken into account during the design phase and for the selection of the FDM process parameters.

FUSED DEPOSITION MODELING WITH METAL POWDER FILLED FILAMENTS 2021

Additively manufactured metal components are increasingly used in the industrial environment for the production of complex component geometries, small series or individualized products. A comparatively new approach for the production of metal components is the use of the Fused Deposition Modeling (FDM) process, in which a polymer filament filled with metal powder is used. In accordance to the conventional Metal Injection Molding (MIM) process, the polymer is removed from the manufactured part (green part) in a post-treatment step (brown part). Afterwards, the metal particles are sintered (final part). This project investigates the processing of a suitable support material. For this purpose, both the processing parameters and the process steps are considered.

PROJECT OVERVIEW

DURATION

05/2021 – 12/2021

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Motivation

According to the current state of the art, metallic end-use-parts can be produced with Selective Laser Melting (e.g. SLM) or Electron Beam Melting (EBM). Due to the high design freedom in the field of Additive Manufacturing (AM), these processes are increasingly used for complex parts, small series or individualized products. Disadvantages of the SLM 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 Fused Deposition Modeling (FDM) process based on polymer filaments filled with metal powder. In accordance to the conventional Metal Injection Molding (MIM) process, the polymer is removed from the finished FDM parts (green part) in a post-treatment step (brown part). Afterwards the metal particles are sintered (final part).

Since the filament contains a polymer and metal, it can be processed with conventional FDM machines that are available on the market. Possible fields 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, which is not possible in the SLM or EBM process. Another advantage of the FDM process is that material is only used for the actual part as there is no need to fill the entire build chamber.

In previous projects on this topic at the DMRC first know-how about the technology has been gathered. Process parameters and material influences on the FDM processing were investigated and optimized. Mechanical properties were investigated for fully filled components and for partially filled components. First exemplary use cases were also attempted to be manufactured. The experi-

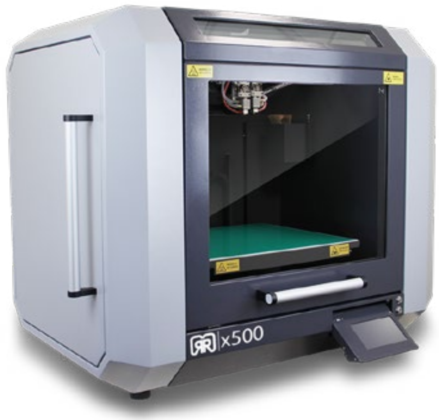

FIGURE 1 Machine used for the fabrication of green part specimens (Source: German RepRap)

FIGURE 2 Process-related design limitations that illustrate the need of a support material

ences during the project were recorded. It has been noticed that for the application and the production of components the biggest limitation is currently the lack of a debindable and sinterable support material.

Aim

The aim of this project is to carry out first investigations on the support material currently being developed by BASF to evaluate and improve the processability. In this context, suitable process parameters should be determined and possible supporting strategies should be investigated. Finally, the results will be used to manufacture first complex geometry components out of 316L, which previously could not be manufactured due to their geometry and the necessity of supporting structures.

Proceeding

At first, FDM processing parameters are developed for the selected support material. For this purpose, a methodology developed at the DMRC is used to qualify the processing parameters. The evaluation of the optimized parameters is carried out on the green part on the basis of the resulting strand geometry. Thereby, not only a functioning parameter set will be found but also the material specific influences on the processing will be considered. Collapsing of the structure and a negative influence on the surface must be avoided.

On that basis, different supporting strategies are evaluated. These include the manufacturing of support structures that only use interface support as well as fully manufactured support. Moreover, the influence of the support strategies, density and strand deposition strategies along the whole process chain is examined.

The components are evaluated after the individual process steps with regard to existing defects and surface condition. This should not only validate the set process parameters, but also minimize the use of support material and the influence of the support material on the component properties. Thus, the aim of a rapid and reliable process should be achieved.

To illustrate the developed parameter set as well as the recorded influences on the component properties, complex geometries are manufactured, which require support material for production. In addition, a comparison with previous results is made in order to assess the potential of the support material in the processing of metal powder filled polymer filaments.

INFLUENCE OF SURFACE ROUGHNESS ON MECHANICAL PROPERTIES

Additive manufacturing (AM) is gradually establishing itself in the production of complex-structured components. Beyond the utility value of design freedom, the target-effective use of materials in a relatively short time is decisive. Dynamic material loads correspond to the reality-oriented use case and are strongly affected by the surface topology. In particular, the nickel-based alloy Inconel 718 is primarily used in propulsion technology and is therefore subject to a relatively frequent peak load within the product life cycle. Synergetically, a next step includes the identification of a cost-efficient post-processing with increased build-up rate.

PROJECT OVERVIEW

DURATION

06/2021 – 12/2021

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Motivation

The surface of additively manufactured components in the "as printed" state is already of a relatively high quality due to the coordination of process parameters concerning the process and material. Nevertheless, post-processing of the surface is unavoidable and requires the commitment of time resources.
Since the process duration is strongly dependent on the parameter sets used, the question arises as to whether an increased build rate with slight losses in surface quality compensates for the time required for the obligatory post-processing.

Aim

A "high-productivity" build rate, with slightly reduced surface quality, means that less machine time is tied up in the build process. A more detailed rework is usually more cost-effective to fulfil the mechanical requirement profile of the component. Finally, a comparison of parameter selection and rework methodology should provide information about the dynamic material behaviour.

Experimental

Following DIN EN ISO 6892 and ISO 12106, the additive manufacturing of specimens from the nickel-based material Inconel 718 - material number 2.4668 is carried out by means of laser beam melting with the additive manufacturing system from SLM Solutions type 280HL stationed at the DMRC. Two different sets of parameters are used, which should differ in terms of the build-up rate. Basically, the layer height (slicing) and the applied laser power are affected. It is expected that with a "high-productivity" approach, the surface quality will be reduced in favour of the production time. At the end of the generative phase of the project, the specimens are machined using various post-treatment methods, such as barrel finishing. Post-processing is used to compensate for surface defects in the contour to minimise the susceptibility to failure for dynamic loads. The differently treated specimens are examined with regard to their surface roughness and provide, in the first instance, an analytical formulation of the service life expectancy. The surface roughness is recorded at the DMRC using optical digital macroscopy. The VR-3100 3D measuring macroscope from

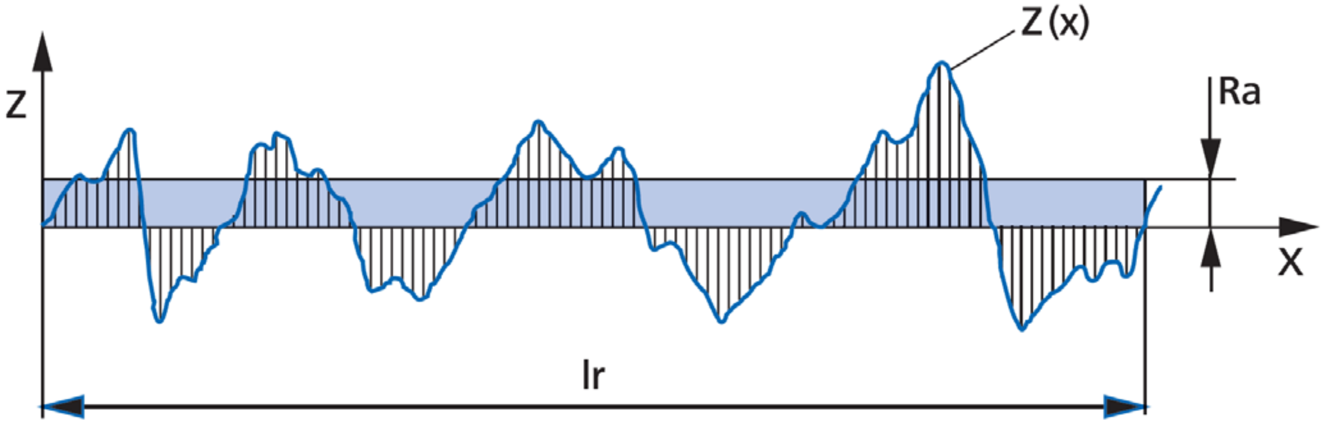

FIGURE 1 Arithmetischer Mittenrauwert

Keyence is used for this purpose to enable comparability of the surfaces.

After completion of the post-processing and its preliminary analysis, the mechanical behaviour of the modified surfaces is recorded by quasi-static and dynamic test methods. The “high-productive” specimens should show at least the same results regarding the material characteristics in the quasi-static and dynamic profile. Based on the quantified characteristic values, it can be deduced which synergetic effect results from the change of parameter sets in the AM range and the choice of a specific post-processing method for the surface. This is based on the influence of the characteristic material behaviour to determine to what extent the different production approaches change the strength and durability.

With the comparison of the final results, it can be deduced whether the reduced surface quality in favour of the construction rate represents a cost- and especially time-optimised approach. Constant performance of the material with modified parameters, compared to a proven standard construction method, is the minimum goal.

INFRARED POWDER BED HEATING UNDER HIGH PURITY ATMOSPHERE (INFRAPUR)

A promising remedy to avoid undesired macro-cracking of hard to weld materials during SLM processing is a build chamber pre-heating system. The increased powder bed temperature reduces cooling rates as well as residual stresses. In this project, a in-house developed build chamber pre-heating system is utilized to process the titanium alloy Ti64 and the titanium-aluminide alloy Ti-48Al-2Cr-2Nb. In addition to the high proceseing temperatures up to 800°C, a gas purification system will be integrated in the SLM Solutions 280 machine in order to reduce residual oxygen content.

PROJECT OVERVIEW

DURATION

05/2020 – 05/2021

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Motivation and objective

In general, selective laser melting (SLM) enables the production of highly complex geometries based on a layer-by-layer material deposition. This process can be used to produce parts and components from materials that are good to weld. However, the defect-free processing of metallic materials that are hard to weld is quite limited. During SLM processing, residual stresses are generated by the laser source imposing rapid heating and cooling in the melt track as well as in the heat-affected zone can result in undesirable micro- or macro-cracks. Ultimately, these crack-affected components cannot be used in practice.

One promising remedy for a crack-free SLM production of materials that are difficult to weld can be identified by increasing the powder-bed temperature. So far, in commercially available SLM machines, a baseplate pre-heating systems up to 500 °C, is considered state of the art. Just by heating the baseplate leads to a significant temperature gradient in the built direction so that after a few millimeters, the preheating is no longer effective.

Based on the latter, a build chamber pre-heating system was developed at the chair of materials science and the chair of automotive lightweight design, in which a homogeneous heat input of the process wall up to approximately 800 °C is feasible (Figure 1). The deposited metal powder, as well as the components, are homogeneously heated in the z-direction, reducing the temperature gradient significantly.

Additionally, the project addresses the effect of residual oxygen during SLM processing on the powder material and the components built. It will be investigated if oxygen contamination occurs, which may lead to reduced powder reusability and deteriorating mechanical performance of the parts manufactured via SLM. A schematic illustration of the gas purification system employed is revealed in Figure 2.

Preliminary investigations have revealed a pronounced oxygen pick-up of the metal powder at higher pre-heating temperatures.

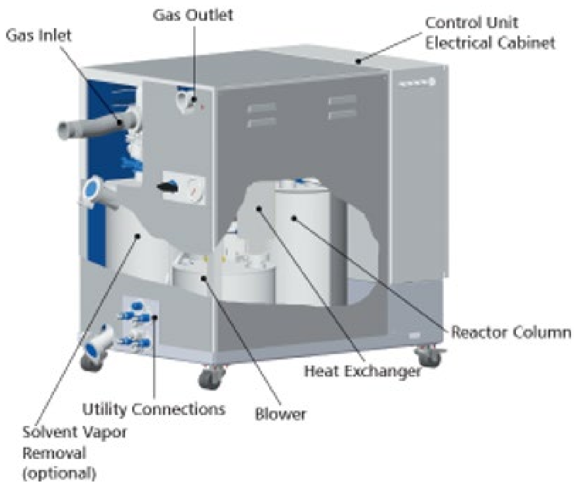

FIGURE 1: Schematic illustration of the MB10 H2O and O2 gas purification system from MBraun, which was integrated into the gas circuit of the SLM system.

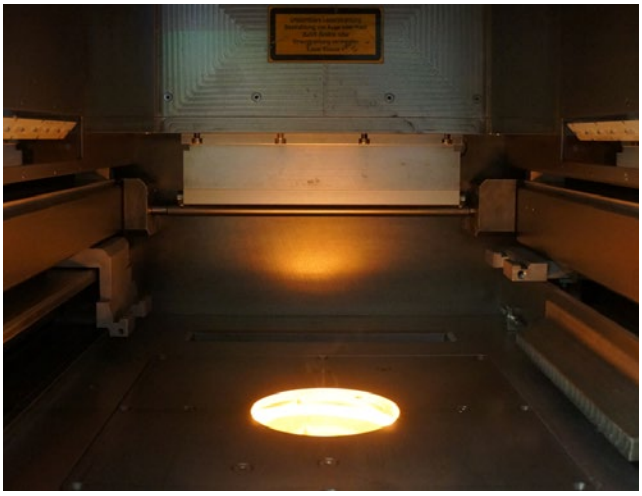

FIGURE 2: Installation of the IR build room heater in the SLM Solutions 280 HL.

Thus, the combination of the pre-heating system with a gas-purification system is highly interesting. A commercially available gas purification system will be integrated into the SLM machine.
Regarding the materials, investigated, the titanium alloy Ti64 and the titanium-aluminide alloy Ti-48Al-2Cr-2Nb will be analyzed. Both materials are highly affine to oxygen. Furthermore, the TiAl-alloy has to be processed at elevated temperatures. These alloys are, thus, excellent candidates to demonstrate the effect of the build-chamber pre-heating system and the gas purification system.

Approach

First, the build-chamber pre-heating system and the gas purification system are integrated into the SLM Solutions 280 1.0 machine. After the machine modification, SLM processing parameters are generated at high pre-heating temperatures to achieve crack-free and bulk specimens. During each build-job, a metal powder will be extracted an analyzed concerning an oxygen pick-up. The specimens printed are then microstructurally and mechanically analyzed to determine the effect of the elevated processing temperatures and the oxygen content in the build chamber. Finally, a prototype is fabricated consisting of Ti-48Al-2Cr-2Nb.

INVESTIGATION OF THE POTENTIAL OF NEW MATERIALS IN DLP

Current developments in the field of materials create new potential for the use of the additive manufacturing process Digital Light Processing (DLP) or similar processes on the basis of vat-photopolymerization. Previously existing weak points, such as brittle components or low UV resistance, are no longer present due to the new materials. Therefore, the suitability of this process for manufacturing end products is increasing. Many new opportunities are emerging, which create a great need for research in this area. For this reason, the DMRC starts with the research of the DLP process and the material properties.

PROJECT OVERVIEW

DURATION

01/2020 – 12/2020

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Process description

In the DLP process a resin is cured layer by layer using UV light. That way three-dimensional components are generated. The liquid resin is in a vat with a transparent film in the bottom (see figure 1). It consists of a mixture of monomers, oligomers and photoinitiators. When exposed with UV light, the photoinitiators trigger a polymerisation reaction and a crosslinked polymer is produced. The light source is a DLP projector. The resin is exposed to the light emitted by the projector from the bottom through the transparent film.

There are other additive manufacturing processes similar to the DLP that are also used to produce components by a vat-photopolymerization. The stereolithography (SLA) and the mask-stereolithography (MSLA) process are two examples for these. They differ in the light source. Most of the available materials can be used for all three mentioned processes.

The in the DLP process possible layer thicknesses are approx. 10 to 100 µm and are therefore lower than in most other additive processes, such as Laser Sintering (LS), Fused Deposition Modeling (FDM) and Arburg Plastic Freeforming (AKF). With the DLP process a very high surface quality and a high resolution of the parts can be achieved. These advantages in connection with new materials make the process interesting again for many industrial applications.

First impressions

The DLP Printer Loctite® EQ PR10.1 will be delivered to the DMRC in June. In order to get some impressions in advance there was the possibility to temporarily use a MSLA-printer for home applications for some tests. In the MSLA process there are LEDs which shine through an LCD Display instead of a projector as light source. The rest of the process and the post-processing is very similar to the DLP process.The first test revealed the advantages and the potential of the DLP process. The surfaces are very smooth and it is possible to build parts with many details and thin structures (see figure 2 and 3). Due to the small layer thickness, the stair-step-effect is almost non-existent. In addition to materials with high hardness, high impact strength or high temperature resistance, elastomers can also be printed using the DLP process, thus enabling the user to manufacture components with a high degree of flexibility. The first tests also show the importance of the post-processing. After the build process is finished any excess resin has to be removed from the part. Subsequently the part has to be cured with UV light. This has an influence on the mechanical properties, the dimensions and partly the color of the parts.

The tests have also shown some disadvantages of the process. Support structures are needed for nearly all parts. After removing the support structures little marks remain and the surface quality is reduced in this area. Up to now only materials of the previous generation have been tested. Based on this the printed parts were very brittle. In further investigation there are tests with the new and improved materials planed.

Investigations

The focus of the investigations is on the material properties. Due to the disadvantages of earlier materials (brittle fracture behavior, low UV resistance), which have been known for many years, the industry is partly skeptical about the DLP process. Therefore, there is a great need for research concerning the new materials in order to test the improved properties and to develop the new application possibilities.

In the experimental investigations, the material properties will be tested and material-specific differences in production will be determined. There is a large range of new DLP-Materials which should be tested. The determination of mechanical properties according to DIN EN ISO 527 and DIN 53504 is important. It is planned to determine the influence of the orientations (X and Z), of the exposure parameters during production and of the subsequent UV exposure on the mechanical properties. Because dimensional accuracy is essential, especially in the manufacturing of end components, this is also examined in more detail. In the tests, the influences of specimen orientation, process duration and finishing on the dimensional accuracy are examined.

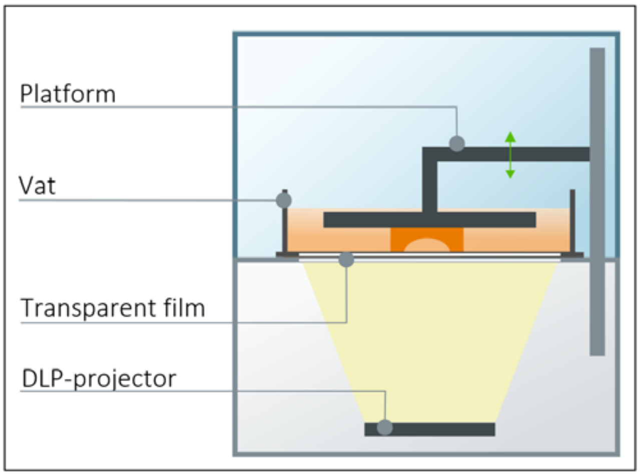

FIGURE 1 DLP-Printer

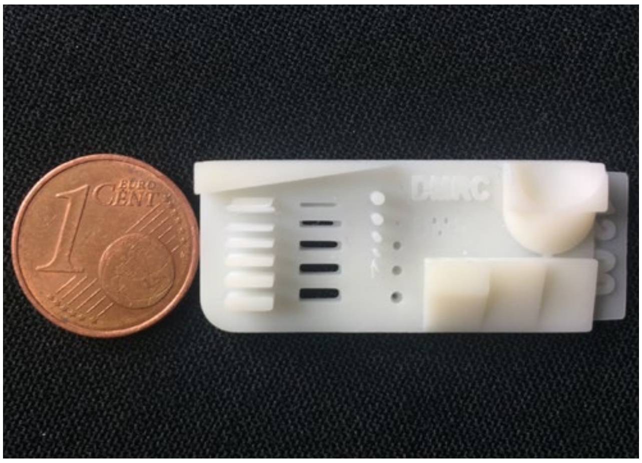

FIGURE 2 Example component 1

FIGURE 2 Example component 2

LASERSINTERING LOW COST PROCESS MONITORING - (LC-PROMO)

Most of the modern Polymer Lasersintering machines are not equipped with relaiable and automated process monitoring systems. Still the process monitoring is a very critical aspect for serial production, as even small coating errors can lead to part failure. The objective of this project is to design and implement a retrofittable monitoring system for the EOS P3 platform, which is capable to detect false powder spread, the recoater filling level and inform the operater, if an event has been detected.

PROJECT OVERVIEW

DURATION

2020 – 2021

PARTNER

- Particle Technology Group (PVT)
- Database and Information Systems (DBIS)
- Software Innovation Lab (SI-Lab)
- DMRC partners

FUNDED BY

DMRC funding cycle 2020

RESEACHER

Research Leader
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DMRC DIRECT MANUFACTURING RESEARCH CENTER RESEARCH INNOVATION EDUCATION

Problem description

Serial production is only possible if the process runs sufficiently stable. The part properties must not vary too much if manufactured with identical machine settings. However even very small coating errors like agglomerates, recoater stuttering, foreigen particles or uneven powder spread in general can lead to high variation within the part quality. Some of those failures are detected directly after the part depowdering, as shown in Figure 1. Then again, some failures are located in the middle of the material and cannot be seen in the final part.

Nowadays, this is most often overcome by additional test parts located side by side with the actual part. This solution is not only expensive, due to the additional parts and tests, it is also unsafe, as this method never gives 100% confidence for no failures in the actual part volume. With the powder spread process monitoring system those failures can be detected and the part is rejected before it is assembled or shipped.

SLM powder spread monitoring systems

Powder spread monitoring systems are already state of the art for the selective laser melting (SLM) technology. Here a machine vision high resolution imaging system is equipped at the top of the build chamber and detects powder spread issues and part curling problems based on different light reflections. The gathered information is fed to a machine image analysis software which gives online information on the build job.
It is possible to use this information in an open loop or even as closed loop control unit for the manufacturing process. However, it is not possible to simply transfer those systems to the polymer lasersintering process. In the SLM process the build camber is not heated and the hardware does not have to be protected in the same way as it is required in lasersintering machines. Furthermore, the light set up is different, as the raw material shows other reflection coefficients and without the IR heating units additional interference radiation needs to be taken into account.

Approach and methodology

The system developed here shall be retrofittable to all EOS P3 systems. Therefore, the changes at the machine itself should be reduced to a minimum. The image sensor will be assembled as an exchange unit for an existing build chamber light. Additional light sources will be installed and shall surround the build plan. A sketch of the installation concept is shown in Figure 2. Images taken with different light directions will deliver enough information of potential failures as the resulting shadows change form related to the detected failure. This is shown in in Figure 3 where the light is coming from the front side along the y-axis. A machine vision system can detect the prominent shadow much better than the groove itself.

Analysis process

The high-resolution images will be analysed with a shape of shade or contour detection approach. Hereby it is most critical to preprocess the images and tune the system to get relaiable results. The system needs to deliver a high failure detection rate with very low or no false alerts.

Working together at the DMRC

For this project the Paderborn University Chairs from Prof. Hans-Joachim Schmid – Particle Technology Group (PVT) and Prof. Dr. Gregor Engels – Database and Information Systems (DBIS) are working together to obtain the best outcome for the job and the partners.

The PVT is supporting with its deep knowledge on the process and is responsible for the hardware implementation and gathering of analyzable information.

The DBIS realize the required software components of this project. This covers the automated analysis of the data and interpretation of the outcome. Based on this information, the operator is informed or the specific layers and positions are highlighted afterward in a system for operator confirmation.

FIGURE 1 Recoater Failure Initiated Part Failure

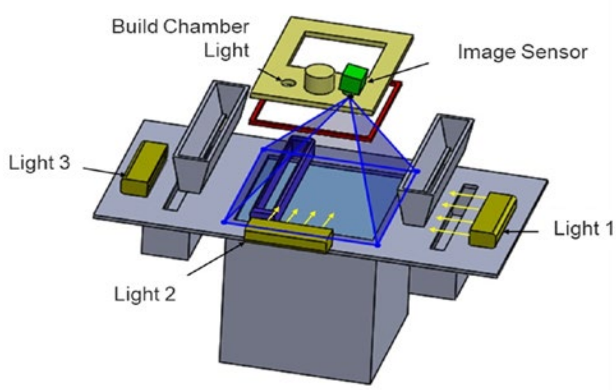

FIGURE 2 Monitoring Concept Sketch

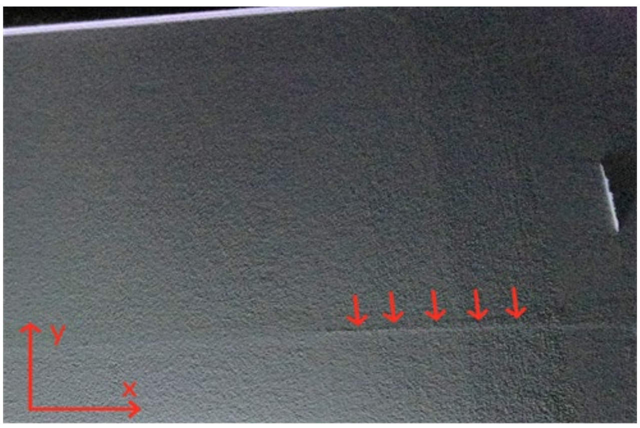

FIGURE 3 Recoater Failure within the Process

MATERIAL CHARACTERIZATION – MECHANICAL AND CORROSIVE PERFORMANCE OF SLM PARTS (MATCHARACT)

So far, just a fraction of steels and metallic alloys conventionally available are processible via selective laser melting (SLM) in a defect free fashion. Weldable metallic alloys can be SLM processed defect free without severe process or alloy modifications. Still, processing parameters must be developed, and material properties must be characterized for the SLM materials. Thus, in this project, three weldable materials are investigated in order to expand the material spectrum in the field of SLM. Microstructural and mechanichal properties are determined for the martensitic tool steel W360, ths quench and tempering steel 36NiCrMo16, and the cobalt-base alloy Ultimet.

PROJECT OVERVIEW

DURATION

01/2019 – 01/2020

PARTNER

Industrial Consortium of DMRC

FUNDED BY

Industrial Consortium of DMRC

RESEACHER

Research Leader
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Research Assistant
Florian Hengsbach, M.Sc.

DMRC DIRECT MANUFACTURING RESEARCH CENTER — RESEARCH INNOVATION EDUCATION

Motivation and objective

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 must be extended in order to industrialize this process further. Based on the latter requirement, this project analyzes the SLM processing as well as the material performance of two steels and one cobalt-based alloy: hot working tool steel W360, quench and tempering (QT) steel 36NiCrMo16, and the cobalt-base alloy Ultimet. The hot working tool steel W360 AMPO is mainly known for the successful additive manufacturing of tools-inserts [1]. The printability of the W360 is thoroughly investigated since the steel must be processed at temperatures above 200°C based on the special alloy design. The second medium carbon steel addressed is the QT steel 36NiCrMo16. This steel exhibits high toughness accompanied by high strength. Thus, the QT steel is utilized in machinery and structures in which an increased yield strength and an abrasion resistance are demanded, e.g., as gears, cutting edges, or camshafts. The third material investigated is the cobalt-base CoCrNiMoW-alloy Ultimet (Figure 1). This alloy possesses superior corrosion properties under aggressive aqueous conditions.

The materials described are microstructurally and mechanically investigated in the as-built as well as the heat-treated condition. Finally, the results obtained are summarized in a material-datasheet.

Approach

The materials investigated were processed with a commercially available SLM Solutions 280 HL machine at a preheating temperature of 200 °C. A standard build-job with tensile-, fatigue-, Charpy-impact-, and cuboid-specimens was designed (as can be seen in Fig 2). Subsequent to the SLM processing, a part of the specimens were machined; thus, the impact of the surface roughness on the fatigue life could be determined. Microstructural investigations were conducted utilizing light microsciópy, scanning electron microscopy (including energy dispersive spectroscopy,

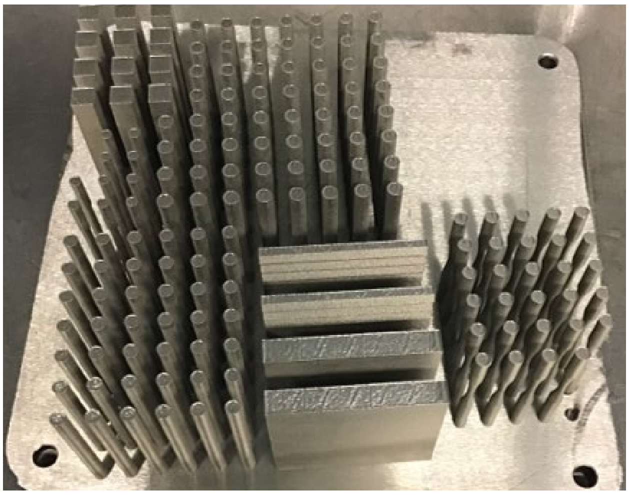

FIGURE 1: Standard build job for microstructural and mechanical characterization for the three addressed materials Ultimet, 36NiCrMo16 and W360.

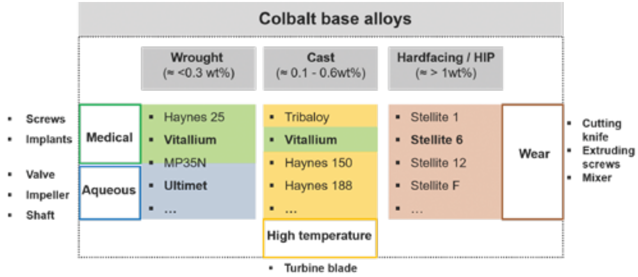

FIGURE 2: Classification of cobalt-based materials and possible areas of application.

electron backscatter diffraction), and transmission electron microscopy.

State of project

A relative density of 99.99 % was achieved in the SLM processed specimens for the three materials analyzed in this project. In addition to the successful SLM processing, a thorough heat treatment study was applied. Generally, additively manufactured materials possess a unique microstructure such that the conventional heat treatment procedure has to be adjusted accordingly. Regarding the martensitic tool steel, the austenitization temperature, as well as the tempering temperature, was modified to obtain the desired hardness in the final component. A case hardening was employed for the 36NiCrMo16 resulting in high surface hardness. The Ulitmet does not require further heat treatment; however, a stress relief procedure is optional.

Hardness measurements and quasi-static tests were conducted an revealed the desired mechanical properties, which are comparable and also increase the mechanical performance of their conventional counterparts. Still, the SLM processing parameters, as well as specimen size geometry, has to be considered.

Moreover, the materials fatigue performance was determined by conducting S-N-curves comparing various material conditions, e.g., as-built and heat-treated.
Along the entire heat treatment procedure development and mechanical characterization, the microstructure of the materials was analyzed in detail. Finally, the material performance was summarized in a material datasheet.

MECHANICAL BEHAVIOR OF AM MATERIALS UNDER DIFFERENT TEMPERATURES

Additive Manufacturing (AM) technologies have a significant potential for the production of individual parts with high complexity and high design freedom. This technology is already widely used, especially in the areas of biomechanics, for example, to produce individual, patient-specific prostheses, in the aerospace area to produce structurally optimized brackets, in the field of passenger services and in the automotive industry. However, the number of possible materials is limited. The materials typically used are TiAl6V4, 316L, Inconel and AlSi10Mg.

PROJECT OVERVIEW

DURATION

2020: 12 month

PARTNER

Industrial Consortium of DMRC

FUNDED BY

Industrial Consortium of DMRC

RESEACHER

Research Leader
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Research Assistant
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Motivation and aim

Over the last few years, a large amount of AM material characteristics have been generated through various projects at the DMRC. For example, fundamental mechanical material properties (e.g. tensile strength, fatigue strength, and fatigue crack growth curves) were determined for different materials. In addition, the influence of essential process parameters (e.g., powder properties, process gas) on the mechanical properties have been investigated. However, the elongation at break or the contraction at fracture obtained from the tensile test show an estimation of the toughness of the material, but this only applies to a (quasi)- static load and only at room temperature. In many cases, components are also subjected to an impact or cyclic load and not always at room temperature. The ideal conditions of the tensile test do not reflect reality. For example, components that have a good toughness behavior in the tensile test become brittle at low temperatures which leads to premature material failure.

In particular, cubic-body-centered (bcc) materials such as ferritic steels and hexagonal lattice structures (hex) show a particularly strong dependence of the toughness on the temperature. The temperature dependence of the notch impact energy can thus be transferred to the fracture behavior of the materials. Therefore, the assumption can be made, that a complete material characterization also includes the knowledge of how the material behaves under different temperatures, for the practical application often takes place under certain temperatures which differ from laboratory conditions. As a result, an appropriate statement can be made for each application profile. By applying different temperatures during experimental investigations, the possible temperature dependence of the material can be identified at an early stage.

The temperature dependence has a significant influence on the stress-strain curves, as illustrated in Figure 1 by the example of σ-ε-curves of TiAl6V4 at varying temperatures. With increasing test temperatures, Ti6Al4V shows decreasing strengths and an increasing elongation at break. However, above 500 °C, a decrease in strength, as well as ductility can be observed. The increasing

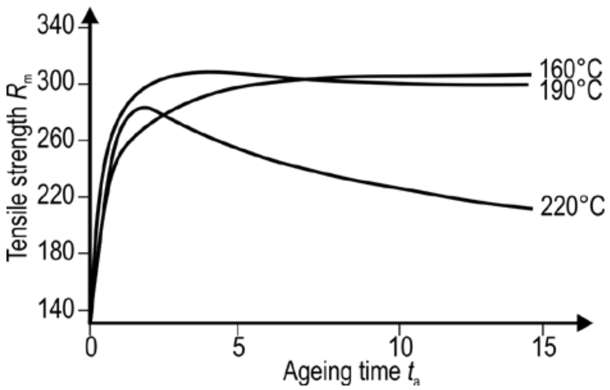

FIGURE 1 σ-ε-curve of TiAl6V4 showing the dependency of the mechanical behavior and the test temperature

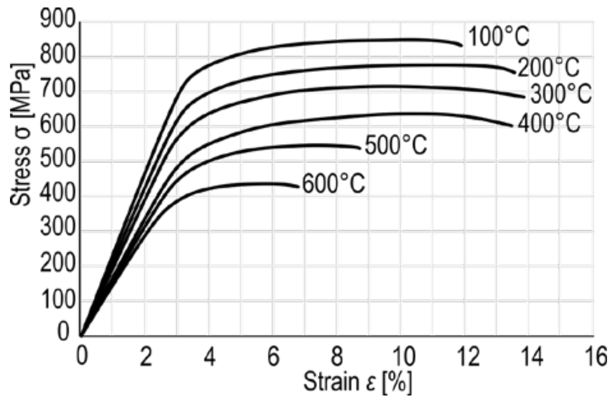

FIGURE 2 Tensile strength as a function of temperature and aging time for AlSi7Mg

embrittlement with increasing test temperature can be traced to the uptake of oxygen from the environment. Thus, it can be seen that other influencing factors have to be taken into account when changing the affected temperature. These examples reveal that the influence of the temperature on the material properties is not negligible. Studies have shown that for conventionally produced materials information focusing on the material behavior at higher temperatures is widely published. For additive manufactured materials, only limited information is available. Knowledge addressing the material behavior at very low temperatures (below 0°C) is missing completely.

Therefore, the scope of this project is to investigate the mechanical behavior of selected AM-materials under varying temperatures as well as the assembly of existing material data to create a complete and up-to-date AM-database. Because of these aspects, the project is separated into five work packages, which are presented in the following section.

Dependence of the material properties on the temperature can also be observed for the basic stainless steel 316L (1.4404) and the corrosion-resistant nickel-based alloy Inconel 718. When the temperature increases, the elastic modulus, the tensile strength as well as the yield point decrease. For aluminum-silicon casting alloys, for example AlSi7Mg, the strength values also decrease significantly at higher temperatures, especially above 250°C (Figure 2). Furthermore, a temperature increase has a negative effect on the mechanical properties during creep and cyclic stress.

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. Especially for these applications the long-term properties are of high importance and are investigated within the described project. In previous projects the material PA613 showed good processability on an EOS P396 laser sintering system and process parameters which result in high part quality were found. Together with determined short term properties the material can be classified within the range of high performance polymers.

PROJECT OVERVIEW

DURATION

01/2019 –12/2019

PARTNER

Industrial Consortium of DMRC - especially EVONIK and EOS

FUNDED BY

Industrial Consortium of DMRC

RESEACHER

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

Research Assistant
Christina Kummert, M.Sc.

DMRC DIRECT MANUFACTURING RESEARCH CENTER RESEARCH INNOVATION EDUCATION

Motivation

Within previous DMRC Projects about PA613 a LS polyamide for high temperature applications, it could be verified that the new material, 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 long-term temperature resistance is investigated within this project and supplements the necessary knowledge about the material. Further, fatigue behavior is regarded as also cyclic loads might play a role in future applications. All this helps to classify the material within the range of engineering plastics to become a new high performance material in industry, as PA613 is not known in conventional manufacturing. For this purpose, more information about part properties must be generated.

Preceding projects

In former projects the general processability of PA613, in terms of powder recoating behavior and process temperatures, could be verified. Furthermore, parameters and machine settings had to be found to manufacture robustly build parts. This was not only tested for virgin powder material but also for recycling powder. Since each new laser sintered material is affected by its own aging effects due to the process conditions, these and their extent must be found first. This was 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) value which helps to qualify the aging stage of the powder material.

The next step was a parameter development. In order to generate material properties that are as representative and as optimal as possible, a parameter development was carried out with the

FIGURE 1 Motivation for the laser sintering material PA613

aid of statistical experimental design prior to the tests. The material PA613 showed in former investigations quite constant mechanical behavior for a wide range of laser energy input into the hatching scanning pattern. However, the contour parameters seem to influence even more the tensile properties especially in z-build direction. Following, the project focused the contour laser exposure parameters and strategy whereas the hatching was kept constant. Nevertheless, in order to reduce the experimental plan, a design of the experiments was created with the help of the statistical software Minitab 18 first. Test results were analyzed to detect correlations between varied parameters and build part quality. Finally, a response optimization was carried out.

The resulting optimized build parameters were taken to manufacture various specimens. Beside testing tensile, impact, bending and compressive properties at different application relevant temperatures, the material behavior after conditioning was regarded. Conducted tests show that, as known for polyamides, the tensile strength of PA613 is decreasing with increasing temperature but is still above 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.

Material characterization – Long term properties

To extent the comprehensive material data base, the content of the project in 2019 was 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. For this purpose, the temperature index (TI) is determined according to the standard UL 746B for polymeric materials respectively EN ISO 2578. Furthermore, fatigue behavior of PA613 laser sintering parts must be known for dynamical applications like in aircraft, electronic or automotive industry and is therefore also tested within the described project. 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) 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 2.0

A widespread additive manufacturing process is the Fused Deposition Modeling (FDM). Not many high performance polymeres 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 with regard to the warpage behavior.

PROJECT OVERVIEW

DURATION

01/2019 – 12/2019

PARTNER

Industrial Consortium of DMRC

FUNDED BY

Industrial Consortium of DMRC

RESEACHER

Research Leader
Prof. Dr.-Ing. Elmar Moritzer

Research Assistant
Julian Wächter, M.Sc.

Introduction and objectives

The Fused Deposition Modeling (FDM) process is an additive manufacturing process. Here, the components are generated by a heated thermoplastic strand that is deposited layer by layer. The used plastic filament is pulled into the FDM head with the help of motors, melted there and applied through a nozzle in a defined way onto a building platform or an already existing structure. Due to thermal fusion, the material bonds with the layer below and solidifies. The FDM process is one of the most frequently used additive manufacturing processes for the production of prototypes, tools, but also end products.

Due to the great popularity of the Fused Deposition Modeling process, the selection of materials on the materials market is growing. There is a wide range of plastics that can be processed using the FDM process. These materials can be modified by the admixture of additives in order to influence certain material properties such as fire resistance, chemical resistance, breaking strength or heat resistance in addition to the basic properties. In principle, almost all thermoplastics are suitable for the FDM process.

In the FDM process, a component is generated by a large number of individual layers. After the strand is deposited, each strand cools down separately and as a result material shrinkage occurs. This shrinkage behavior is caused, for example, by the change of the density of a polymer resulting from the temperature change from processing temperature to room temperature. The shrinkage that occurs leads to stresses in the component, which can cause the component to warp. Excessive warpage leads to areas in the component that bend upwards out of the manufacturing plane and thus negatively affect the manufacturing process. This is one reason why the choice of materials in the FDM process is limited compared to conventional plastic processing technologies.

The aim of the research project is to investigate the shrinkage and warpage behavior as an additional criterion for evaluating the processability of plastics in the FDM process. The focus of the material selection is on high-temperature materials. Here,

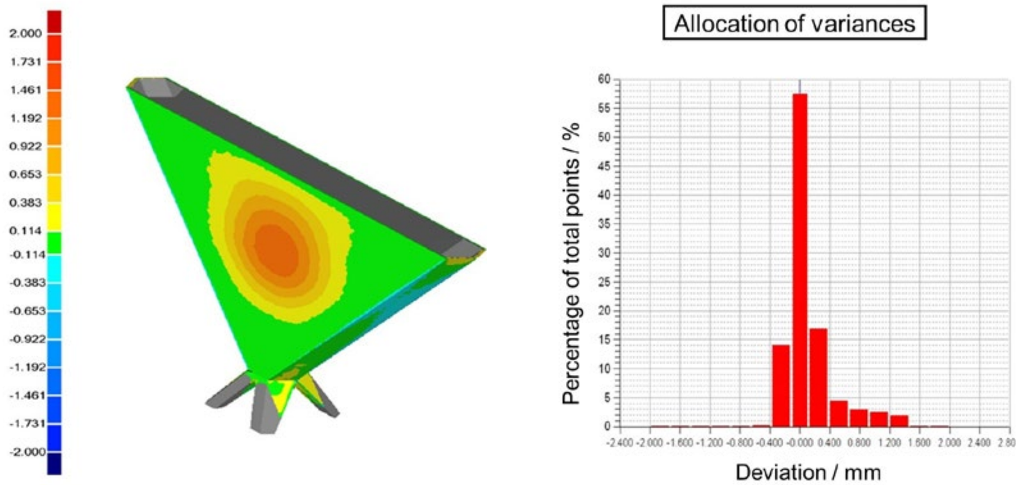

FIGURE 1 Three-dimensional deformation of the test specimen

the complete process chain from granules to component will be represented. This means that in the first step, filaments must be produced out of the standard granules (as starting material). In the following step, these are processed on an open parameter FDM system. Finally, the process parameters are optimized in consideration of the shrinkage behavior and the results of the project “Processing of alternative FDM materials 1.0”.

Review

In this previous project, the processability of different materials has been investigated with regard to the weld seam strength. For the characterization of the materials a weld factor was determined and the weld seam widths were evaluated in addition to the weld seam strength. During preliminary investigations, experimental points of a test plan with suitable temperature settings of the nozzle, the build chamber and the heating bed were determined. This test plan is also used for the investigation of the warpage behavior in order to compare the results of the two projects.

Project contents

In the past project year, in close cooperation with industrial partners of the DMRC, the following materials were investigated for their processability in the FDM process: unreinforced polyether ether ketone (PEEK), thermally conductive PEEK, polyphenylsulphone (PPSU), glass-fibre reinforced polypropylene (PP) and polyamide (PA) 12. In test series, the warpage of test specimens was quantified using various measuring methods in order to be able to draw conclusions about the material shrinkage. Figure 1 shows an example of the amount of deformation of the used test specimen geometry.

In the experimental investigations, the influence of the build chamber temperature and the nozzle temperature were investigated. For each material, five test points with material-specific temperature conditions were investigated. The temperature parameters were varied one after another and thus the influence on the shrinkage-related warpage of the test specimens was determined. Under the specific conditions, test specimens were manufactured using the FDM process and the amount of warpage caused by a shrinkage-related surface bulge of the test specimen was quantified. In addition to the influence of the different temperatures, also the influence of the position in the build chamber on the shrinkage behavior was investigated. Mechanical measuring equipment, a camera method and an automated 3D scanner were used to determine the warpage. Finally, the results of the previous project were applied to determine a process window for the individual materials in order to achieve the highest possible weld seam strength and at the same time minimum warpage.

PROCESSING OF ALTERNATIVE FDM MATERIALS 3.0

The qualification of new polymers for the FDM process, using known material data, is not practicable and the qualification of processing are conducted experimentally. During the qualification process of a new material, further material properties must be considered in addition to the general processability in the FDM process. In a previous DMRC project in 2018 it was investigated which alternative high-performance plastics can be processed in general. After the general processability of the materials was examined the achievable weld seam strength was determined. In the subsequent project in 2019 the shrinkage and warpage behavior was studied. In this project, fully developed FDM process parameters are generated, based on the basic parameters defined in the previous projects.

PROJECT OVERVIEW

DURATION

05/2020 – 11/2020

PARTNER

Industrial Consortium of DMRC

FUNDED BY

Industrial Consortium of DMRC

RESEACHER

Research Leader
Prof. Dr.-Ing. Elmar Moritzer

Research Assistant
Julian Wächter, M.Sc.

DMRC DIRECT MANUFACTURING RESEARCH CENTER – RESEARCH INNOVATION EDUCATION

Project objective

The aim of the board project "Processing of Alternative FDM Materials 3.0" is to set up fully developed FDM process parameters based on the basic process parameter developed in the previous projects. So, the FDM process parameters are to be optimized for a selection of successfully tested materials to get a material specific adaption. The final outcome is the development of a material specific method for determining FDM process parameters in relation to the slicer and the firmware.

Review

In the past project in 2018, different materials were tested with regard to their processability in the FDM process in close consultation with the DMRC industrial partners. Different polyether ether ketone (PEEK) materials and a glass fiber reinforced polypropylene (PP) were processed. In particular, PEEK is 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. In the following project year 2019 the warpage behavior of different materials was examined. Warpage results due to the shrinkage behavior of a material and is therefore a material specific property. The shrinkage and warpage behavior were investigated, because in the FDM process, the part is produced out of a large number of layers. Strands are deposited, each strand cools down and shrinks separately. The occurring shrinkage leads to residual stresses in the part which can lead to warpage. With a special specimen geometry, the warpage has been detected and quantified.

In the further course of the project the task was to combine the project results from the years 2018 and 2019. The aim was to determine a process window for the used materials, in which the highest possible weld seam strength with at the same time low warpage is achieved. Thus, an optimized nozzle temperature as well as an optimized build chamber temperature could be determined. These processing parameters will be adopted and used in the project "Processing of alternative FDM materials 3.0".

Project procedure

The aim of the board project "Processing of Alternative FDM Materials 3.0" is to set up fully-developed FDM process parameters. The first step is to select the materials to be used in this project. The material selection will be based on the materials from the previous project in 2019. Then the FDM processing parameters will be optimized. This will start by optimizing the FDM process parameters that are defined in the slicing software. Here, the goal is to prevent typical error patterns such as oozing/ stringing (Figure 2) by adapting in the slicer software. Different slicers are examined. Additionally, advanced FDM processing parameters that are usually handled by the machine firmware (e.g. for controlling the material extrusion during strand deposition) should be optimized for the chosen materials. Finally, the mechanical properties will be determined by manufacturing and testing tensile specimens according to DIN EN ISO 527-2 or ASTM D638 in XY- and Z-direction.

Thus, the transition from material specific process parameter optimization to component characterization is made. The material properties can be identified and compared with conventionally available materials. Then a demonstrator part will be manufactured with the developed parameter set. An example is shown in Figure 3. This concludes the process parameter development.

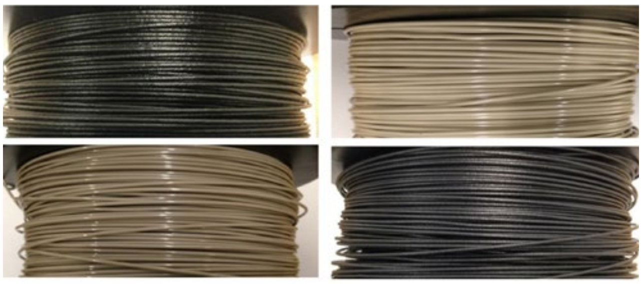

FIGURE 1 Material selection

FIGURE 2 Typical FDM error pattern oozing / stringing

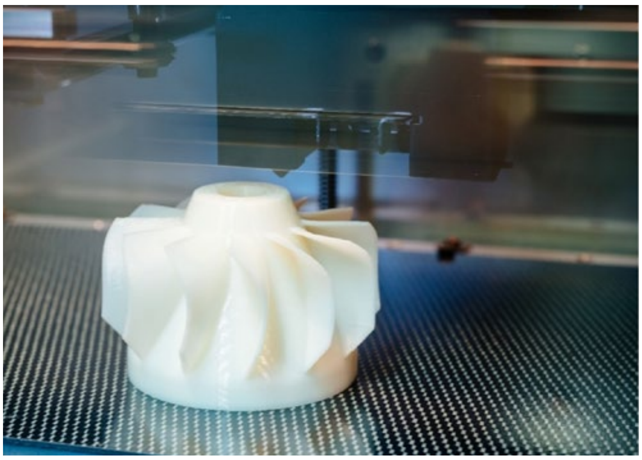

FIGURE 3 Manufacturing of a demonstrator

SCREENING OF POLYMER BASED AM TECHNOLOGIES

Many different processes are established in Additive Manufacturing (AM). The processes differ from each other in a number of points, partially significantly, such as the required support, build-up rates, resolution, material variety, anisotropy, repeatability, surface roughness, investment costs and much more. These many differences make it difficult to compare the processes and to select a suitable process for a component. In this project, the polymer-based AM will be compared comprehensively and the advantages and disadvantages will be worked out. Based on this, a tool will be developed to support the process selection. This is intended to support persons with no experience in AM as well as those with a great know-how.

PROJECT OVERVIEW

DURATION

07/2021 – 12/2021

PARTNER

Industrial Consortium of DMRC

FUNDED BY

RESEACHER

Research Leader
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Research Assistant
Christine Driediger, M.Sc.

DMRC DIRECT MANUFACTURING RESEARCH CENTER RESEARCH INNOVATION EDUCATION

Motivation

There are a lot of different AM processes available on the market. Each process has its own advantages and limitations. These are often process specific and a comparison of the processes is usually not easily feasible. If a suitable process for an application is sought, detailed knowledge of the different processes is necessary. As the technologies differ in so many aspects it is challenging to keep track of them all.
At the DMRC many years of experience in the field of Fused Deposition Modeling (FDM), Laser Sintering (LS) and Arburg plastic freeforming (APF) are available. This will be used in the project to conduct a comprehensive comparison of polymer AM technologies. In addition to the processes comparison, different machine types will be compared where possible. The machines are divided as far as possible into two groups. The desktop printers and the industrial printers.

Aim

The aim of this project is to give an overview of the technologies and to support the technology selection technologies with a tool. Independent of the state of knowledge about the technologies, the selection tool can be a helpful tool. The tool is used to determine the suitable process considering the numerous technology specific differences. Furthermore, the requirements for the processes and the component properties can be prioritized in the tool. In this way, process selection is made easier, improved and faster.
The screening focuses on the technologies FDM, LS, APF, and Digital Light Processing (DLP). These are the present polymer processes at the DMRC. It is possible to expand this range with further processes like Multi Jet Fusion.

Process Comparison

The process comparison is primarily based on existing data and experience at the DMRC. The knowledge of the last more than 10 years is to be used and brought into a comparable form. In order to consider as many aspects as possible, several AM experts have already been interviewed and the advantages and disadvantages of the various technologies as well as geometric limitations of the

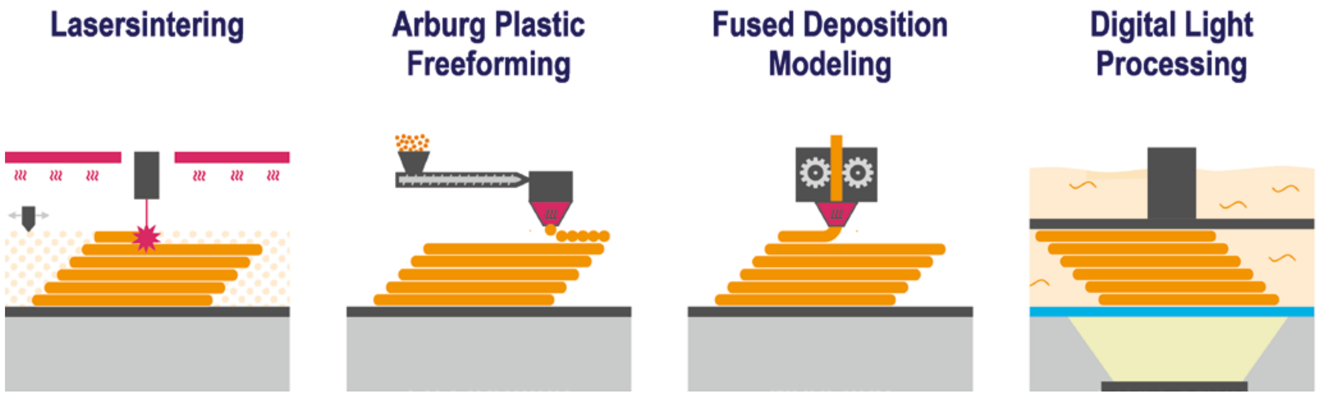

FIGURE 1 Polymer based AM technologies

processes have been collected. All values are to be stored in a material and printer database and then compared.
An important aspect here is the source reference. In the process comparison, numerical values should always be traceable back to the original source. This allows a distinction to be made between data sheet values, values determined experimentally at the DMRC and literature values. In addition, an extension with other materials and printers as well as a correction of existing values should be possible. This offers the possibility that each user e.g. stores own material or printer prices and for the comparison. In addition to the data available at the DMRC, the database is filled with values from a literature research and a small experimental study. The focus of the experimental study is on the geometric capability of the processes according to EN ISO/ASTM 52902.

Selection Tool

On the basis of the technology comparison a procedure for a process selection is developed. The aim is to create a tool that recommends a suitable process based on the entered requirements.
Possible inputs can be the requirements for the mechanical properties or the accuracy. In addition, it is possible to rank certain properties such as printing costs, printing speed, investment costs, etc. The tool helps to find the best process and shows the advantages and disadvantages of the processes depending on the component to be manufactured.

Validation

Finally, the entire process selection is to be tested using real components. Suitable requirements are selected and the result is checked with a selection based on experience. In the case of discrepancies, these are analyzed in detail and, if necessary, the process selection procedure is adjusted. Depending on the DMRC partners input, the real components and requirements will be determined supplemented with further measurements. In addition, the data basis will be expanded and a procedure for selecting a suitable AM Process for an existing component will be developed.

SURFACE FINISH

One of the biggest advantages of Metal AM is the ability to produce complex internal structures, cavities and freeform geometries. Surface finish and tolerances of as-print parts often don't meet the criteria of technical applications. Therefore, additional processes are necessary. The conventional processing of such surfaces and structures can only be realized with very great effort, if at all. This is true for all metal AM processes. For this reason, the need of surface finish, support and powder particle removal is necessary for every component. Right now, the ability of surface finish often limits the AM-design because surface have to be attainable for conventional processes.

PROJECT OVERVIEW

DURATION

2020: 3 month

PARTNER

- John Deere GmbH & Co. KG
- Walther Trowal GmbH & Co.KG
- Heraeus Holding GmbH
- Siemens AG

FUNDED BY

Industrial Consortium of DMRC

RESEACHER

Research Leader
Prof. Dr.-Ing. Thomas Tröster

Research Assistant
Dominik Ahlers, M.Sc.

DMRC DIRECT MANUFACTURING RESEARCH CENTER — RESEARCH INNOVATION EDUCATION

Introduction

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.

Objectives

In the end, surface finish is necessary for nearly every application (e.g. adherent particle removal for hydraulic applications, optical purposes, etc.). Due to this limitations of surface finishing, more studies and investigations are necessary in the field of metal surface finish.

On this account a study about effect of different surface finish technologies of metal AM parts for internal structures and freeform geometries (e.g. mechanical, electro-chemical, etc.) is conducted. The aim is to apply different surface finish processes and mearure the roughness values after the treatments. Moreover, an evaluation of the ability of removing adherent particles and a valuation of the material deduction will be applied.

Workpackages

This project is divided into three major workpackages. The first workpackage addresses the development of a suitable demonstrator to evaluate the performance of the different treatments regarding outer surfaces, edges, corners and surface roughnesses. In the second major workpackage the three treatments are applied and the demonstrator geometry is surface finished. As postprocessing processes, a vibratory finish on a Walther Trowal machine, a dry electro polishing on a DLyte system and classic sandblasting is conducted. The third workpackage includes the surface measurementson the different areas and the comparison of the technologies. On the one hand the surface treatment is evaluated, on the other hand the economic suitability of the technologies.

Expectations

Surface finishing is very important for additive manufacturing and of great interest to industry. For this reason, we expect exciting results from this project (project start May 2020) with regard to an effective and economical finishing of additive manufactured components.

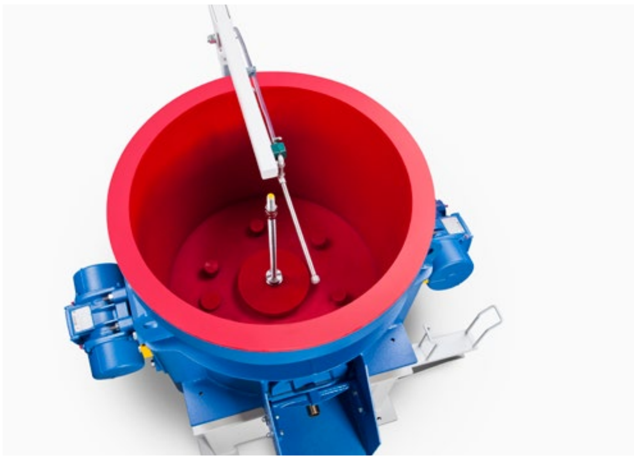

FIGURE 1 Equipment used in this project – Walther Trowal AM2

FIGURE 2 Fixation of a component in the vibro polishing system

FIGURE 3 Finished part

CONTENT

PUBLIC FUNDED (PIAF) PROJECTS

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)

RESEACHER

Research Leader
Prof. Dr. Thomas Tröster
Research Assistant
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

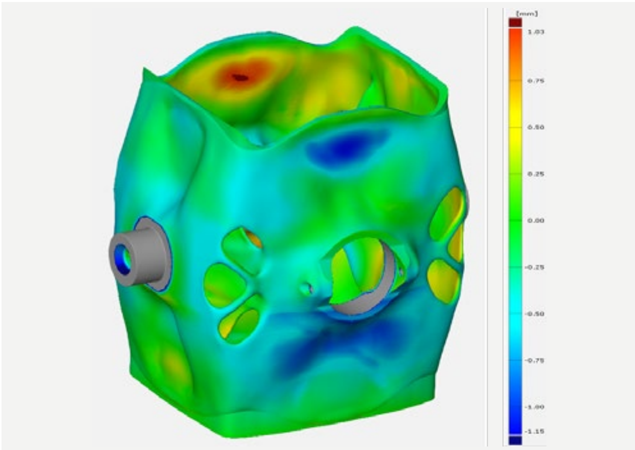

FIGURE 2 Distrotion measurement with CT analysis of the component

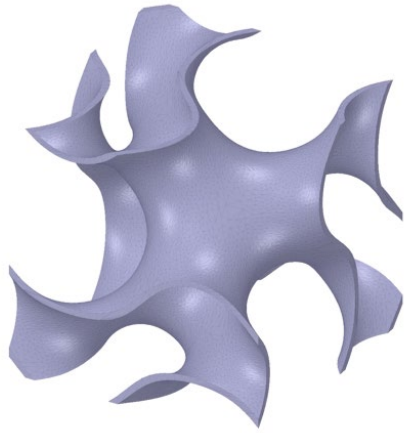

FIGURE 3 Gyroid structure as high performance support structure

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

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

PROJECT OVERVIEW

DURATION

03/2020 – 08/2020

PARTNER

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

FUNDED BY

German Research Foundation (DFG)

RESEACHER

Research Leader
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Prof. Dr.-Ing. habil. Mirko Schaper
Prof. Dr.-Ing. Detmar Zimmer (KAt)

Research Assistant
Sebastian Magerkohl, M.Sc. (KAt)
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Stefan Urbanek, M.Sc. (IAL)

DFG Deutsche Forschungsgemeinschaft
German Research Foundation

Motivation

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

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

Approach

In order to be able to exploit the above-mentioned potential, a suitable material must be identified. This is done in two steps. First, parameter studies are carried out on one selected iron-cobalt and two iron-silicon alloys. This is followed by the determination of mechanical and magnetic properties before and after heat treatment.

Based on the results of the material research, the effects of rotor-side inclination on additively manufactured PMSM rotors with buried magnets as well as concepts for the suppression of eddy current losses on the surface of PMSM rotors by means of AM will be investigated.

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

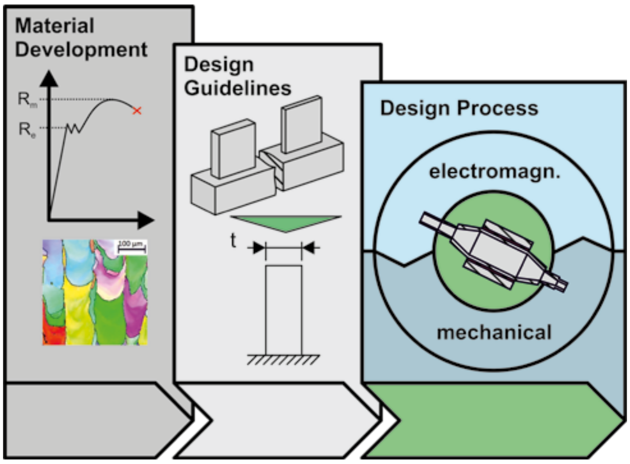

FIGURE 1 Project phases

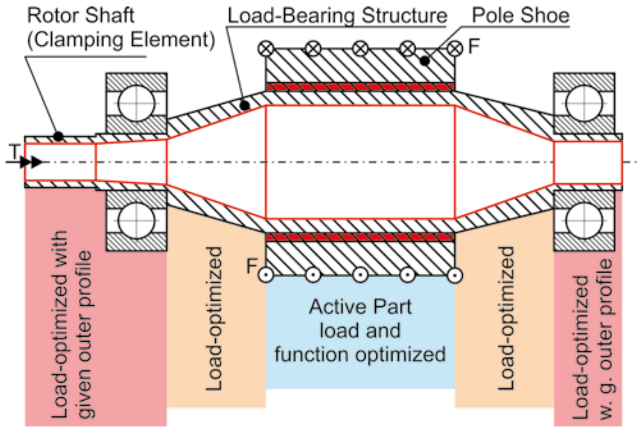

FIGURE 2 Exemplary illustration of a rotor with the different functional sections

cesses and is an example of the newly gained possibilities in the design of electrical machines.

Project status

The alloys CoFe50 and FeSi2.9 were chosen for the project to enable a comparison to the currently most common materials in electrical machines. Furthermore, the alloy FeSi6.5 was chosen to show the potential of AM. FeSi6.5 has the highest permeability in the iron-silicon phase diagram and a reduced electrical conductivity, which reduces the formation of electrical eddy currents and thus the resulting losses.

In the first step, parameter studies were carried out. Then, 16 different heat treatments with a focus on primary recrystallization with subsequent grain growth were analyzed for each alloy. To measure the magnetic properties as-built and after an adapted heat treatment, toroidal test specimen were printed, from which hysteresis curves were measured in different frequency ranges. FeSi6.5 showed the greatest potential with a maximum permeability of 7056 and exceeds the achieved values of FeSi2.9 by 254%. Due to its solid design and high electrical conductivity, FeCo50 has higher eddy current losses.

During the subsequent manufacturing of specimen, the brittle FeSi6.5 led to uncontrollable stress cracks in larger components. Therefore, FeSi2.9 is further used in this project. In order to qualify the promising FeSi6.5 for the SLM process and to further improve the magnetical values, tests will be carried out with a newly developed build chamber heater after the the project is finished.

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

Besides the optimization of the active part, which is essential for the electromagnetic function, the mechanical requirements have already been analyzed. The integration of the active part in the mechanically loaded structure (Figure 2) eliminates the need for form-fitting or force-fitting connection areas and replaced them by using material connections. This results in more design options and lightweight, heavy-duty structures, such as hollow structures. In particular dynamic tests of the torsional fatigue strength have to be carried out. These are necessary to characterize the material properties of additively manufactured FeSi2.9 and to take AM-specific features such as surface roughness into account. The collected knowledge is implemented in an overall design of a rotor demonstrator.

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

To reduce climate change impact, CO2 emissions must be reduced. One of the key technologies is lightweight design. Most CO2 savings can be achieved during the product use phase – especially in the area of mobility – through weight reduction. In the BIKINI project, bionic design algorithms and AI based assistance services are developed to support product development. Examples subsume semi-automated requirement extraction and sustainability assessment. The project started in July 2021, comprises a project volume of around four million euros for a period of three years and is funded by the Federal Ministry for Economic Affairs and Energy (BMWi).

PROJECT OVERVIEW

DURATION

06/2021-07/2014

PARTNER

- EDAG Engineering GmbH, FEYNSINN EDAG Production Solutions GmbH & Co. KG
- Additive Marking GmbH
- Atos Information Technology GmbH
- Alfred-Wegener-Institute
- Krause DiMaTec GmbH
- rhaug GmbH
- Paderborn University (Heinz Nixdorf Institute, Product Creation / C.I.K.)

FUNDED BY

Federal Ministry for Economic Affairs and Energy (BMWi)

RESEACHER

Research Leader
Prof. Dr.-Ing. Iris Gräßler
Prof. Dr.-Ing. Rainer Koch

Research Coordinator
Dr.-Ing. Jan Leilich (EDAG Engineering GmbH

Research Assistant
Daniel Preuß
Christian Oleff
Stefan Hillebrand
Manuel Ott
Pascal Bökemeyer
Klaas Tuschen

DFG Deutsche Forschungsgemeinschaft
German Research Foundation

Topic and aims of the project

It is a challenge for Germany and its companies in the 21st century to reduce the impact of climate change while increasing economic performance and maintaining its own quality expectations "Made in Germany". One of the key technologies for achieving this goal is lightweight design . It enables weight reduction and lowers the associated CO2 emissions. This is particularly relevant for the mobility sector. The CO2 intensive production and recycling processes cannot be ignored. Holistic development approaches need to be developed, which enable sustainable products over the entire life cycle. Vertical and horizontal process chain have to be considered.
To address this issue, research institutes, IT partners and engineering service providers from different branches and research areas founded the BIKINI consortium: EDAG Engineering GmbH, Additive Marking GmbH, Atos Information Technology GmbH, Alfred-Wegener-Institut, Krause DiMaTec GmbH, Rhaug GmbH and Paderborn University.

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

Current evaluation criteria for lightweight design products such as costs and performance are expanded to include sustainability aspects such as holistic CO2 emissions, resources used in the manufacturing process and recyclability of materials. This is achieved through an AI & algorithm supported development process. Established discipline-specific models such as CAD design are networked with new elements such as bionic lightweight design algorithms. Eight core areas are defined. The implementation of these areas enables the efficient development of lightweight products which are sustainable considering the complete product life cycle.

Core areas are:

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

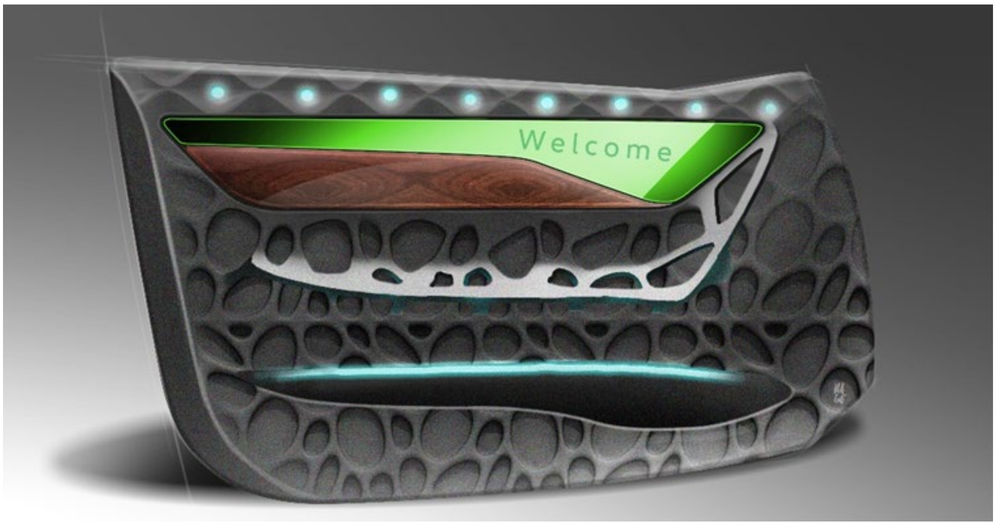

FIGURE 1 From the function to the AM part - identifying and exploiting potentials

- 3D structure and performance analysis of construction principles of biogenic lightweight structures of plankton organisms as well as generation of bionic lightweight construction algorithms.
- concepts and methods for the synergetic combination of skills for intuitive human machine collaboration through the integration of AI in engineering processes.
- automated sustainability assessment of a product design in the early phases of the development process using a sustainability- oriented lifecycle assessment.
- increase in production flexibility by taking into account a product life phase dependent production selection already in the development phase in order to achieve decentralized, application oriented and thus resource saving on demand production.
- production integrated labelling to reflect production and usage data back into development via digital twins and for life cycle tracking.
- building a knowledge base with semantic models to represent the design knowledge, the dependencies of information models in the context of sustainable development and the semantic annotation of the design artefacts.
- configurable combination of the modules to a holistic AI & algorithm supported development process for development optimization with regard to lightweight construction with simultaneous process acceleration through automation.

Research areas of Paderborn University

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

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

The chair for computer application and integration in design and planning (Prof. Dr.-Ing. Rainer Koch) develops different approaches during the project in cases of sustainability and AI use in structural optimization processes. To create a sustainability assessment, a web tool is implemented by using an economic analysis. This is the basis to identify the processes needed. In cases of AI and structural optimization various lightweight principles are improved and a data model is derived . Supported by AI the whole product development process is designed more efficiently.

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

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 are determinded 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, Institute of Materials Engineering (LWT)
- University of Veterinary Medicine, Hannover, Foundation (TiHo)

FUNDED BY

German Research Foundation (DFG)

RESEACHER

Research Leader
Prof. Dr.-Ing. habil. Mirko Schaper (LWK)
Prof. Dr. med. vet. Manfred Kietzmann (TiHo)
Prof. Dr.-Ing. Wolfgang Tillmann (LWT)

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Dr.-Ing. Kay-Peter Hoyer (LWK)
Maxwell Hein, M.Sc. (LWK)
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Dr. med vet. Jessica Meißner (TiHo)
Dr. med. vet. Rafael Hernán Mateus Vargas (TiHo)
Dipl.-Ing. Dominic Stangier (LWT)
Nelson Filipe Lopes Dias, M.Sc. (LWT)
David Kokalj, M.Sc. (LWT)

DFG Deutsche Forschungsgemeinschaft
German Research Foundation

Objective

Materials used for biomedical applications, such as permanent or bioresorbable implants, see Figure 1, 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 substitution of vanadium, the biocompatible performance of such an alloy can be enhanced. So far, the main focus of the research is on the (α+β)-type TiAl6Nb7 in comparison to TiAl6V4, so that the required properties for biomedical applications can be achieved, see Figure 2.

The aim of this research project is the analysis of the coatability of additively manufactured specimens made of TiAl6Nb7 and TiNb24Zr4Sn8 with PVD coatings. Furthermore, the influence of the coatings on the biocompatibility and fatigue behaviour of the components used as implants will be investigated.

Approach

The Chair of Materials Science (LWK) analyses the processing parameters for the additive manufacturing of TiAl6Nb7 and TiAl6V4. In addition, the LWK investigates the mechanical properties for quasi-static and for cyclic loading as well as the corrosion resistance of the alloys and coating systems. The Institute of Materials Engineering (LWT) in Dortmund examines the coating parameters and various layer architectures concerning the feasibility and the effects of the stress states of the coating. The University of Veterinary Medicine Hannover, Foundation (TiHo) inspects the influences of the coatings regarding biocompatibility, cell adhesion and biofilm formation. The collaboration between the LWK, the LWT and the TiHo is shown in Figure 3.

For manufacturing components with selective laser melting the process parameters have to be adapted for each alloy. Additively and conventionally manufactured components of both alloys, TiAl6Nb7 and TiAl6V4, are investigated and compared to provide information regarding the processability of the materials.

To analyze the microstructure optical light and scanning electron microscopy are employed, including various techniques as electron backscatter diffraction and X-ray diffraction. The microstructures of conventionally and additively processed materials influence 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.

Corrosion tests are conducted in Ringer's lactate solution to identify degradation rates, promising coating systems and to characterize the corrosion properties of the alloys and coatings.

Outlook

In further researches the longterm mechanical behavior of TiAl6Nb7 and TiAl6V4 under cyclic loading will be investigated. The aim of this research project is to investigate the processability, coatability and biocompatibility of TiAl6Nb7 and TiNb24Zr4Sn8 components manufactured by laser beam melting. The correlation of the microstructure and mechanical properties as well as the influence of the adapted process parameters and coatings on the fatigue behaviour will be determined. Finally, the biocompatibility and degradation characteristics under conditions similar to those experienced in the human body are examined.

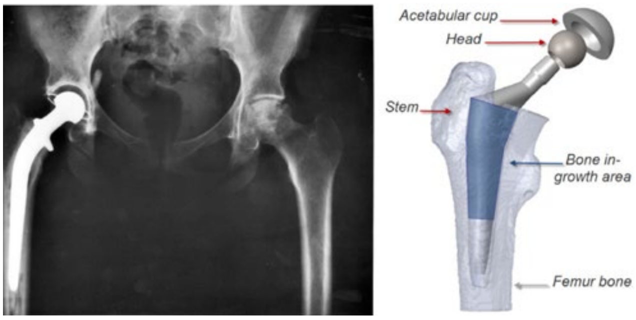

FIGURE 1 X-ray of a total hip replacement (left) and schematic overview of the different parts of an permanent implanted hip endoprosthesis (right); [1].

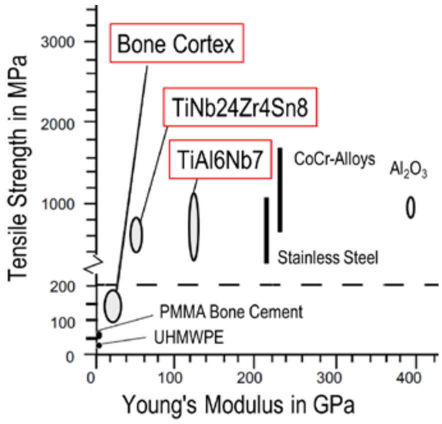

FIGURE 2 Comparison of mechanical properties of different implant materials used in hip arthroplasty and bone cortex; based on [2].

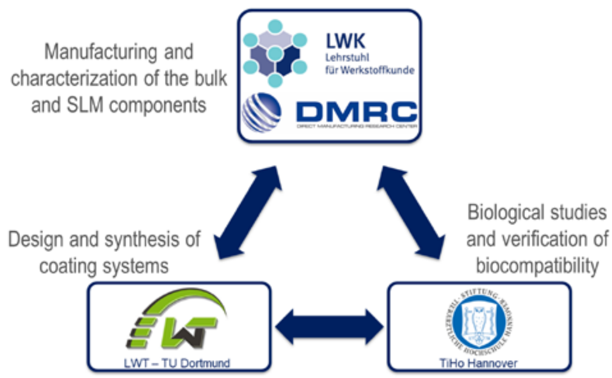

FIGURE 3 Organization and responsibilities within the DFG project

[1] The Use of Additive Manufacturing in the Custom Design of Orthopedic Implants; Marie Cronskär (2011).
[2] Medizintechnik - Life Science Engineering; Erich Wintermantel, Suk-Woo Ha (2008).

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 – 03/2020

PARTNER

- Siemens AG
- H&H mbH
- Eisenhuth GmbH & Co. KG
- GKN Powder Metallurgy
- John Deere GmbH & Co. KG
- Schübel primeparts GmbH
- Karlsruher Institut for Technology (wbk)
- Paderborn University (KAt)

FUNDED BY

Federal Ministry of Education and Research (BMBF)

RESEACHER

Research Leader
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Prof. Dr.-Ing. Zimmer (KAt)

Research Assistant
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Thorsten Koers, M.Sc. (KAt)

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

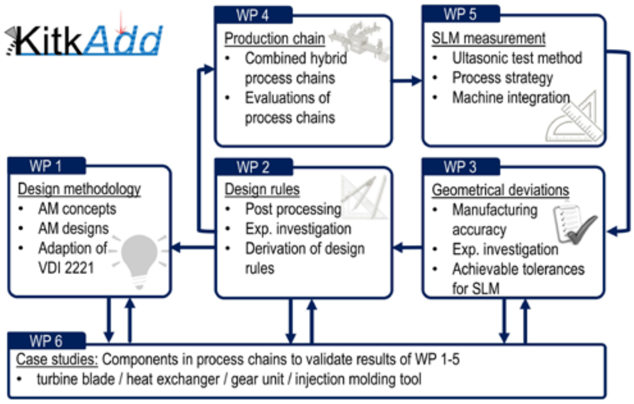

FIGURE 1 Work packages of the KitkAdd project

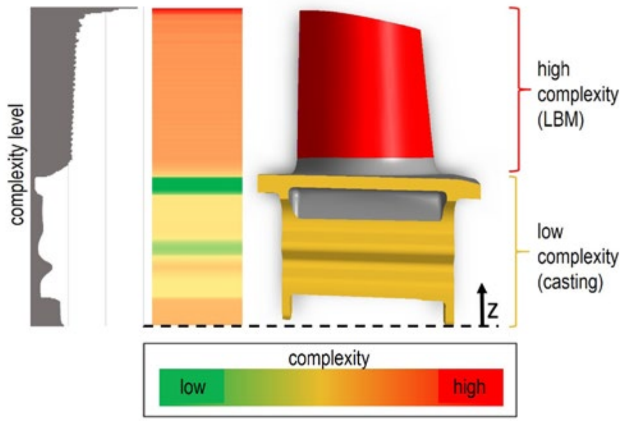

FIGURE 2 Complexity analysis of the turbine blade to identify LBM areas in hybrid manufacturing (Siemens: casting – LBM)

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 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.

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

Since bioresorbable implants are highly interesting for biomedical applications to reduce patient burden, significant efforts are ongoing to develop adjusted metal alloys. Apart from magnesium (Mg) alloys, the iron-manganese (FeMn) system is promising concerning its biocompatibility. Although Mn increases the degradation of Fe, further efforts are necessary to enhance the degradation rate. For example, silver (Ag) phases promote the cathodic dissolution of the matrix material due to their high electrochemical potential. Therefore, the development of new Ag alloys with an adapted degradation profile, are a focal point of this work. Due to the immiscibility of Fe and Ag, it is not possible to cast FeMnAgX alloys, but it is feasible to manufacture these alloys using powder-bed-based additive technologies.

PROJECT OVERVIEW

DURATION

04/2019 – 03/2021

PARTNER

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

FUNDED BY

German Research Foundation (DFG)

RESEACHER

Research Leader
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Prof. Dr. Guido Grundmeier (TMC)
Prof. Dr. med. Manfred Kietzmann (TiHo)

Research Assistant
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Jan Krüger, M.Sc. (LWK)
Dr. Christoph Ebbert (TMC)
Dr. Chen-Ni Liu (TMC)
Dr. Jingyuan Huang (TMC)
Markus Voigt (TMC)
Dr. med vet. Jessica Meißner (TiHo)
Dr. med vet. Viviane Filor (TiHo)

DFG Deutsche Forschungsgemeinschaft
German Research Foundation

Objective

The aim of the research project is to develop and char-acterize bioresorbable FeMnAgX alloys and their qualifi-cation for additive manufacturing, specifically Laser Beam Melting (LBM). The cooperative approach includes the development, production and characterization of additively manufactured structures made of convention-ally immiscible alloys with strongly different melting points such as FeAg. Due to the potential application of resorbable implants in biomedical engineering, the bio-compatibility as well as higher 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 challeng-es to process management in LBM and in the post-processing of the manufactured to some extend com-plex components. Due to the high stiffness and strength of FeMn alloys compared to the human bone, the re-quired mechanical properties are moderately. Therefore, the biocompatibility and degradation behaviour are in focus of the process adjustment. The microstructural properties, especially the distribution, including size, structure and shape of the Ag particles in the FeMn matrix, have 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 Ag alloy to prevent complications, e.g. blocked blood vessels. Upon its antibacterial effect, silver is a promising candidate for the devel-opment of a degradable alloy with high electrochemical potential. Unfortunately, the extremely slow corrosion of silver needs to be increased via alloying based on the formation of interme-tallic phases or eutectica. Apart from degradable Ag alloys, further approaches are the processing of Ag coated FeMn particles to achieve fine distributed Ag phases as well as the mixture of FeMn with other de-gradable elements, like pure Fe.

Approach

Primary to the fabrication of specimens from the final FeMnAgX and FeMn-Fe alloy, the base materials (FeMn, Fe) are manufac-tured via LBM. These samples are characterized regarding their chemical composition (spark spectroscopy) and microstructure e.g. porosity (light microscopy, scanning electron microscopy, micro-computertomography, X-ray-diffraction). In addition, different potentially degradable AgX alloys are conven-tionally casted and examined regarding their microstruc-ture (light microscopy, scanning electron microscopy, X-ray-diffraction). Furthermore, the surface chemistry of the silver-based alloys and base materials is character-ized at the Department of Technical and Macromolecular Chemistry (TMC) and the biocompatibility is investigated at the University of Veterinary Medicine Hanover, Foun-dation (TiHo). Corrosion tests are conducted in Ringer's lactate and modified simulated body fluid (m-SBF) solutions to identify promising alloy systems and to charac-terize the corrosion properties (TMC, TiHo). As the gas-atomization of each potential AgX-alloy is to expensive, conventionally casted bulk material is taken as reference for fundamental examination. Only the AgX alloy with best chance to fulfil the requirements (biocompatibility, degradation rate, processability) is casted and gas-atomized.

The gas-atomized and sieved powder of base material and AgX alloy is analyzed concerning particle size distribution (mastersizer), morphology and chemical composi-tion (scanning electron microscopy, micro-computertomography). Parallel to the alloy-design, a modification of the FeMn powder particles within the synthesis of nanoparticular Ag on the surface is addressed at the TMC. All promising alloy systems are investigated in terms of degradation behavior (ex-vivo and in-vitro), immunotoxicity and microbiological behavior at the TiHo.

Outlook

The influence of the interaction between mixed FeMn and AgX powders during LBM will be investigated. Final-ly, the biocompatibility and degradation characteristics under conditions similar to those experienced in the human body will be examined for additively manufac-tured specimens.

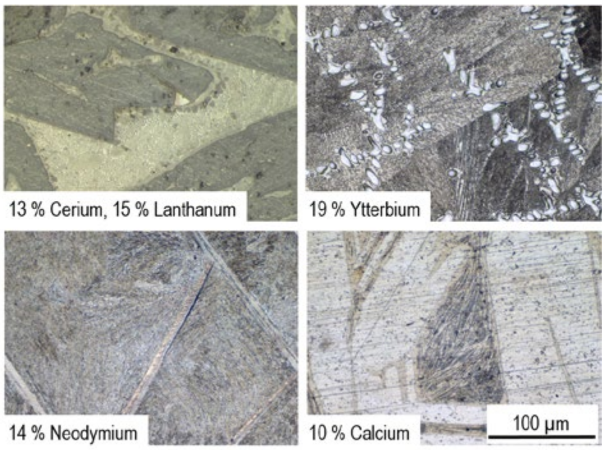

FIGURE 1 Microstructure of conventionally casted degradable silver alloys (alloy content in weight percent)

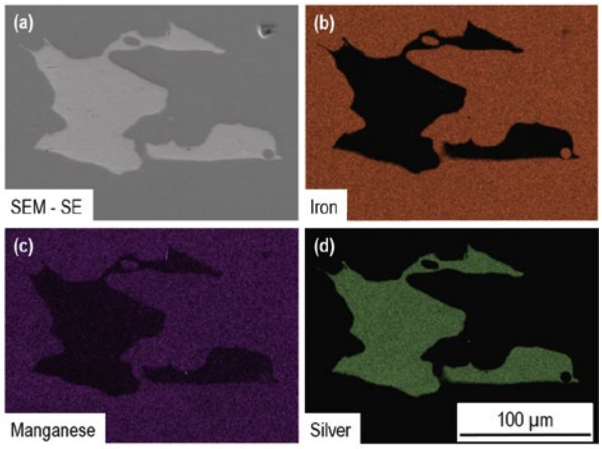

FIGURE 2 SEM-images of pure Ag particles embedded in an iron-manganese matrix (processed via LBM); SE-image (a) and EDS mapping (b)-(d)

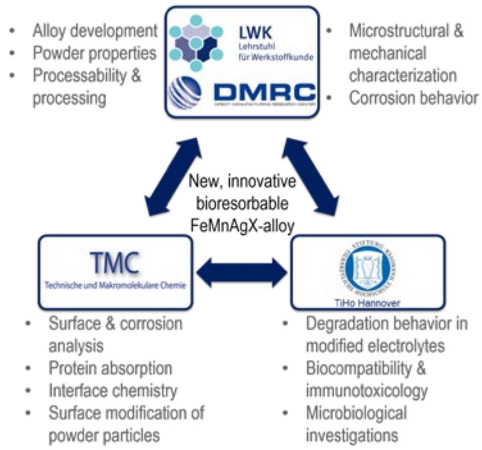

FIGURE 3 Organization and responsibilities within the DFG project

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

This project is about the ability 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 – 08/2019

PARTNER

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

FUNDED BY

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

RESEACHER

Research Leader
Prof. Dr.-Ing. Volker Schöppner

Research Assistant
Dr. Jessica Meißner
Dr.-Ing. Frederick Knoop

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 protection elements is limited due to the restricted geometry as well as the inflexible production (Figure 1). A challenge of 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, for this 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 can bear 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 have shown 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 material Ultem 9085 (cf. Figure 3). To determine the correlation between porosity and venting, an air permeability test setup was developed. FDM samples were tested with 10 bar air pressure and the pressure drop was 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)

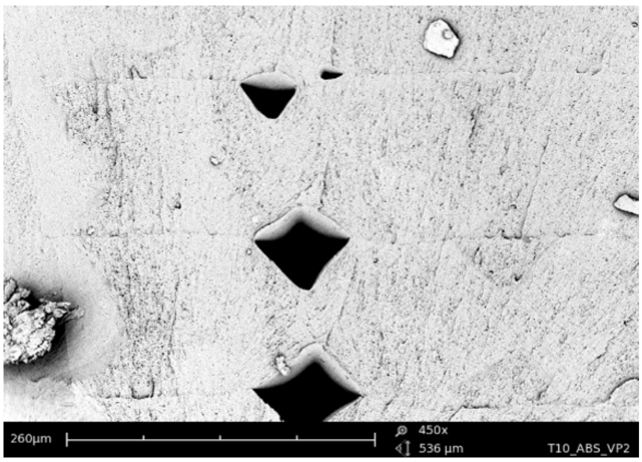

FIGURE 2 SEM-Image of a FDM structure shows process-related porosity

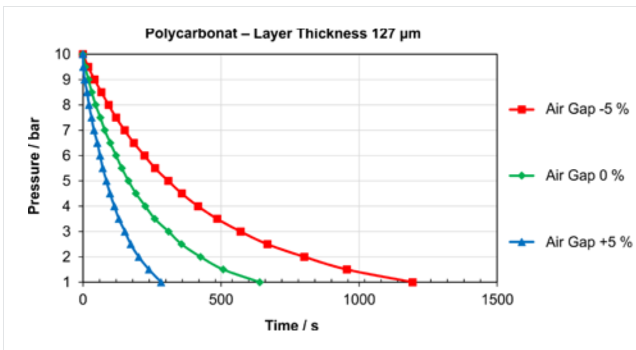

FIGURE 3 Influence of the air gap on the pressure time behaviour

DEVELOPMENT OF DESIGN AND MANUFACTURING GUIDELINES FOR ARBURG PLASTIC FREEFORMING

The Arburg Plastic Freeforming (APF) is an additive manufacturing process with which three-dimensional, thermoplastic plastic components can be produced. The components are produced layer by layer through the deposition of fine, molten plastic droplets. The aim of this research project is to determine the potential and process limits of the APF process. The focus is on the mechanical, geometrical and visual properties in correlation to the process parameters. 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)

RESEACHER

Research Leader
Prof. Dr.-Ing. Elmar Moritzer

Research Assistant
Andre Hirsch, M.Sc.

DFG Deutsche Forschungsgemeinschaft
German Research Foundation

Objectives

The aim of this research project is the development of manufacturing and design guidelines for the Arburg Plastic Freeforming (APF) process. With these guidelines a quicker process design and optimization shall be achieved. Therefore, the key target values concerning the mechanical properties, the geometrical and visual properties of the components, warpage and material degradation must be taken into account separately. Through a detailed process understanding regarding the limits of and the influences on the process, the efficiency of the incremental steps of material qualifications and process parameter optimization shall be increased significantly. At the same time, the capabilities as well as the boundaries for the manufacturing of components using the APF should be identified in the course of this research project. For this, the properties of components manufactured using the APF process are compared to comonents fabricated trough injection molding and fused deposition modeling. All investigations are carried out with ABS.

Recent findings and 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 boundaries. In the course of the research project the key mechanical values for the characterization of additive manufactured specimens were determined. For the influencing factors the process specific process parameters e.g. formfactor, layer thickness as well as processing temperatures were investigated. The in the preliminary investigations acquired understanding of the process serves as the basis for a design of experiments (DOE). In the DOE the response surface method is chosen. With this method not only the main effects and interactions but also quadratic effects can be detected and described.

During the investigations the influences of the process parameters on the mechanical and visuall properties of components manufactured using the APF process are identified. Using the model of the process, obtained through the DOE, a process parameter optimization with a maximization of the target parameters (tensile strength, Young's modulus, elongation at break) has been achieved. The validation of the model shows a 15 % discrepancy between the model and the achieved values for the tensile strength and Young's modulus. For the elongation at break higher descrepancies were observed.

In the following progress of the research project the transferability of the model and the developed guidelines onto other materials is evaluated. Probably the effect of the influencing factors on the results will be similar. Besides, further investigations concerning the mechanical properties in the Z-direction shall be conducted. The previous results show a significant weakness of the specimen in the Z-direction. This causes a reduced maximum resilliance of parts. A process parameter optimization aimed at improving the properties in Z-direction is planned.

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 APF process. The material degradation is investigated with regard to both the molecular mass distribution and its effects on the rheological behaviour. For this, the influence of material degradation of ABS on the characteristic material properties shall be investigated. With these results the maximal occurring material degradation of ABS during the process can be determined.

In addition, it will be investigated how the building strategy influences the dimensional stability of the additive produced parts. In this context, component dimensional stability describes the resulting warpage of the components and the achievable visual quality of the APF 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.

FIGURE 1 Arburg Freeformer (Source: Arburg)

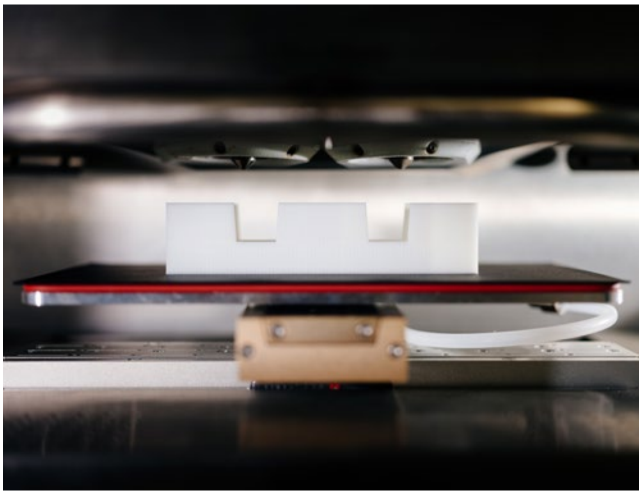

FIGURE 2 Manufacturing of test specimens for the analysis of the specific droplet deposition

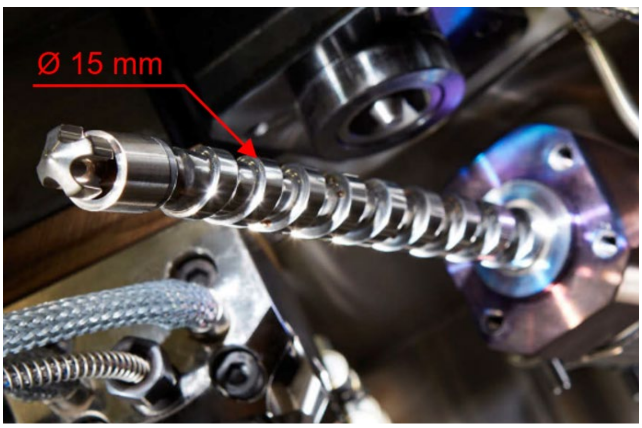

FIGURE 3 Analysis of material degradation: Screw in the Freeformer (Source: Arburg)

GUIDELINE FOR FUNCTIONAL INTEGRATION WITH AM

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

PROJECT OVERVIEW

DURATION

18 Month

PARTNER

- Fraunhofer Institute for Mechatronic Systems Design

FUNDED BY

- FVA – Research Association for Drive Technology

RESEACHER

Research Leader
Prof. Dr.-Ing. Detmar Zimmer (KAt / DMRC)
Research Assistant
Prof. Dr.-Ing. Roman Dumitrescu (IEM)

The process-specific characteristics of additive manufacturing (AM) offer many possibilities and the AM industry has recorded enormous growth rates in recent years. The high degree of design freedom and the cost-effective production of small quantities are only some of the advantages. The technology is now used across all industries for the production of prototypes or tools, but is also increasingly used in the production of series parts. In addition to the possibilities, the new processes are also creating unknown challenges that the users of this technology must consider.

Drive technology as a field of application

Drive technology components are used wherever a movement is to be generated. Due to increasing automation, drive technology is becoming more relevant. Innovation efforts in this field are correspondingly high, since in addition to functional optimisations, even small increases in the efficiency of these components can enable significant savings due to the high degree of use. In this context, additive manufacturing represents an innovative group of manufacturing processes that process-specific characteristics offer new possibilities for manufacturing that can be used to optimise the function and increase the efficiency of drive components.

New possibilities require new approaches

In order to use the given potentials, a corresponding development and optimisation process is required, which must be accompanied by a methodical procedure due to the variety of requirements and the complexity of the components. In this mostly iterative process, the requirements are identified and, via successive detailing, the designers are confronted with process-specific possibilities that do not exist in conventional manufacturing processes.

The functional and economic potential of additively manufactured components can only be fully exploited if suitable approaches are developed and applied already in the conception. Process-specific characteristics of additive manufacturing require a rethinking already in the concept phase. Due to the geometric design possibilities of additive manufacturing, complex components can be produced economically and thus enable a higher degree of

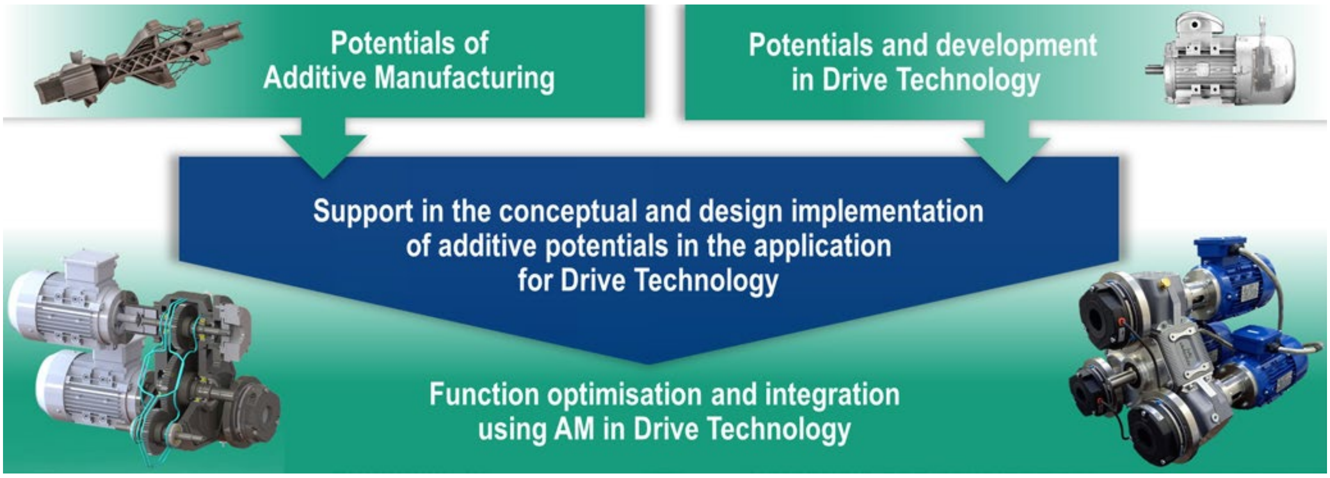

FIGURE 1 From the function to the AM part - identifying and exploiting potentials

functional integration. The possibility of implementing several functions in one component and thus saving material and assembly steps offers ecological and economic advantages.

Possible tools to support the new challenges in the design of additively manufactured components are active principles and design guidelines. The active principles represent basic solution approaches for concrete functions and are intended to describe promising possibilities in the early development phase. This can include conventional approaches, but also additive solution approaches that were previously not possible or economically uninteresting. Design guidelines describe the limits of manufacturing possibilities, boundary conditions and specifications which must be considered for a robust manufacturing process and safe application. These two tools support the user in the conceptual design and constructive implementation of new, additively manufactured functional components.

Research objective

The research objective is to develop a catalogue to support the designer in the context of conceptual and design-related challenges. The scope is focused on the possibilities of function integration in the application field of drive technology.

The consistent use of additive manufacturing still represents a major challenge for many companies. It is particularly difficult for small and medium-sized companies to build up experience in this area, as the barriers to entry are high due to investments and initial application attempts are evaluated accordingly critically. The catalogue with active principles and design guidelines is intended to serve as support for the user in this initial phase, but also beyond. This assistance in the conceptual and design development phase is intended to promote innovative and functional AM components and thus support the application of additive manufacturing. For highly specialised companies in particular, additive manufacturing offers the possibility of gaining a significant lead in international competition through the consistent improvement of components. To achieve this, the advantages of additive manufacturing must be exploited to the best possible extent and the disadvantages must be consciously minimised. This requires a comprehensive rethinking along the entire product development process.

To convey the AM-specific challenges and the resulting methodological aspects, a self-learning document is being developed. This training approach enables small and medium-sized enterprises to use the possibilities of AM with regard to function integration and to objectively identify risks in advance.

IAMNRW - POLYMERS

The limited choice of materials still portrays the obstacles faced in diverse applications of selective laser sintering process. Most of the products are therefore manufactured using PA12. Currently, there are no suitable methods for the production of powders from other polymers. Within the framework of the EFRE-project, two different powder manufacturing methods shall be adapted and introduced here. The first method describes a cryogenic milling with an aftertreatment involving thermal particle rounding while the second method describes the PGSS process, also known as the high-pressure spray process. Through these production plants, new powders for the laser sintering shall be manufactured in the future.

PROJECT OVERVIEW

DURATION

09/2018 – 08/2021

FUNDED BY

EFRE

RESEACHER

Research Leader
Prof. Dr.-Ing. Hans-Joachim Schmid (PVT)
Prof. Dr.-Ing. Volker Schöppner (KTP)
Research Assistant
Moritz Rüther, M.Sc.
SathishKumar Ponusam, M.Sc.
Jan Hendrik Martens, M.Sc.

EFRE.NRW
Investitionen in Wachstum und Beschäftigung

EUROPÄISCHE UNION
Investition in unsere Zukunft
Europäischer Fonds für regionale Entwicklung

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

Background

On the technical level, the processes described here are relatively well-known. As such, the PGSS method was developed at the Ruhr-University Bochum and used for the pulverization of polyethylene glycol and biological growths. Nevertheless, the application of this process for technical polymers such as PP, PA6 and PA6.6 is yet unsuccessful.

Furthermore, the cold milling process with an aftertreatment based on thermal rounding of the milled products were previously studied at the University of Erlangen. However, the aftertreatment process currently delivers a low yield of 30-50% and hence, is without any further process modifications relatively unsuitable for the mass production.

Despite these existing problems, the principles behind both of these methods coupled with the essential modifications of the process designs would enable the continuous productions of SLS-powders. Both processes are described in detail below and moreover, the adapted plant engineering as well as the research objectives of these processes are focused separately.

Particles from Gas Saturated Solutions (PGSS)

PGSS is a high-pressure spray process. It is based on the phenomenon that supercritical fluids (e.g. N2, CO2) can be easily dissolved in other substances. High pressures are required to reach the supercritical state of the fluid. If the mixture is expanded via a nozzle, the aggregate state of the dissolved fluid changes, its solubility decreases and it escapes from the surrounding matrix. The matrix is torn apart and fine droplets are formed. Due to the Joule-Thompson effect, the gas temperature also decreases as a result of the expansion, causing the droplets to cool and finally solidify.

The supercritical fluid used here is CO2 (6 in Figure 1), which is preconditioned by diaphragm pumps (7) and heat exchangers (8). The dissolution of CO2 into the polymer matrix is essential for the process. In the plants at the Ruhr- University Bochum,

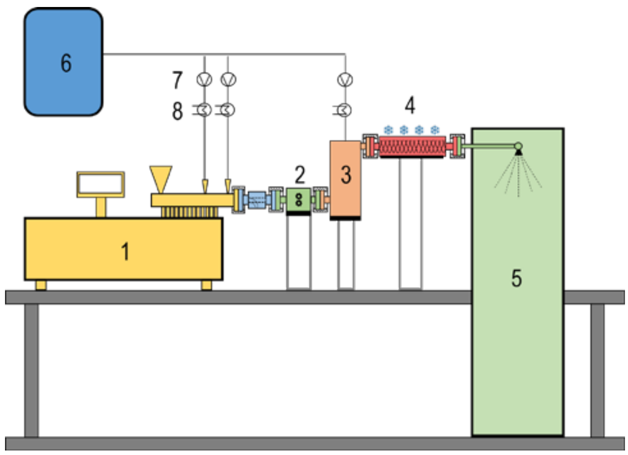

FIGURE 1 Schematic layout of the PGSS plant

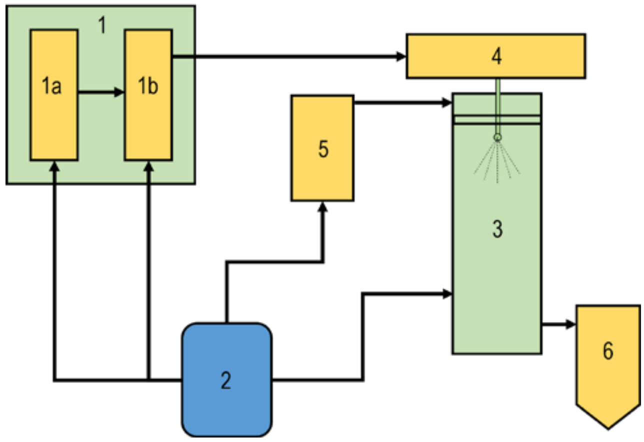

FIGURE 2 Schematic layout of the cryogenic mill and the downer-reactor

this was done by static mixers. In the plant presented here, the supercritical fluid is fed into a twin-screw extruder (1 in Figure 1) during the compounding itself. In addition, further homogenization takes place in a dynamic mixer (3). If necessary, further fluid can be injected into this mixer. A gear pump (2) and another heat exchanger (4), which also functions as a static mixer, are used to regulate the pressure and temperature of the polymer/ CO_2 mixture. These three mixing stages are intended to ensure a homogeneous mixture. At the end, a nozzle in a spray tower (5) produces the spray, out of which the particles are formed.

The main objective of the project is to enable a continuous production of SLS-powders from granulated polymers. For this purpose, the PGSS system must be parameterized. In addition, the behavior of gas-laden melts is to be investigated in depth. At the moment the plant technology is being set up.

Cryogenic milling & particle rounding in the gas phase

In this initial process, the granules are fed continuously to the cryogenic mill (1 in Figure 2). Prior to the grinding step, the granules are embrittled in a screw cooler (1a) integrated into the mill, in which the cooling process is achieved by an external supply of the liquid N_2 (2).The embrittlement of the granules occurs when the process temperature is lower than the glass transition temperature of the polymer. The brittle granules are then fed to the grinding chamber (1b) which is also cooled down by the liquid N_2 to ensure the particles do not undergo a phase transition into the elastic region due to the heat generation. Due to the mechanical stresses during the milling step, the resulting particles often exhibit ragged surfaces with sharp edges and therefore, possess low bulk densities and flowabilities. To improve these features, the particles are then continuously dispersed into a hot downer-reactor (3) by using a powder disperser (4).The aim of this procedure is to heat the particle up to its molten state, thereby improving its sphericity due to the resulting effect of the surface tension. Thus, a pre-heated secondary N_2 gas (5) is fed to the downer reactor to enable the particles to rapidly achieve its molten state. After the thermal rounding of the particles is completed, the hot multiphase flow is instantly quenched using the liquid N_2 and the cooled, round particles are then separated from the flow using a gas cyclone (6). The secondary N_2 gas also acts as a sheath gas to avoid particle losses due to the frequent collisions between the particles and the hot reactor wall.

Through the parametrization of the milling and thermal rounding processes as well as the modification of the gas distribution system in the downer-reactor, this project offers the possibility to attain a high continuous yield of SLS-powders.

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

The overall objective for iBUS was 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 Ltd.
- ManOpt Systems Ltd.
- 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)

RESEACHER

Research Leader
Prof. Dr.-Ing. Rainer Koch

Coordination
Anne Kruse, M.Sc.

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 was 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 had a budget of 7.440.362€ whereas 6.065.305€ are funded by the European H2020 programme.

Main participation of DMRC was in the WP3 "Customised Product Design Virtual Environment". Here a software system was 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.

In the last month of the project, the web based software solution was 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

Laser Beam Melting (LBM) allows not only the cost-effective production of metal components with highly complex geometries, but also the processing of materials that cannot be produced by conventional methods such as casting. The design of new application-adapted alloys therefore enables the manufacture of intelligent products with superior properties as well as the expansion of additive production to new areas of application. The aim of the project is to establish a process chain from alloy design and powder production 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

RESEACHER

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Research Assistant
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2014-2020 EFRE.NRW Investitionen in Wachstum und Beschäftigung

EUROPÄISCHE UNION
Investition in unsere Zukunft
Europäischer Fonds für regionale Entwicklung

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

Objective

One of the biggest challenges in additive manufacturing (AM) is to guarantee a high powder quality, since only a few external companies produce metallic powder for AM. Although the material and the desired powder fraction may be specified, the quantity of powder ordered is not always sufficient due to the high production costs. Furthermore, the process of the powder production itself is not necessarily prescribed and can take a long time, which limits the research activities within ongoing projects. Finally, powder producers do not guarantee the desired particle morphology, particle size distribution and precise chemical compositions – especially for light elements such as carbon. Since both, an exact chemical composition and the powder quality, i.e. particle size and morphology, have a decisive influence on the microstructural and mechanical characteristics of the additively manufactured components, research should not only focus on LBM itself, but also on powder production and characterization.

The design of new alloy concepts addresses three main scientific issues:

- Soft magnetic iron-based alloys for the additive manufacture of electric motors.
- Functionally graded materials with defined local differences in microstructure and/or chemical composition, which for example enable a reduction of the moving mass in additively manufactured electric motors.
- Innovative silver-based alloys as an additive to iron-based biodegradable components for medical purposes, which are expected to degrade at a predefined rate parallel to the dissolution of the Fe-matrix.

Soft magnetic iron-based alloys

The gas-atomization of powder with a predefined particle size of the alloy FeSi9 has been performed.
Adjusting the process parameters of LBM enabled a significant reduction in the porosity of the specimens (Figure 1). In addition, appropriate post-processing, especially heat treatment, allows the simultaneous reduction of residual stresses and adjustment of the

desired grain size. The greatest challenge in processing this alloy is its high susceptibility to cracking during production. This can be explained by an excessive temperature gradient in the samples during manufacture. Therefore, investigations are ongoing to minimize the crack formation, e.g. via the reduction of the laser power and the use of a space heater.

Functionally graded materials

The processability of the functionally graded specimens made of the alloy FeSi3 (soft magnetic middle part of the rotor) and the quenched and tempered steel (Q & T steel) 34CrNiMo6 (shaft end with reduced mass compared to FeSi3) has already been confirmed. Not only cube samples, but also tensile and fatigue specimens with a density > 99.9 % have been successfully manufactured. The analysis of the microstructure shows a non-porous bond between the two materials (Figure 2a). By a subsequent heat treatment, the desired profile of mechanical properties can be adjusted, which means reducing the residual stresses in the soft magnetic alloy FeSi3 while ensuring a high ductility and strength in the Q & T steel (Figure 2b). The next step is to analyse the fatigue properties of the metal compound.

Innovative silver-based alloys

Based on the results of degradation tests (immersion tests), performed on various silver alloys containing Ca, Mg, Si, Ge and La, two alloys were selected, namely Ag-14Mg and Ag-7Ca. These alloys show a faster degradation rate than pure silver (Figure 3) and are electrochemically nobler than iron, which should allow the desired catalysis of iron-based matrix degradation in the human body. Here, the Ca content can be further increased up to 14.0 wt.-% and the Mg content up to 18.5 wt.-% in order to control the degradation process of the silver-based particles. As a next step, the selected alloys will be atomized and added to the iron-based powder. Subsequently, the specimens will be manufactured via LBM followed by an analysis of their degradation behaviour.

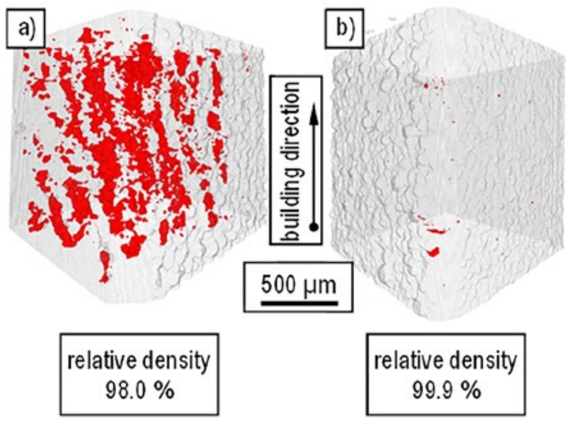

FIGURE 1 µCT-scans of specimen build with standard LBM-parameters (a) and with optimized LBM-parameters (b)

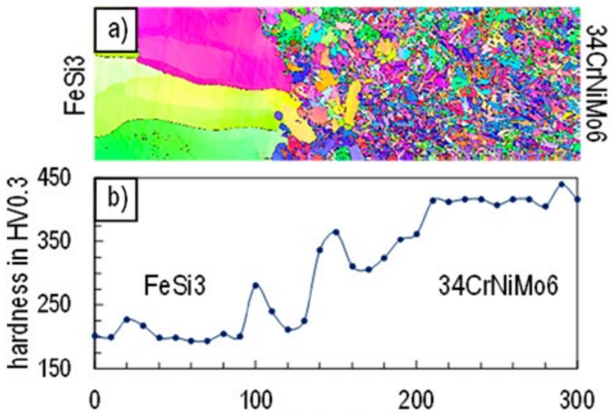

FIGURE 2 Microstructure of the interface between FeSi3 and 34CrNiMo6 in a functionally graded specimen (a) with corresponding hardness profile after heat-treatment (b)

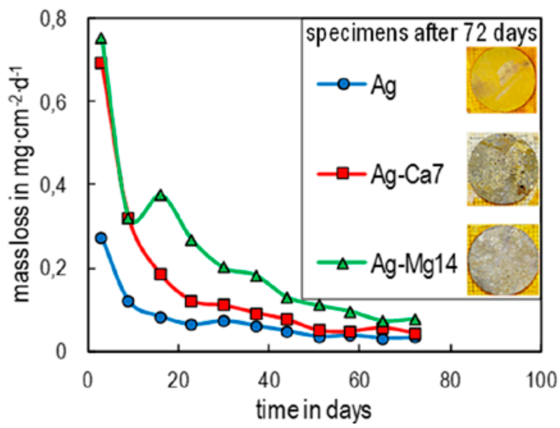

FIGURE 3 Degradation of different silver-based alloys after immersion tests

INNOVATIVE LIGHTWEIGHT DESIGN AND COOLING CONCEPTS FOR ELECTRICAL MACHINES USING ADDITIVE MANUFACTURING (ILUKADD3D)

The aim of this project is the successful implementation of additive manufacturing in electrical engineering. In order to introduce and exploit the advantages of additive manufacturing in electrical engineering, innovative application concepts will be identified and investigated. This is achieved by the identification of innovative cooling and lightweight design concepts within engine components. However, the main focus of this project is very interdisciplinary. Therefore, this project is a collaborative project between the DMRC and the IAL (Institute for Drive Systems and Power Electronics) at Leibniz University Hannover, combining the experise of alloy-design, design guidelines and mechanical as well as electrical characterization.

PROJECT OVERVIEW

DURATION

11/2019 – 04/2022

PARTNER

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

FUNDED BY

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

RESEACHER

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

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FVA Forschungsvereinigung Antriebstechnik e.V. iGF

Motivation and objective

Despite the many advantages of additive manufacturing (AM), it is primarily used in aerospace and medical technology, thus in areas in which lightweight design and individualization have the highest priority. In other areas, it is only slowly establishing itself due to the high production costs in series production. Nevertheless, AM offers the potential of improvment and economical use in other areas. In the field of electrical engineering, there is potential for improvement in form of lightweight design and cooling concepts and the functional expansion of individual components.

The objective of this research project is the integration of additive manufacturing into electrical engineering by designing and manufacturing an optimized permanent-magnet synchronous machine (PMSM) (Fig 1). In the fabrication of electric motors, conventional manufacturing, in form of the lamination of electrical sheets, leads to restrictions on design freedom. These restrictions do not apply in additive manufacturing, which allows the integration of previously unproducable concepts. An existing electric motor is to be optimized by integrating innovative cooling and lightweight design concepts into the exisitng motor components, possible through the design freedom of additive manufacturing. In addition, the geometry and microstructure of the rotor and the shaft should ideally support the magnetic flux in the motor. Despite the high production costs, the potentials of the component complexity and the high functional density increase the parts value and result in cost-effective production processes. The knowledge gained from the project shell be used specifically to develop new innovative products in electrical engineering in order to enter new markets with the help of additive manufacturing.

Previous studies

Current and completed projects, carried out in a cooperation of the DMRC and the IAL, such as the “Feasibility study 3D printing of electric motors; FVA 731I & 731 II” and the DFG project “Research into the potential of additive manufacturing in rotors of permanent-magnet synchronous machines”, have already demonstrated the potential for the use of additive manufacturing

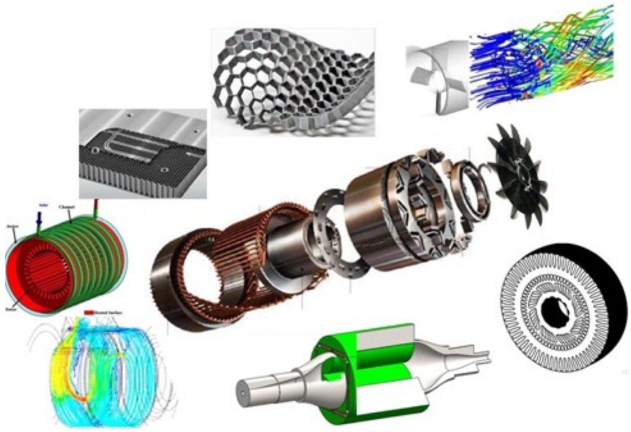

FIGURE 1 Considerable concepts for the PMSM optimization

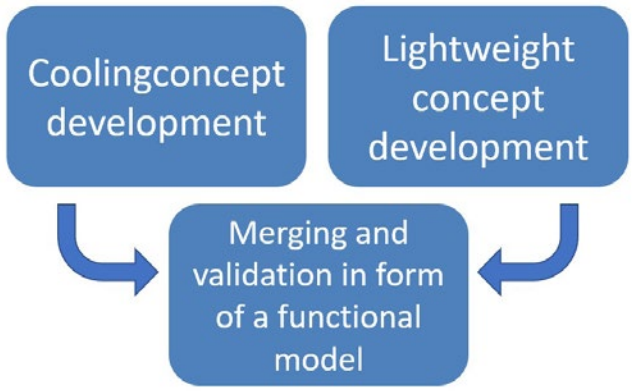

FIGURE 2 Project structure

in electrical engineering. A high potential could be proven and previous knowledge gained which is used in this project. Extensive experience from these projects is used, particularly for the material selection. Material characterizations that have already taken place, as well as challenging issues, such as defects due to high residual stresses at FeSi6.5, serve as prior knowledge for this project.

Approach

The additively manufactured engine components are designed suitable for munufacturing and optimized with regard to their cooling and lightweight potential. The project is divided into three work packages (WP). While WP1 and WP2 focus on the development of cooling and lightweight design concepts, in WP3 the previously gained knowledge will be applied to a functional model in order to validate the results (Figure 2). At the beginning of the project, in the work packages WP1 and WP2, which are being carried out in parallel, the aim is to develop applicable cooling and lightweight design concepts on the basis of literature research. A subsequent evaluation is intended and selected concepts will be further adapted to a geometric shape optimized for additive manufacturing. Experimental investigations and numerical simulation models will be carried out to provide a scientific foundation in order to be able to quantify the optimized cooling and lightweight properties. The experimentally and numerically determined results are used in WP3 to design the functional model, which is supposed to be an optimized version of an electric motor provided by industry. Finally, the functional model will be manufactured and its engine properties determined on a test bench in order to validate it in comparison to the original model.

State of project

Since the beginning of the project, several promising cooling and lightweight design concepts have been identified in an extensive literature research, considering the manufacturing conditions of additive manufacturing. These concepts are currently being analyzed and evaluated in order to make a closer selection. At the same time the first test specimens for material characterization are manufactured and analyzed. The aim is to compare the two, for the rotor selected alloys, FeCo50 and FeSi2.9 and determine the relevant material parameters for the design of the functional model. In particular, the influence of FeCo50 heat treatment is considered, as this appears to be a promising option for adjusting the material's parameters.

Furthermore, an electric motor was determined as a demonstrator. The selected PMSM is a Prototype manufactured by Wittenstein cyber motor GmbH which is used as a startingpoint for concept development, and later for comparison and validation of the engine developed.

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

The automotive industry is a key industry in Germany and one of the country's largest employers. To withstand international competition and meet increasing customer requirements, innovative, flexible and versatile types of production are in demand. Particularly, electric mobility is greatly interested in lightweight and low vibration parts with a high degree of function integration. Additive manufacturing can make a significant contribution towards realizing such requirements. Within this project, a prototype additive series production will be implemented for the automotive industry.

PROJECT OVERVIEW

DURATION

10/2019 – 09/2022

PARTNER

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

FUNDED BY

Federal Ministry of Education and Research (BMBF)

RESEACHER

Research Leader
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Federal Ministry of Education and Research

In additive manufacturing, laser powder bed fusion (LPBF) is on the threshold of being installed in industrial series production. Having been used in prototype production for many years, it has become a more and more established process for small series production of motor sports components and spare parts. A wide range of applications in the series production of the automotive industry is becoming relevant, especially in the premium segment and for specific components in derivatives. However, LPBF should not be seen as an isolated process, but rather as an important step in a whole process chain extending from part design, powder supply, and the actual LPBF process to post-processing. A major obstacle in further expanding such process chains is the lack of vertical and horizontal data integration and the insufficient coordination of design parameters along the process chain. Nevertheless, data integration must be seen as an exigence for safe production, opening further optimization potentials in the hybrid additive process chain, so that the requirements of automotive series production can be met.

Project overview

Regarding the implementation of a series production of additive manufactured parts in the automotive industry, one aim of this project is the realization of a prototypical line integration. This will allow to gain general knowledge and help in planning of future lines. Threrefore, suitable in-line and in-process measurement technologies will provide feedback from the individual steps of the process. Thereby, in conjunction with suitable algorithms, a control of the individual process parameters in the LPBF process chain can be implemented. For example, information of the LPBF process about geometrical accuracy or part status can be used in the final machining process to ensure optimal and reproducible technical functionality of the finished part by defining appropriate process parameters. The materials used in series production will be specifically attuned to the needs of the applications. To ensure the robust and safe processing of different material, a new type of heating system is developed and integrated into the machine. For an economical production, the system technology is automated at the key points. Therefore, appropriate system and factory con-

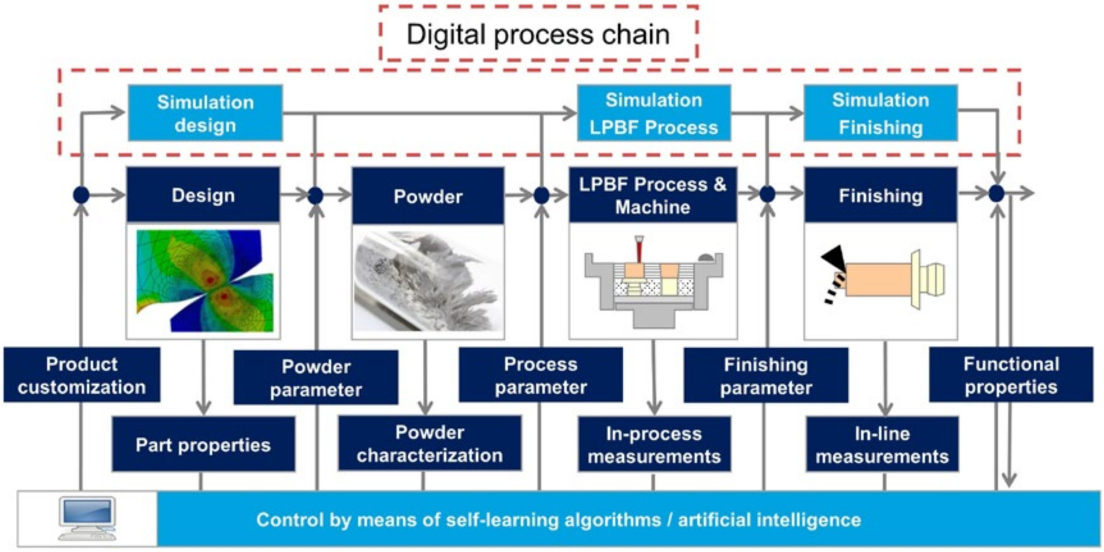

FIGURE 1 Digital process chain and possible control loops

cepts will be designed and implemented for partial automation. In order to realize control of the whole process chain and configuration of all parameters, a data integration will be implemented in the planned serial production. For this purpose, all parts of the process chain including the part design, the powder, the LPBF process itself and the post-process are connected and a vertical and horizontal data integration will be achieved.

Part design

Especially, in part design for additive manufacturing, the conception and design phases can be digitized for line integration. Within the conception of parts, vibration damping through additively manufactured structures can be improved significantly, whereby the parts have achieved a high level of function integration and function density. These potentials are quantified by experimental investigations, thus enabling the designer to improve the performance of parts. Thereby, additively and conventionally manufactured parts can be compared at an early stage in the design process. As a result of this research, design guidelines for using particle impact damping as an active principle will be derived. The part design is further extended by design guidelines for a manufacturing-oriented support design, which will be digitized in design catalogues. With regard to post-processing, it is indispensable to evolve geometric deviations experimentally and evaluate these results with machine learning methods. Recommendations for a design of the parts suitable for measuring must also be drawn up. The aim is to optimize the part design based on their function and the necessary tolerance values and thus enable a robust process chain. The process parameters and their influence on the part quality will be examined by differnt project partners. Results at the end of the process chain can be given back into the part design in order to iteratively analyze and improve either the parts or the process parameters. The experimentally determined results in particle impact damping, manufacturing-oriented support design and geometric deviations are converted into digital active principles, design guidelines and tolerance catalogues and thus serve the line integration in software tools within the project. Using artificial intelligence and machine learning will help create a universally applicable and general digital process chain as an addition to the actual process chain

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

To achieve the performance of conventionally manufactured components, additively manufactured components have to fulfill at least the same requirements. This includes the possibility of functionalized surfaces with 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

FUNDED BY

German Research Foundation (DFG)

RESEACHER

Research Leader
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Prof. Dr.-Ing. Wolfgang Tillmann
Research Assistant
Kai-Uwe Garthe, M. Sc.
Dipl.-Wirt.Ing. Leif Hagen

DFG 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. In this context, 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. Therefore, a fundamental understanding of both, the process and the combination of the advantages of both process steps to substitute further process steps, such as metal-cutting surface treatments, is mandatory. 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

First, for the manufacturing of the samples a parameter adaption is carried out. Subsequently, established sample geometries for fatigue tests (dog bone samples for room temperature and cylinder samples for 650 °C) are produced. The investigation of the manufacturing parameters ensures definable sample properties with a negligible porosity for a robust process and reproducible mechanical properties. After the production, all samples are examined regarding roughness, residual stress and porosity. This is followed by a pre-treatment using grinding or corundum blasting with a subsequent additional characterization of the roughness and residual stresses. The effects of the respective pretreatment methods on the surface are measured and correlated. Untreated samples (with and without heat treatment) are carried along as reference. Furthermore, half of the samples are coated via atmospheric plasma spraying using Al2O3 as coating material. The coating is performed at the Institute of Materials Engineering (TU Dortmund).

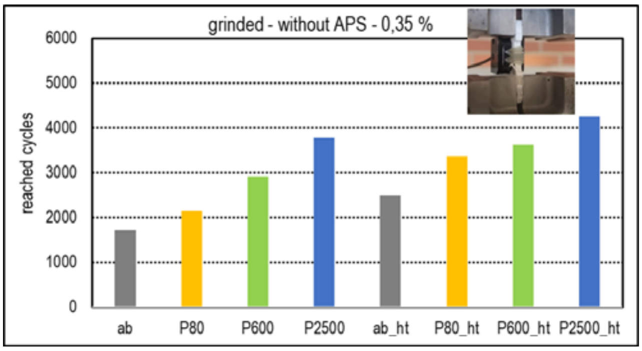

FIGURE 1 Low cycle fatigue strength of grinded, un-coated 316L samples without coating at a strain amplitude of 0.35%

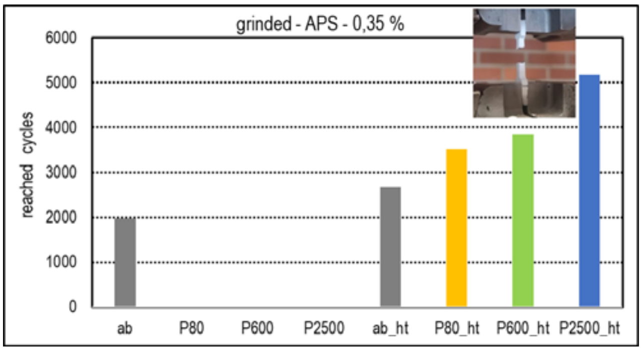

FIGURE 2 Low cycle fatigue strength of grinded 316L samples with a Al2O3 coating at a strain amplitude of 0.35 %

Afterwards, the porosity is quantitatively measured by micro-CT and image analysis. The final step of the investigations is the implementation of low cycle fatigue tests with different total strain amplitudes (0.35 %; 0.50 % and 0.80 %) and the characterization of the fracture surface, crack initiation and crack spread.

Results

In order to investigate the influence of the different pre- and post-treatments (grinding, blasting, heat treatment and coating) on the low cycle fatigue, fatigue tests are carried out. Here, the additively manufactured 316L samples (different states) are fatigued at a total strain amplitude of 0.35 %, a strain rate of 6*10-3 s-1 and at R = -1 at room temperature. Figure 1 shows the low cycle strength of grinded 316L specimens (different states) without coating at a strain amplitude of 0.35 %. Based on the results it can be seen that grinding with a finer grain size leads to a better surface quality, and therefore to better fatigue properties. Furthermore, it can be seen that heat-treated samples exhibit the same tendencies, but with higher numbers of cycles. This can be explained by the fact, that the performed heat treatment reduces residual stresses, which are known to have a negative effect on the fatigue behaviour. Figure 2 summarizes the low cycle strength of grinded 316L samples (different states) with Al2O3 coating at a strain amplitude of 0.35 %. The results reveal that an additional Al2O3 coating ensures a further increase of the low cycle strength. This trend does not apply to the heat-treated samples for the layer adhesion in this state is too low. It can be assumed that the residual stress condition has a negative effect on the adhesion.

Outlook

The restrictions currently present in the SLM process, such as porosity, residual stresses and surface roughness, are to be minimized based on the investigations carried out in this project. Therfore, a general improvement in fatigue life for 316L and Inconel 718 SLM components is achieved. Furthermore, a correlation between the adhesion of different coating materials and the different coating processes regarding their influence on the short-term fatigue of SLM components is addressed in the final period of the research project. The results are then correlated with post-treatment methods, like coating processes and the material pairing, with the aim to specify a critical criterion for adhesion. This approach is very important because a coating, allows non-corrosion resistant materials to be coated with a corrosion resistant material or for example to make it wear resistant.

IT'S OWL TRANSFER PROJECT – POTENTIAL ANALYSIS AND IMPLEMENTATION OF SELECTED ADDITIVE MANUFACTURING TECHNOLOGIES IN PRODUCTION

Additive manufacturing offers enormous potential not only in common industries such as aerospace and automotive but also in the medical sector. The Condor MedTec GmbH has identified this potential for itself and in particular for the so-called extension shoe which is used to fix the foot during hip operations. The laser-sintered extension shoe offers advantages in terms of dimensional accuracy, reproducibility and economy compared to conventional ones. Individualization of the extension shoe can also be realised quickly and cost-effectively. The main aim of this subdivided project (part A and B) was to create know-how for AM and the laser sintering technology at Condor MedTec GmbH in order to meet the high quality requirements of the medical industry.

PROJECT OVERVIEW

DURATION

12 months

PARTNER

Condor MedTec GmbH

FUNDED BY

it´s OWL – Das Technologie-Netzwerk: Intelligente Technische Systeme OstWestfalenLippe

RESEACHER

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

Research Assistant
Dennis Menge, M.Sc.

Transfer project A – Analyses and conception

In transfer project A various approaches were pursued to achieve the objectives in the form of analysis, conception and knowledge transfer between the DMRC and Condor MedTec GmbH. Initially, work package 1 included intensive training of Condor MedTec employees for the introduction to additive manufacturing.

The main focus was on the process chain of additive manufacturing and the basics of the most common additive manufacturing processes. The laser sintering (LS) technology, which has been available at Condor MedTec GmbH since shortly before the start of the project, was examined in detail. The LS technology is used to manufacture a previously conventionally produced extension shoe (see figure 1, the grey part is laser sintered) for the Rotex Table (see figure 2) which is used for hip operations. In order to meet the quality requirements of the extension shoe, which is an essential goal of the project, an extensive market analysis for the post-processing of laser-sintered components was carried out in work package 2. The post-processing of laser-sintered components is of major relevance, especially with regard to surface quality and colouring or coating. The analysis concluded with a detailed overview of the post-processing possibilities, which resulted in four post-processing strategies (combinations of: vibratory finishing, chemical smoothing, infiltration and colouring), which are evaluated in the transfer project B. In the sense of value creation for Condor Medtec, an analysis of the product portfolio was carried out in work package 3 in order to identify economic and manufacturing potentials through additive manufacturing in the product portfolio. Using a decision tool, pre-selected components (pre-selection by Condor on the basis of the training) were analyzed and evaluated with regard to an advantageous production using additive manufacturing based on various criteria such as component integration, material change or lightweight construction, considering economic efficiency.

Transfer project B – Application and validation

Transfer project B dealt with three work packages with different objectives in order to create a knowledge and technology transfer in the context of the digital transformation and thus extend the value chain at Condor Medtec GmbH. First of all, the basic training carried out in transfer project A was extended by an application-oriented expert training on the topics of design guidelines, potential analysis and economic efficiency for additive manufacturing in order to advance the implementation of additive manufacturing.

Furthermore, in the course of the implementation, especially for the laser sintering technology and the special application of the extension shoe, various post-processing concepts for the surface of the product were evaluated. Post-processed specimens, which were processed by means of vibratory grinding, chemical smoothing, infiltration, coloring as well as combinations of these methods, were obtained from various suppliers and the surface quality and mechanical properties were investigated. Furthermore, the influences of steam sterilization, disinfection and detergents on the post-processed test specimens were investigated. In the last work package measures for a quality assuring and economic serial production of the extension shoe were derived. Tensile test specimens are included in every build job and tested on a specially developed test rig. Furthermore, the dimensional accuracy of the shoe is checked using a flange distance. The tensile strength and the flange distance are recorded in process control cards, thus ensuring and checking reproducibility.

In the course of the economic production of the shoe, different build job layouts with different throughput times are transferred into work plans (including cooling and cleaning times) in order to identify the best possible work plan. An exemplary build job is shown in figure 3.

FIGURE 1 Extension shoe [Source: Condor MedTec GmbH]

FIGURE 2 Rotex table [Source: Condor MedTec GmbH]

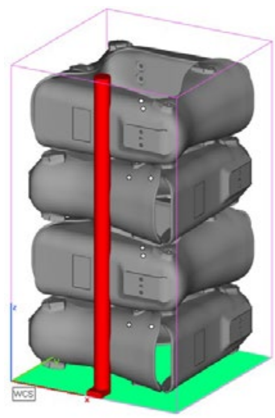

FIGURE 3 Examplary build job for the extension shoer

MATERIAL DEVELOPMENT OF NON-REINFORCED AND FIBER-REINFORCED POLYMERS FOR FUSED DEPOSTION 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

RESEACHER

Research Leader
Prof. Dr.-Ing. Volker Schöppner

Research Assistant
Dr. Christian Schumacher

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 characteristics 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 definied. 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 identified prior to the investigations and custom-built specimens are created during this project to evaluate the identified characteristics.

After the specimens have been verified using well-know materials, for which a good processing suitability has been proven, series of tests are run for each characteristics with different 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 experimental 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 reinforcement was investigated 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

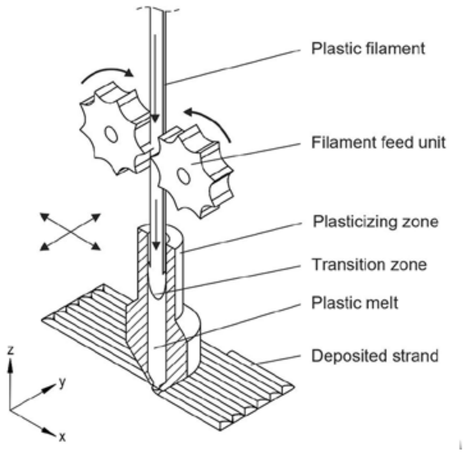

FIGURE 2 Process principle of the FDM process

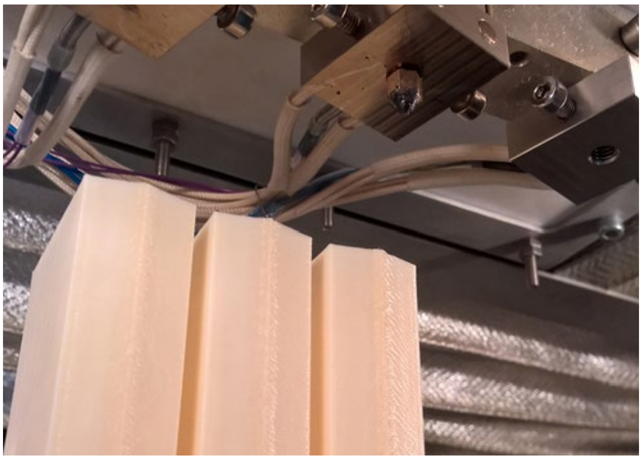

FIGURE 3 Custom built specimen in a build chamber of an FDM machine

MULTI-TARGET-OPTIMIZED PRODUCT DESIGN FOR ADDITIVE MANUFACTURING (OPTIAMIX)

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 – 06/2020

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)

RESEACHER

Research Leader
Prof. Dr.-Ing. Rainer Koch (CIK)
Prof. Dr.-Ing. Iris Gräßler (HNI-PE)
Prof. Dr.-Ing. Detmar Zimmer (KAt)
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Research Assistant
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Johannes Tominski, M.Sc.
Jan Gierse, M.Sc.
Christian Oleff, M.Sc.

Federal Ministry of Education and Research

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.

Latest results

In the first year of the project, promising progress has been achieved in all the sub-objectives of the project. In the sub-goal “Method for strategic-technical part selection”, the researchers of the C.I.K. developed the already existing trade-off methodology for cross-industry application. The branches automotive, food technology and plant and mechanical engineering represented in the project were focused on this objective.

In the target areas “Method for deriving design guidelines” and “Tool for automated and target-optimized component design”, the chairs KAt, LiA and CIK initially developed, produced and tested test specimens for the development of design guidelines for load-, post-processing, cost- and production-oriented design. These methodically derived design guidelines serve as the basis for the optimisation software. The KAt-researchers validated guidelines using the project-accompanying demonstrator and implemented them in a database that can be accessed by the software tool developed by INTES GmbH. In addition, the methodically derived design guidelines were recorded in design catalogues and prepared graphically.

In the development of a methodology for the “Integration of additive manufacturing in companies”, the product development processes of all project partners were analyzed and partially optimized. From this, an “ideal AM process” was derived, which in the future should serve as a component in the field of process integration. Already integrated in this process are the results from the “Method for strategic-technical part selection” as well as the “Method for Part Marking”.

Outlook

The developed methods and the software tool for design verification are finalized and will be validated on further demonstrators until the end of the project. The results will be documented and made available to a broad public through publications.

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.

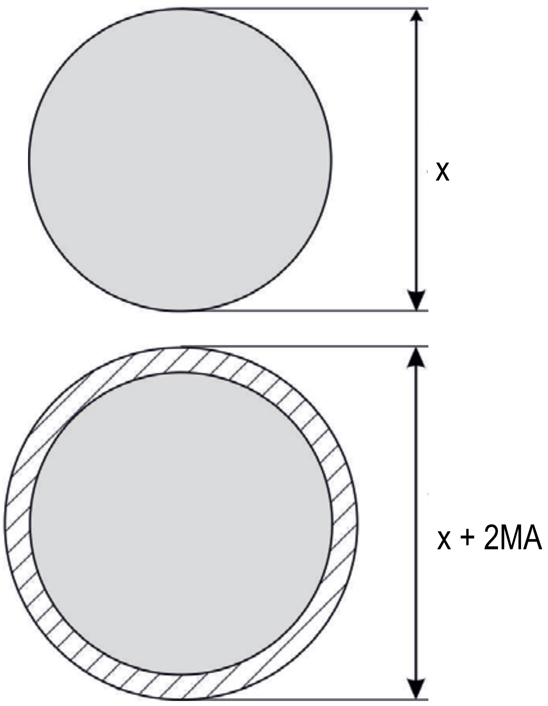

FIGURE 1 Design guideline turning

FIGURE 2 Rear wing bracket

POLYLINE – INTEGRATED PRODUCTION LINE FOR POLYMER-BASED AM APPLICATIONS

POLYLINE
Integrierte Linienanwendung von polymerbasierten AM-Technologien

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

PROJECT OVERVIEW

DURATION

02/2020 – 01/2023

PARTNER

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

FUNDED BY

Federal Ministry of Education and Research (BMBF)

RESEACHER

Research Leader
Prof. Dr.-Ing. Rainer Koch

Research Assistant
Anne Kruse, M.Sc.
Klaas Tuschen, M.Sc.

Federal Ministry of Education and Research

Project objective

The main objective of the POLYLINE project is to further develop additive manufacturing with polymer-based laser-sintering (LS) into an automated and efficient production process (see figure 1). The additive manufacturing technology (AM technology) will be enabled to meet established processes (machining, casting, etc.) in high performance line production systems. In the future, this will result in a production that is more flexible with parts manufactured directly in Germany. This will be demonstrated using examples of series parts from the automotive industry.

Motivation

Currently, both vertical and horizontal integration of additive manufacturing processes in conventional lines is only feasible to a limited extent. On the one hand, this is due to AM-specific production steps (e.g. production time in a “batch process”) as well as the generally low degree of automation of the machining and transport processes. This leads to very discrete production intervals and high manual effort. On the other hand, the digital data chain along the horizontal process chain is not continuous at many interfaces, which currently leads to intransparency, error susceptibility and limited monitoring along the processes and makes integration into relevant production control systems more difficult. These barriers greatly limit the high potential of additive manufacturing processes in existing series production and assembly lines.

Procedured

In order to achieve the formulated project objective, the project aims at a digital and physical system breakthrough. This means that from the CAD model to the finished component, all central characteristic values and quality criteria (including identification, history and measured values) are recorded and documented. The individual sub-processes of production - from process preparation to the laser-sintering process, cooling and unpacking as well as cleaning and post processing of the parts - are automated and brought into the planned production line, where all the trades of an LS production chain are fully linked for the first time.

Project Information

The research project prevailed within the framework of the research program “Line integration of additive manufacturing processes” of the Federal Ministry of Education and Research (BMBF). It is funded with 10.7 Mio. € by the BMBF and supported by the VDI-Technology Center (VDI-TZ GmbH) as project executing organization.

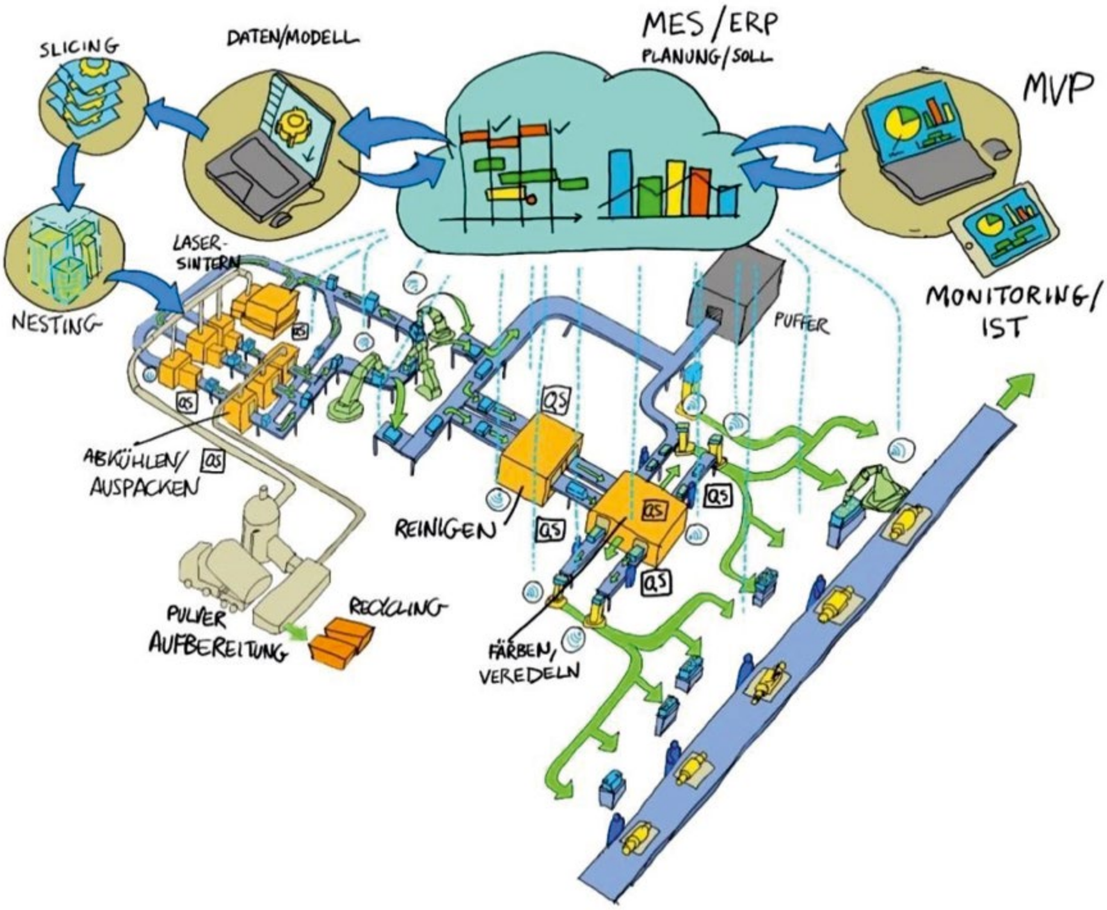

FIGURE 1 Aim of the project

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 is 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 is planned, which is adjusted 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)

RESEACHER

Research Leader
Prof. Dr.-Ing. Rainer Koch (CIK)
Coordination
Anne Kruse, M.Sc.
Research Assistant
Manuel Ott, M.Sc.
Lena Risse, M.Sc.

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. The 3D printing online platform will include 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 uploading 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 enables the transfer of the idea of one individual across Germany. Beyond the developed installation aids can be conduced 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, especially in the assambly aids area, were realized and tested within 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 with less problems. This increases the proportion of people who are capable of this work and thus the scope of duties of the affected persons.

Additionally, first ideas for everyday aids were developed and the manufacturability and usability will be evaluated at the university. One oft he most impressive examples so far is a food dispenser for an assistant dog of a highly disabeled young child (see figure 3). This enables him to reward him for good action, thus, this will raise interaction between both to bond their relationship in daily life.

For the workshop, the location was selected under consideration of different requirements, which are important for a location that works for and with people with disabilities. The workshop aims to purchase two Ultimaker printers.

Outlook

The implementation of the online platform will be elaborated further in order to bring a prototype into action at Bethel by the end of the year. Furthermore the development of the trainings for the online platform and the 3D printing workshop will start.

The overall project aim of identifying required products for people with disabilities will be increased. Bethel has planned over 30 workshops, who all have different assembly aids, which will be 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 is funded 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 receives a funding of 1.4 Mio. € by the BMBF and is supported by the PTKA (Projektträger Karlsruhe).

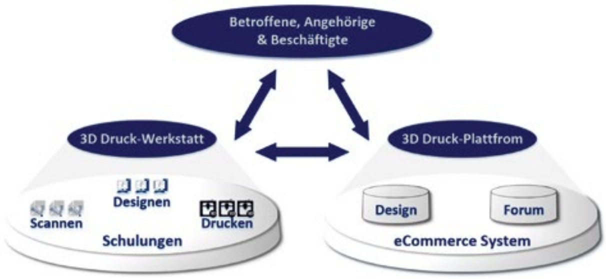

FIGURE 1 Aim of the project

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

FIGURE 3 Food dispernser

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 venture through a public-private partnership between the European Commission and the European aviation industry to achieve defined environmental objectives. Environmental goals are, for example, the reduction of CO2, gas emissions and noise level produced by oder of aircrafts. 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

RESEACHER

Research Leader
Prof. Dr.-Ing. Elmar Moritzer

Research Assistant
Julian Wächter, M.Sc.

Project aim

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 fibers with thermoplastic resins, the use of the FDM process with short fiber reinforced thermoplastics and the development of a new method for joining components on the basis of rivet-free applications.

Role in the project

Within the project, the Paderborn University respectively the Institute of Polymer Technology "Kunststofftechnik Paderborn" (KTP) is working on the additive manufacturing of rib structures. The focus is on the development and optimization of the Fused Deposition Modeling (FDM) process for short fiber reinforced thermoplastics. As a first step, a review of the current state of the art is necessary and requirements have to be defined. Subsequently, materials that are relevant for the project are selected and determined. Once the material selection is finished, filaments are developed and produced which can be processed in the FDM process.

The aim is to select the material and the used machine in such a way that a good processability and a sufficient quality of the resulting parts are achieved. This is followed by the determination of a complete parameter set for the manufacturing of test specimens with the selected material. The test specimens are used to define the FDM specific mechanical properties which can be achieved with the selected material. These mechanical properties are then used for the topology optimized rib concept. The aim of the topology optimization is to create a new and lighter design for the ribs that improves the mechanical performance and meets the requirements of FDM manufacturing. The topology optimization is performed at the Center for Advanced Aerospace Technologies (CATEC) with the support of the Paderborn University (KTP) by contributing AM manufacturing rules and FDM specific constraints.

Further procedure

The selection of materials has been completed and the first processing tests have been carried out. To determine a complete set of parameters for processing the material in the FDM process, optimized process parameters must be determined. Process parameters which have to be optimized are the build chamber temperature and the nozzle temperature. These parameters are varied and examined with regard to the achievable weld seam strengths. Differences due to the selected process parameters can be identified with the help of manufactured test 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 with the help of tensile tests. This procedure is illustrated in Figure 2. The real weld area between the individual strands is then determined to calculate the weld seam strength of the individual test points by using microsections to measure the weld seam width (see Figure 3).

After these investigations, the occurring warpage behavior is analysed, as the warpage during the FDM process should be kept as low as possible. Then, in a further step, material-specific adjustments and investigations are carried out to generate a parameter set for the material and to manufacture test specimens. The selection of the test specimens and the definition of the mechanical properties which have to be determined will be done in close cooperation with the project partners.

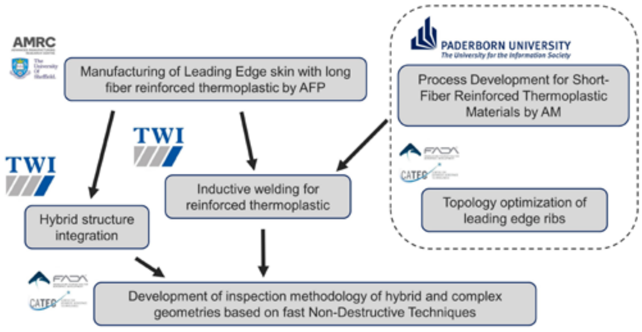

FIGURE 1 Workflow RIB-AM

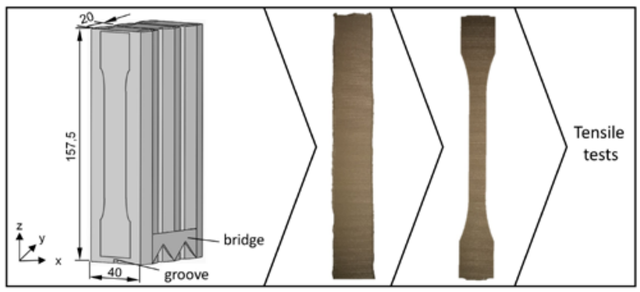

FIGURE 2 Process chain for determining the weld seam strength

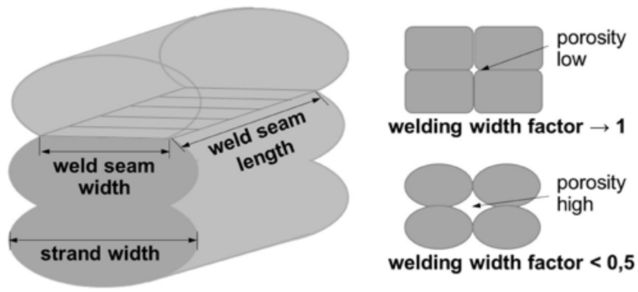

FIGURE 3 Structure of the welding surface and influence of porosity of a component

SIMULATION OF THE SHRINKAGE BEHAVIOR IN FUSED DEPOSITION MODELING

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

PROJECT OVERVIEW

DURATION

01/2019 – 05/2022

PARTNER

- Kunststofftechnik Paderborn (KTP)
- Konstruktions- und Antriebstechnik (KAt)

FUNDED BY

German Research Foundation (DFG)

RESEACHER

Research Leader
Prof. Dr.-Ing. Elmar Moritzer

Research Assistant
Felix Hecker, M.Sc.

DFG Deutsche Forschungsgemeinschaft
German Research Foundation

Objectives

As with other additive manufacturing processes the components built with Fused Deposition Modeling (FDM) are generated layer by layer. Therfore a thermoplastic filament is conveyed into the FDM head. Here it is plastified inside a heated nozzle and deposited onto the building platform or an existing structure. The heat of the newly deposited strand is responsible for a successfull welding of this strand to the prior deposited material.

As the temperature inside the building chamber is lower than the nozzle temperature and therefore the temperature of the strand exiting the nozzle, the material cools down. In the course of this cooling the strand shrinks. As the component to be manufactured is built up strand by strand and layer by layer, the shrinkage of the strands is not steady. Rather the overall shrinkage of the part depends not only on the shringake of a single strand but is influenced by the surrounding strands. Therefore the shrinkage is influenced by process parameters that vary the position of the strands relative to each other, as well by the geometric properties of the component to be manufactured. This is related to the already solid strands obstructing the shrinking of the newly deposited strands as well as the influence of different temperature levels due to changing cross sections of the component to be manufactured.

In the course of this project the decisive influencing factors and their effects on the shrinkage shall be determined. With the help of simulations the shrinkage behavior is to be modelled. Subsequent to the validation of the simulations a local scaling of the component to be manufactured is intended to avoid a discrepancy concerning the CAD model and the resulting component manufactured with the FDM process.

Procedure

The invastigations are carried out with a Stratasys Fortus 400mc FDM machine processing the material ABS M30. In the course of the investigations two further materials will be taken in account. These are Ultem 9085 and FDM Nylon 12.

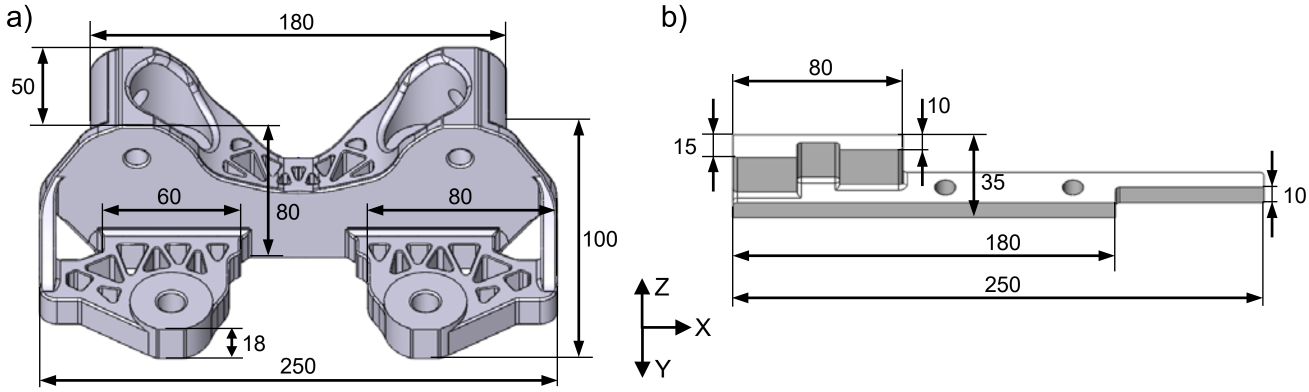

FIGURE 1 Visualisation of the demonstrators used to validate the determined local scaling factors.

To begin with the investigation of the shrinkage behavior, at first an elementary cell shall be determined. The aim of this procedure is to achieve a division of any component to be manufactured into the smallest volumes possible. During the finding of this elementary cell it is mandatory to pay attention to a reasonable size of the elementary cell. If the volume of the cell is chosen too small, the simulation of the shrinkage occurring in the cell cannot be validated, as the cell may be to small to be manufactured using an FDM machine.

In order to simulate the shrinkage behavior at first several information must be gathered. For the simulations it is crucial to know the temperature of the material the moment it leaves the nozzle. The temperature of the nozzle is displayed by the machine. Due to the continuous feed of new material through the filament and the positioning of the temperature sensor, the temperature of the material at the point of leaving the nozzle is expected to be lower than the displayed nozzle temperature. To determine the correct material temperature, in addition to physical temperature measurements, a simulation shall be carried out.

For all the simulations certain material properties must be known. These are for example the Young's modulus, Poisson's ratio, thermal conductivity and thermal diffusity, heat capacity as well as the coefficient of linear expansion.

As soon as the temperature of the material leaving the nozzle is identified, the simulation of the cooling behaviour can be conducted. For this the software Abaqus by Dassault Systèmes is used. This software enables the user not only to consider the thermal conduction, shrinkage and cooling behaviour but also the evaluation of surpressed shrinkage by the allready cooled strands and the resulting residual stress.

These results shall then be validated. For this, thermal sensors can be placed inside the component to be build during the building process. This can be achieved by pausing the process and inserting the thermal sensors at defined locations on the current layer of the component. As the building process is continued the thermal sensor is embedded into the component. With this the temperature profile can be tracked and compared to the results of the simulation. Not only the correct simulation of the temperature profiles but also the resulting geometrical deviations shall be validated. Therefore, several specimens with different geometries shall be manufactured using the FDM process. Subsequently the geometrical properties of these specimen are to be measured using a coordinate measuring machine. A comparison of these measurements with the results of the simulation provides conclusions about the informative value of the simulation regarding the shrinkage of components manufactured with the FDM process.

Using these results a method for determing ideal scaling factors to compensate the shrinkage prior to the manufacturing process is to be found. In a further step local scaling factors are to be determined as they vary depending on the nominal length of the considered section of a component. These local scaling factors are to be validated using two demonstrators shown in Figure 1. Furthermore the possibility of an automated adaption of the CAD models for complex parts using the identified scaling factors will be investigated.

SURFACE INOCULATION OF ALUMINIUM POWDERS FOR ADDITIVE M ANUFACTURING GUIDED BY DIFFERENTIAL FAST SCANNING CALORIMETRY

New materials and processes enable saving weight of parts and components and thereby saving energy. To develop and modify materials to make them suitable for additive manufacturing, 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 are cooperating within the Special Priority Program (SPP) 2122, promoted by the German Research Foundation (DFG). Together, they face the challenge to process hard to weld materials like high-strength aluminum alloys by using powder bed-based laser beam melting (PBF-LB/M). One approach in this project is the modification of initial state powder with nano-size particles.

PROJECT OVERVIEW

DURATION

10/2018 – 09/2021

PARTNER

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

FUNDED BY

German Research Foundation (DFG)

RESEACHER

Research Leader
Prof. Dr.-Ing. habil. Olaf Keßler (LWT)
Prof. Dr.-Ing. habil. Mirko Schaper (LWK)
Prof. Dr.-Ing. Guido Grundmeier (TMC)
Dr. rer. nat. Evgeny Zhuravlev (°CALOR)

Research Assistant
Steffen Heiland, M.Sc. (LWK)
Pascal Vieth (TMC)

DFG Deutsche Forschungsgemeinschaft
German Research Foundation

Objective

The combination of lightweight materials and laser beam melting (LBM) is well suited to realize new opportunities to achieve a lightweight design. In particular, high strength aluminum alloys like EN AW-7075 (AlZn5,5MgCu) and EN AW-7021 (AlZn5,5Mg1,5) offer great potential for lightweight applications. Unfortunately, they are susceptible to pores and hot cracking during welding processes and therefore in LBM, too. Up to now, this behavior prevents their using application in additive manufacturing (AM). One solution to counteract this challenge is a modification of the aluminum powder with nanoparticles. This effect reduces or avoids the issues mentioned above and makes sure the processability of these alloys via LBM.

Approach

Based on previous research and experiences, grain refiner such as Al-5Ti-1B is used in continuous and shape casting to minimize cracking issues. In this case, Al_3Ti dissolves in the melt and TiB_2 conduce to nucleation. For application in AM, TiC and Ti_2B as nano-sized particles are applied to achieve an effective grain refinement.
With parameter studies, the appropriate adjustments of factors like laser power, scan speed, hatch distance and layer thickness are determined to achieve a high relative component density. Subsequent the micro- and nanostructure, grain orientation and corrosion behavior have been analyzed. For this, FE-SEM, TEM, XPS as well as optical spectroscopy and techniques like potentio-dynamic polarization are deployed.
The melting and cooling behavior of individual powder particles for extremely high heating and cooling rates and thus the effectivity of the surface covering grain refiner is investigated by CALOR with Differential Fast Scanning Calorimetry (DFSC). In this project, TMC has developed wet-chemical procedures to decorate the initial state powder with grain refiner. Depending on the usage of TiC or Ti_2B, new methods have to be developed to achieve a uniform distribution of nanoparticles on the surface in a stable state. Up to now, the aluminum powder was modified by adding an aqueous dispersion containing TiC nanoparticles and Polyethyleneimine

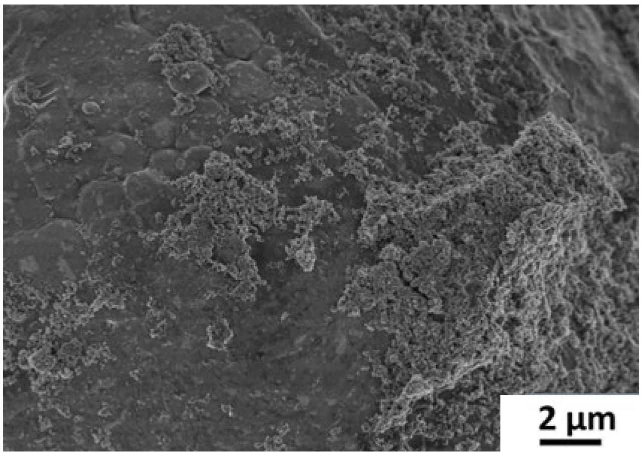

FIGURE 1 FE-SEM image of surface inoculated aluminum particle

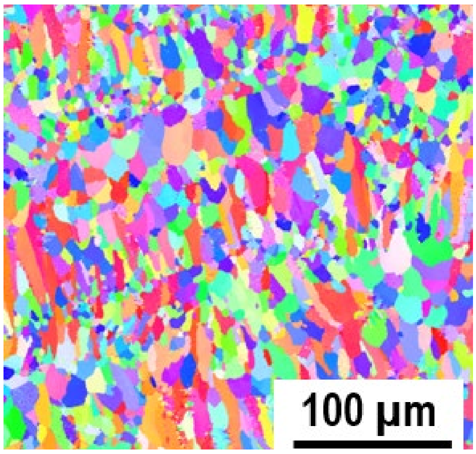

FIGURE 2 EBSD image of sample, made of blended, TiC modified EN AW-7075 powder

(PEI) as a stabilizing agent. The stable dispersion was generated by using high power ultrasonic. For improved microstructure of the additive manufactured parts, TMC has enhanced the system for inoculating particles. Nanoparticles are added to an ethanolic system with a mixture of polymers as a stabilizing agent. The formed dispersion is sprayed on the aluminum particles and the resulting slurry is dried subsequently under vacuum for 16 hours. An exemplarily inoculated aluminum particle is given in figure 1.

Results

Using a ring shear cell for powder characterizing unveiled a flowability enhancement for nanoparticle modified aluminum powder. The growing distances between each single aluminum particle of few nanometers cause the reduction of Van der Waals forces. A good flowable powder ensures a good coating during LBM. All samples made of powder which was modified with the aqueous method, exhibit cracks. The variation of LBM parameters did not lead to the envisaged objective of pore and crack reduction. However, grain refinement occurred and was proven with electron backscatter diffraction (EBSD). The decreased grain size and nearly globular grains at the edge of the melt pool are shown in figure 2. Therefore, different exposure strategies were investigated. For a second exposure during LBM, a reduction of crack size at the slight change of chemical composition was determined. With a consecutive heat treatment, hardness could be increased by 19 % to 20 % towards to specimens in additively manufactured as-build condition. Nevertheless, no significant improvement in crack reduction has been achieved. Moreover, it was only possible to investigate the combination of aluminum alloys with TiC.

The successful inoculation was proven for the aqueous and ethanolic dispersion by FE-SEM. The surface chemistry of the modified particles was further investigated by XPS. Upon the aqueous surface inoculation process, the natural passive layer of aluminum is thickened based on reactions with the aqueous dispersion. Due to the alkaline pH of the dispersion, the process of particle adsorption leads to an etching of the natural aluminum oxide coating. The natural aluminum hydroxides are then reconverted to oxide layers with adhering the nanoparticles during the drying process. For the ethanolic surface inoculation procedure, no oxide layer was detectable.

After substituting the aqueous procedure by an ethanol-based process to decorate the basic powders, new samples have been manufactured utilizing LBM. With the new powder, still hot cracks appeared. Independent of the amount of exposure and variation of layer thickness, the desired objective is not met. Currently, an extensive analysis of the correlation between parameter variation and both, pores and crack occurrence is performed. It seems that a reduction of cracks is possible but only with simultaneous increasing of numbers of pores.

Outlook

Due to the challenges of wet-chemical procedure for powder decoration, a mechanical method is taken into account: using a roller mill offers new possibilities. The ratio of initial state powder and grain refiner can be set easily. Moreover, almost unlimited powder combinations are possible. First investigations show the efficiency of mechanical decorating. Nevertheless, other procedures shall be examined concerning the applicability for powder decoration.

[1] Heiland, S.; Vieth, P.; Zhuravlev, E.; Hoyer, K.-P.; Grundmeier, G.; Schaper, M.; Keßler: Surface Inoculation of Aluminum Powders for Additive Manufacturing guided by Differential Fast Scanning Calorimetry. Lecture at LightMAT; Manchester, 6 11 2019.

VERONIKA – EFFICIENT AND INTERCONNECTED PRODUCT AND PRODUCTION DEVELOPMENT FOR AIRCRAFT PASSENGER CABINS

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 built 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

Feder Ministry for Economic Affairs and Energy (BMWI)

RESEACHER

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

Research Assistant
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 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 is prepared for the selected aircraft cabin components from WP2. Finally, a validation of the process chain shall be considered. 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 cooling fins and a heat pipe. The projector is housed close to the contours and directly picks up the heat through partly complex structures in the optical area (see Figure 1). It consists of five SLM aluminum and four SLS polyamide 12 parts.

Furthermore, an aluminum bracket is optimized concerning weight and part number reduction. The weight can be saved drastically by up to 60 % and the number of parts can be reduced from two to one part. 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. Figure 2 shows a trowalized bracket.

Part integration, material change and weight reduction were performed in another case study, handling 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 LS in polyamide 12 (see Figure 3). The connection of a flange to a surrounding component was achieved using integrated, additively manufactured floating anchor nuts.

Within the mentioned optimization procedure the manufacturing technology of laser sintering and laser melting were applied. For this reason, the production instruction for these technologies regarding the case study parts were prepared and the process chain was 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 catalogue of standardized work processes within the variation of AM technologies is generated with the deep knowledge and experiences of the DMRC.

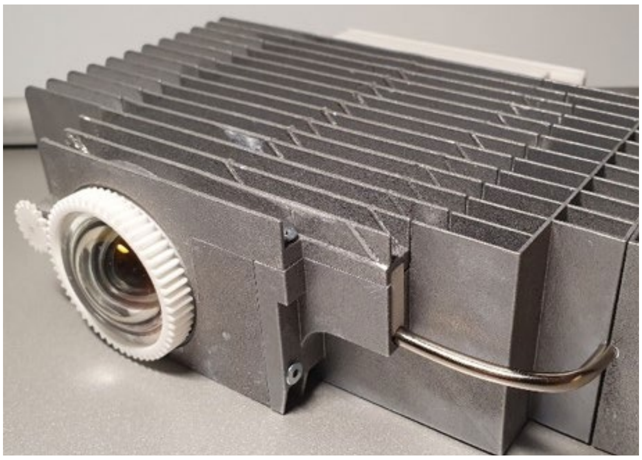

FIGURE 1 Mounted projector housing

FIGURE 2 Trowalized Bracket

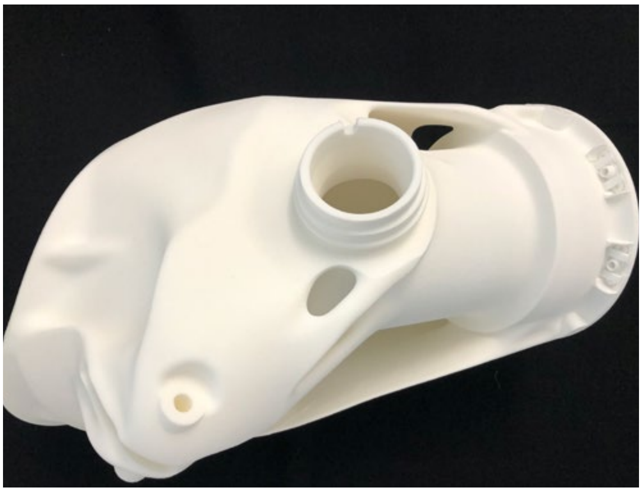

FIGURE 3 Drain tube manufactured by laser sintering PA12

INNOVATION

CONTENT

INNOVATION & APPLICATION

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

For applications in electrical machines, AM provides exciting new possibilities. The process-specific freedom of design enables the economical production of geometrically complex components, since the component complexity has only a minor influence on the production costs. As a result, almost any three-dimensional structure can be realised, for example to guide the magnetic flux three-dimensionally or to increase the proportion of lightweight design.

To present the potential of AM in this field, the possibilities for optimisation are shown on an additive manufactured permanent magnet synchronous machine rotor. The research on this topic was founded by the DFG.

Approach

Regarding design possibilities and limitations, the influence of the material and the process parameters has to be be considered. Finding a material and specific process parameters for the Laser Beam Melting (LBM) process, which are suitable for the mechanical and the electro magnetical functions of the rotor, was the basis for further investigations.

Different requirements have to be considered during development. It is necessary to design a light but mechanically strong structure that also serves the electromagnetic function at the same time. In addition to these functional requirements, the rotor design needs to be manufactured in the LBM process. A design that is suitable for a robust manufacturing process, considering geometric deviations in the manufacturing process and necessary subsequent processes, is therefore essential.

Achievements

The final rotor design (Figure 1) was developed in an iterative design process and supported by simulations and experimental investigations. The integral design of the rotor enables a weight-optimised solution in the shape of a hollow shaft and therefore reduced the weight by 52,7%. In the active part, only the material areas that are relevant for the electromagnetic function remained and serve the magnetic flux guidance. An optimised surface contour on the active part and a continuous bevelling have increased the average motor torque by 5.4% and reduced the torque ripple during operation by 90% (Figure 2). The percentage values relate to the non-skewed reference machine.

PROJECT OVERVIEW

PARTNER

- DFG

RESEACHER

Research Leader
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Prof. Dr.-Ing. habil. Mirko Schaper
Prof. Dr.-Ing. Bernd Ponick

Research Assistant
Sebastian Magerkohl, M.Sc.;
Lennart Tasche, M.Sc.; Stefan Urbanek, M.Sc.

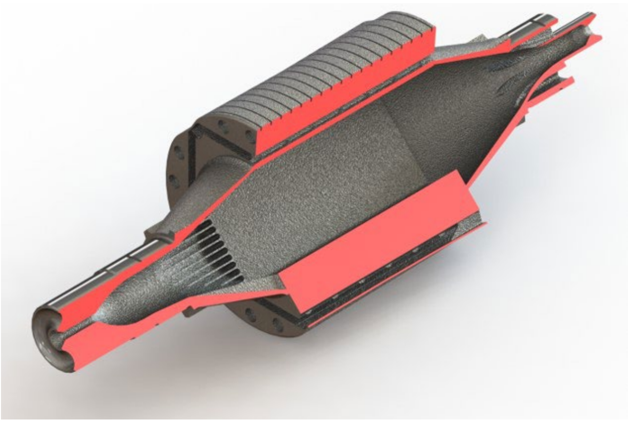

FIGURE 1 Sectional view of the optimised AM rotor

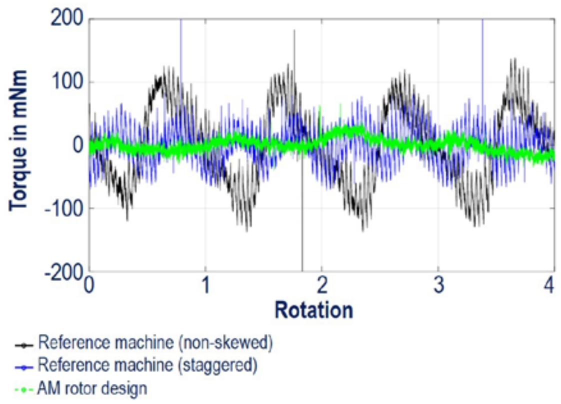

FIGURE 2 Experimentally determined results for torque ripple in comparison to the reference machines (unslanted / staggered)

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

PROJECT OVERVIEW

PARTNER

Industrial Consortium of DMRC

RESEACHER

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”.

ADDITIVE MARKING

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

RESEACHER

Research Leader
Prof. Dr.-Ing. Dettmar Zimmer

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

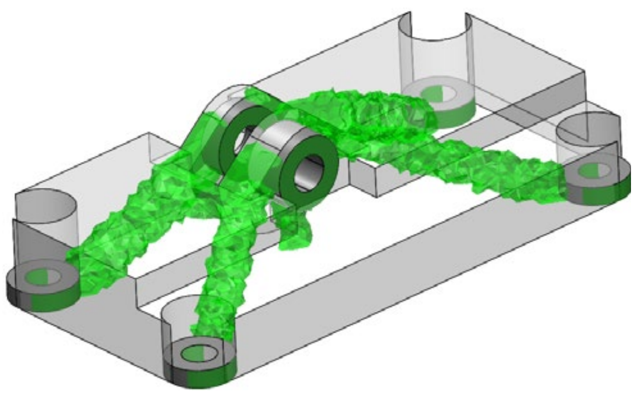

FIGURE 1 Topology optimization of the bracket

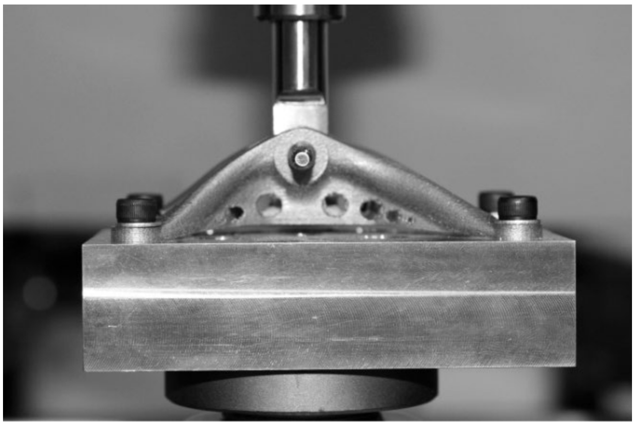

FIGURE 2 Testing of the manufactured bracket

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

RESEACHER

Research Leader
Prof. Dr.-Ing. Rainer Koch

Research Assistant
Dr.-Ing. Thomas Reiher

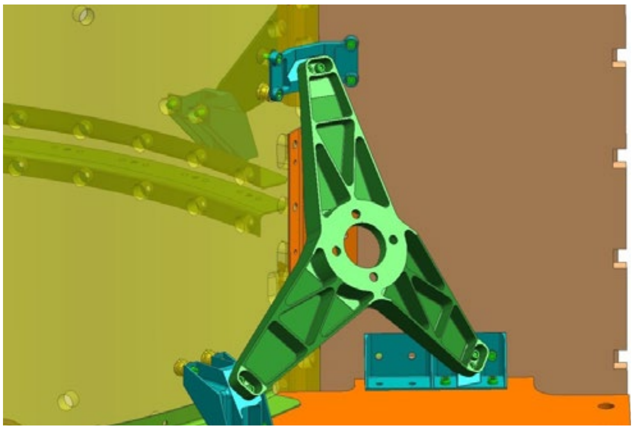

FIGURE 1 Traditional design of Reaction Wheel Bracket mounted in Exo Mars satellite

FIGURE 2 AM Designed Reaction Wheel Bracke

AMENDATE – INNOVATIVE AM OPTIMIZATION

PROJECT OVERVIEW

PARTNER

AMendate

RESEACHER

Dr.-Ing. Thomas Reiher
Dr.-Ing. Gereon Deppe

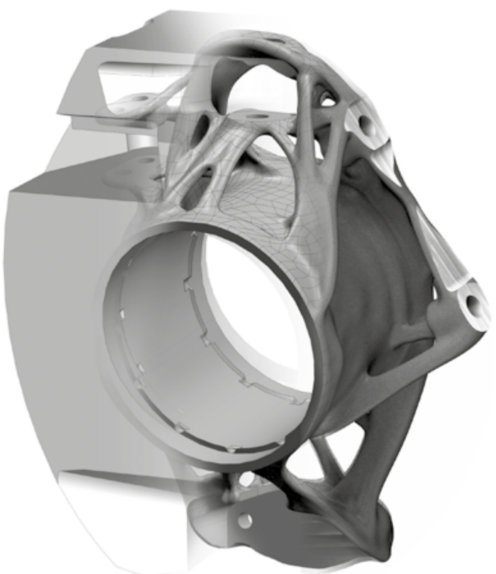

FIGURE 1 Optimization from CAD to CAD in 6 hours combined in one automated software

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

RESEACHER

Research Leader
Prof. Dr. rer. nat. Thomas Tröster
Prof. Dr.-Ing. Volker Schöppner

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Dr.-Ing. Matthias Fischer
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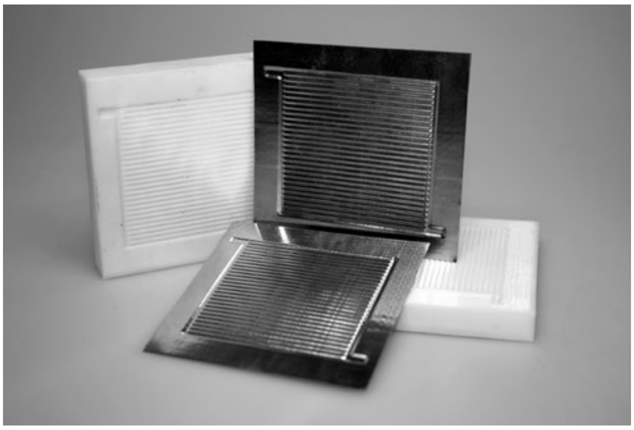

FIGURE 1 Pressed sheet metal

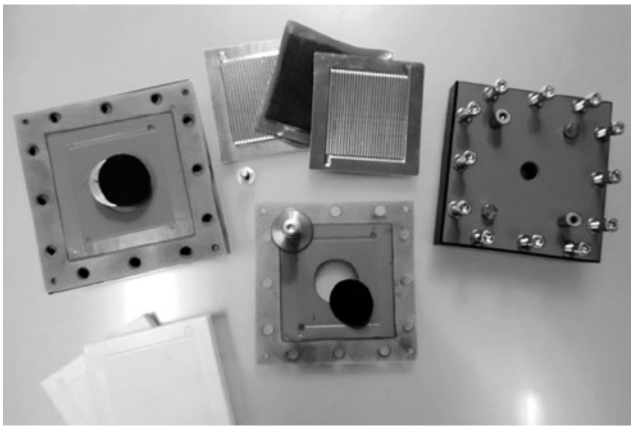

FIGURE 2 Experimental setup of the fuel cell

BUILD-CHAMBER PREHEATING SYSTEM FOR SLM

PROJECT OVERVIEW

RESEACHER

Research Leader
Prof. Dr.-Ing. habil. Mirko Schaper

Research Assistant
Florian Hengsbach

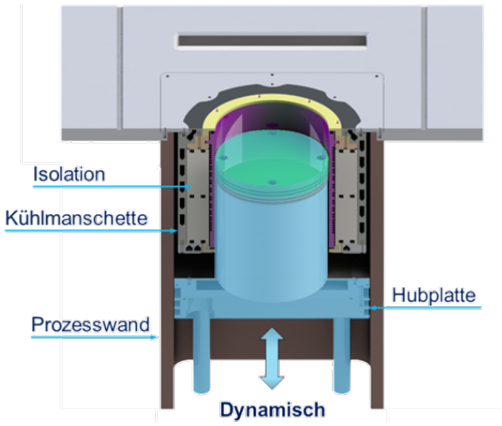

FIGURE 1 Rendering of preheating system revealing important components of the preheating system developed

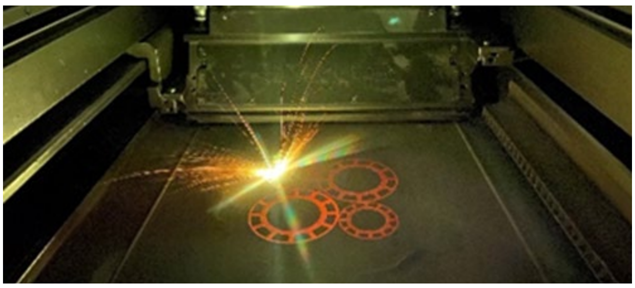

FIGURE 2 Optical image during high-temperature SLM processing at 750 °C of Stellite 6

FIGURE 3 Successfully built, crack-free Rotor consisting of Stellite 6

UPB & Deloro Wear Solutions

Additive manufacturing (AM) of metal components attracts substantial attention. By employing AM, highly complex parts can be generated with additional functionalities such as contour near cooling, sensor systems, or permeable structures. With regard to selective laser melting filigree parts can be generated in a near net shape fashion. However, alloys processible via SLM are limited. Improved SLM manufacturing conditions can be achieved either by material adjustments consistent powder heating up to 800 °C. Thus, an optimized heat distribution in the SLM build chamber is achieved by heating the process wall in addition to the standardly heated baseplate.

Previous investigations by the applicants show that SLM processing of Stellite 6 using a standard build platform heating of 200°C lead to significant cracks in the test specimens, already after a few millimeters. Even an adjustment of the exposure parameters, which addressed the lowest possible energy input, did not lead to a successful result. A representative light microscope image of a Stellite 6 specimen produced by SLM.

Achievements

The preliminary work is intended to illustrate in general that the crack-free SLM processing of Stellite 6 using an in-house developed build chamber heater was successfully carried out by the applicants. However, it must be mentioned that the used prototype of the build chamber heater could not be used robustly and that the build chamber is comparatively small with a diameter of 100 mm and a height of 110 mm. Against this background, a new, reproducibly processable build chamber heater was developed. This version has a build chamber with a diameter of 160 mm and a height of 170 mm. The achievable preheating temperatures can be set up to 900°C. In addition to additive manufacturing, the material properties are the essential component of this application

DESIGN AND DRIVE TECHNOLOGY IN AN AM-OPTIMIZED MODULAR DRIVE

Introduction
The focus of the scientific work of the Chair of Design and Drive Technology (KAt) are electromechanical drive technology and design aspects in additive manufacturing processes. In the research project "KAtAMaran" ("Design and drive technology in an AM-optimized modular drive"), a modular multi-motor drive system (short: MMDS) is being developed as a research platform that exhibits the design freedom of additive manufacturing and the advantages of function integration. The modularity of the system offers the possibility of implementing and investigating a wide variety of drive concepts, so that the innovations in design and drive technology and the research topics of the KAt are combined in one demonstrator.

Objectives
Due to the freedom in terms of materials and design, additive manufacturing in this project enables improved implementation of active principles while at the same time complying with design rules and geometric tolerances, e.g. in the following areas:

- Vibration damping
- Heat transfer
- Electromagnetic flux control
- Fluid transport

Achievements
Application- and load-oriented design of gearbox housings achieved through function integration and the degrees of freedom offered by additive manufacturing processes:

- Integrated damping structures
- Cooling close to contour
- Minimal use of materials
- Self-supporting surfaces

PROJECT OVERVIEW

RESEACHER

Research Leader
Prof. Dr.-Ing. Detmar Zimmer (KAt / DMRC)
Research Assistant
Thorsten Koers, M.Sc.
Tobias Bührmann, M.Sc.

FIGURE 1 Assembly of the modular drive "KAtAMaran"

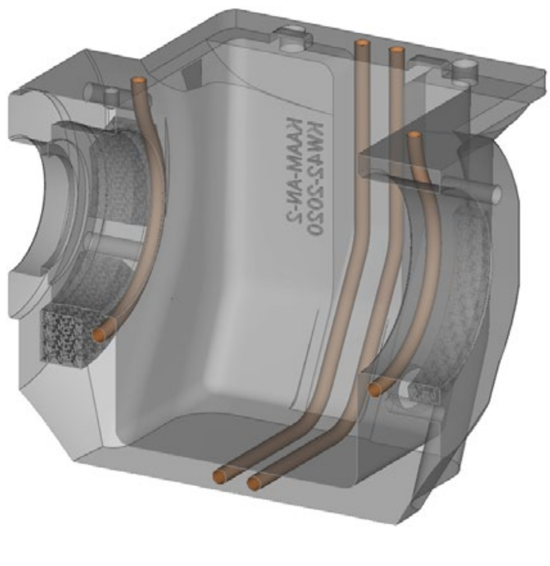

FIGURE 2 Virtual sectional view of a drive housing

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

PROJECT OVERVIEW

RESEACHER

Research Leader
Prof. Dr.-Ing. Detmar Zimmer

Research Assistant
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.

EXPLOITING THE ADVANTAGES OF ADDITIVE MANUFACTURING PROCESSES IN MEDICAL TECHNOLOGY

Additive manufacturing processes are playing an increasingly important role in the field of medical technology. They make it possible to meet the demand and need for patient-specific products. The high design freedom of additive manufacturing processes in combination with CAE methods is used to provide approaches to solve the existing stiffness problem in hip endoprosthetics. Using stress adapted geometries and the finite element method, stiffness adapted variants of a short shaft hip endoprosthesis are developed in an iterative process.

Approach

One way to vary the stiffness of the implant is the choose of the material. It must be ensured that the selected material not only provides the desired stiffness, but also guarantees the fulfilment of the function by sufficiently good mechanical characteristics. A material that meets the above-mentioned requirements is the titanium aluminum alloy Ti6-4, which can be processed reliably by selective laser melting. A striking feature is the low Young's modulus compared to other biocompatible metallic materials, which has a positive influence on the stiffness optimization of implants. The optimization process is carried out by systematically changing the cross-sectional profile of the hip prosthesis for stepwise stiffness adjustment. The result is a more homogeneously stressed bone contact surface, which allows a more extensive transfer of stress to the bone and reduces bone degradation due to stress shielding.

Achievements

A stiffness-adapted short shaft hip endoprosthesis could be developed by targeted use of the potentials of selective laser melting, in particular the possibility of creating filigree internal grid structures and variable wall thicknesses as well as internal cavities. By numerical analysis of the stress situations of bone and implant, the problem of "stress shielding" and thus potential problems of the patient could be reduced and the expected service life of the prosthesis increased. The stiffness-adjusted hip endoprostheses were checked for their operational reliability by numerical methods. The findings on stiffness adjustment by exploiting the potential of selective laser melting can now be transferred to other components. Especially for implants, the problem of the stiffness difference between bone and implant is of immense importance, but also technical applications can profit from these considerations.

PROJECT OVERVIEW

RESEACHER

Research Leader
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Research Assistant
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FIGURE 1 Hip prostheses manufactured with selective laser melting

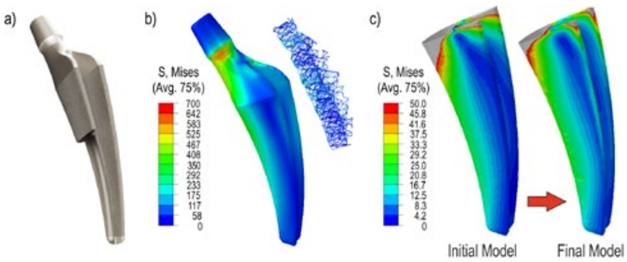

FIGURE 2 Summary of results of hip prosthesis optimisation
a) Final model of the hip prosthesis
b) Simulation result with stress of the outer and inner structure
c) Comparison of stresses from initial model to final model

FAST DEVELOPMENT AND RAMP UP OF FACESHIELD PRODUCTION FIGHTING SHORTAGE DURING COVID19 PANDEMIC

PROJECT OVERVIEW

RESEACHER

Research Leader
Dr. Christian Lindemann

Research Assistant
Dr. Christian Schumacher
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FIGURE 1 Model wearing the faceshield, preventing droplets to get in eyes and ears, the respiratory tracts require still protection by a medical mask.

FIGURE 2 Overview of the faceshields serial production befor washing, sanitizing and separate packaging

FIGURE 3 Involved project partners and companies

DMRC Fights Covid19 – LS Faceshields

In times of Covid-19 the DMRC and partners became active helping hospitals and social institutions with additive manufactured personal protective equipment. Together with medical device manufacturer Condor MedTec and several hospitals in and close to Paderborn, the project team defined the requirements for the faceshields.

In addition to the demands on functionality, the design considers the advantages and conditions of additive manufacturing in the laser sintering process. Thus, the design takes advantage of the design freedomes and integrates various functionalities. At the same time, process-related influences are considered in order to be able to produce a high number of parts in a reliable and cost-effective way.

Requirements

To meet the high standards for medical products, the faceshields had to fulfill several requirements, which goes from several end user demands, as one size fits all, protection from liquid droplets also from above or easy to sanitize (no corners, pockets or rough surface), over the comfort and weight by wearing this pease of personal protection equipment.

On the laser sintering side, the requirements are equally demanding, as the faceshield holder should contain less parts as possible with integrated fastening mechanism for the visor itself and the headband. At the time elastic straps were not deliverable, hence all components shall be laser sintered. The parts shall be dense nested, hence the design was adapted to fit perfectly together and allowed up to 136 faceshield holders and headbands to be manufactured on an EOS P3 at a total build job height of 353 mm. Additionally, the main load directions, the maximal exposure area and time per layer, part and frame distances have been optimized.

Achievements

4500 face shield holder and headbands have been manufactured by the DMRC and Condor MedTec with the sponsored material from EOS and Evonik. Visors were manufactured by Centroplast and cut by LST-Laserschneidtechnik.
The AM personal protective equipment parts have been sponsored to hospitals and social institutions in need.

FUSED DEPOSITION MODELING WITH METAL POWDER FILLED FILAMENTS

Introduction and Objectives

The processing of metal powder filled polymer filaments in Fused Deposition Modeling (FDM) presents a comparatively new technology for the production of metal components. This technology enables powder-free handling of the base material and processing on low-cost FDM equipment.

The aim of the research in cooperation with DMRC industrial consortium is to achieve a better understanding of the technology throughout the entire process chain. In addition to the general evaluation of the resulting component properties, the development of user guidelines is also at focus. These will be used to reduce the iteration steps from the first steps using the filament to a high-quality metal component. For this purpose, test specimens as well as methods are developed to show and evaluate the influencing variables on the manufacturing process.

Procedure

As a basis for establishing processing guidelines, the process parameters and in particular the volumetric polymer discharge must first be controlled. For this purpose, both the areas of stationary and non-stationary strand deposition are considered. This enables the technology-specific design and processing limitations to be investigated. These limitations include the minimum manufacturable overhang angle, the maximum manufacturable hole diameter and the minimum manufacturable wall thickness. In order to demonstrate the specific design limitations, all geometries are manufactured without the use of a suitable support material. The results are evaluated both after FDM fabrication and after the debindering and sintering process. Important variables are the evaluation of warpage or distorsion and defects in gerneral occuring in the components.

Achievements

The specific optimization of the process parameters as well as the development of the user guidelines lead to a better understanding of the processing of metal powder filled polymer filaments in FDM. This results in user-oriented support for the realization of desired metal component geometries.

PROJECT OVERVIEW

PARTNER

- Industrial Consortium of DMRC

RESEACHER

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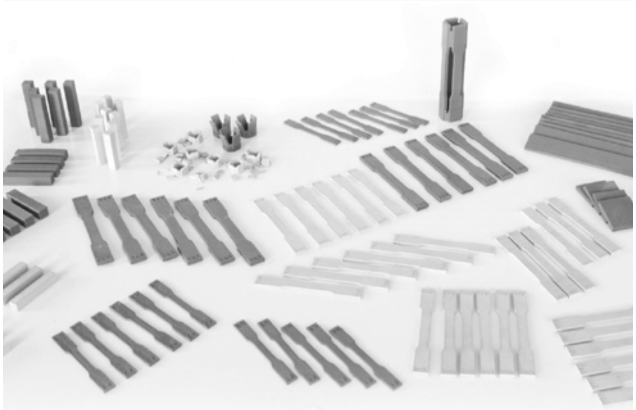

FIGURE 1 Specimens for the evaluation of the mechanical properties

FIGURE 2 Geometries for the Investigation and Evaluation of the design limitations

KOBFS - LUFO

PROJECT OVERVIEW

RESEACHER

Research Leader
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Dominik Ahlers, M.Sc.

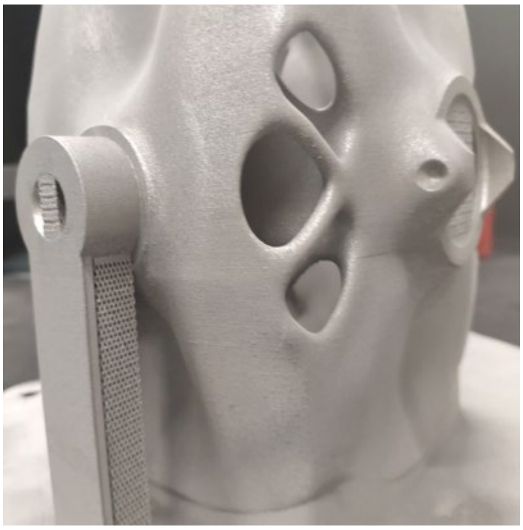

FIGURE 1 Gimbal built with high speed parameter

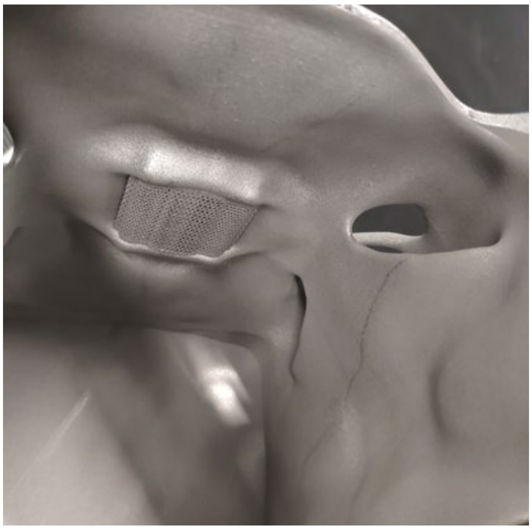

FIGURE 2 Inner surfaces of high speed build job

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 single-track 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.

LIGHTWEIGHT CONSTRUCTION OF HYDRAULIC CLAMPING DEVICES PROCESSED BY SLM

Partner

ELHA-MASCHINENBAU – a company with a long tradition – stands for technical innovation with customized machine tools providing individual manufacturing processes for advanced ma-chining 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 fea-sibility 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 ad-dition, 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 %

PROJECT OVERVIEW

PARTNER

ELHA-MASCHINENBAU Liemke KG

RESEACHER

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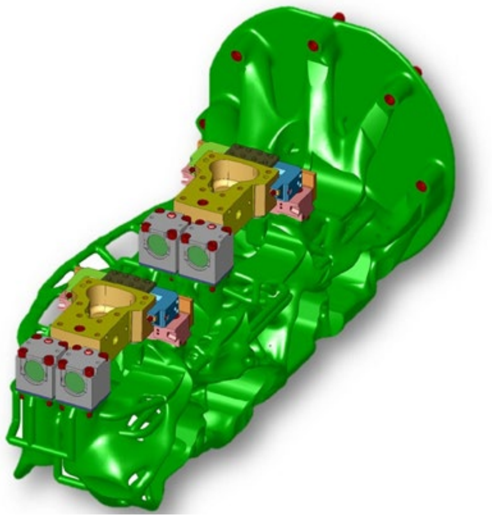

FIGURE 1 Topology optimized clamping device

LIGHTWEIGHT ROTOR SHAFT FOR PMSM

PROJECT OVERVIEW

PARTNER

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

RESEACHER

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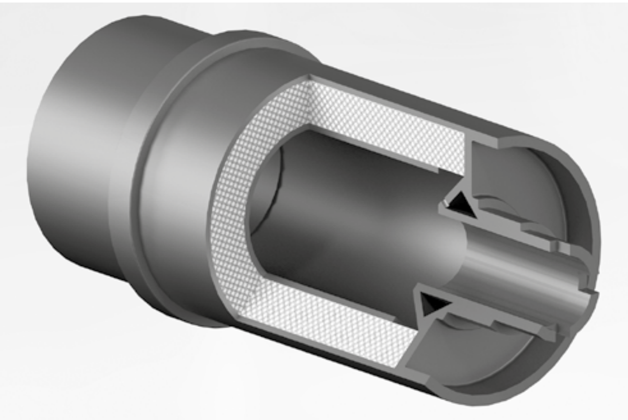

FIGURE 1 Optimized rotor shaft with lattice structures for a lightweight design

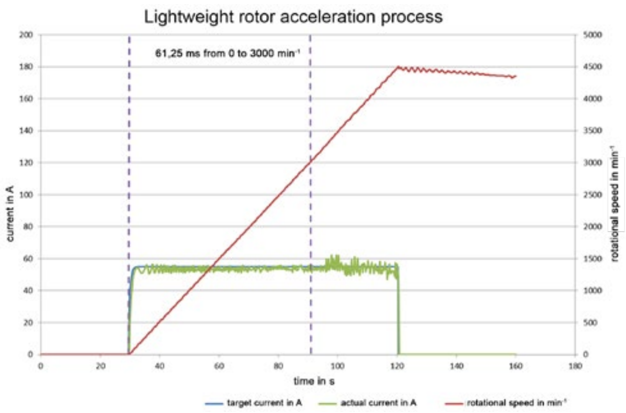

FIGURE 2 Results of the motor characteristics investigations.

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.

LOW TEMP LASER SINTERING

Motivation

The laser-sintering process has, beside all the advantages like a high productivity and a great design freedom, significant disadvantages with the low material variety and material ageing. A major proportion of all LS components are still made of PA12 and PA11. High performance materials e.g. PA6, PPS, PEKK, etc. are appearing increasingly on the market but they cannot be processed on standard LS systems due to the higher processing temperature. High temperature systems, on the other hand, are very cost-intensive. Additionally, the surrounding and unused powder material ages due to high process temperatures, resulting in not fully reuseable material which is not very sustainable and leads to increased costs.

Low temperature laser sintering addresses those problems by drastically reducing the process temperature, so that the material undergoes significantly less aging. In addition, the method of low temperature laser sintering enables standard laser sintering systems to process high-performance polymers. However, the process-related changes in parameters, which include adjusted exposure parameters and strategies in addition to the reduced build chamber temperature, also create new challenges. The high temperature gradients between the melt and the powder bed can lead to early recrystallization of the melt which might result in the so-called “curling” of the component´s top layers and the warpage of the whole component which further might lead to job aborts. By connecting the components to the building platform “curling” and warpage should be avoided to significantly increase the process stability. In addition to the advantages already mentioned, low temperature laser sintering can bring further benefits such as new design freedoms.

Achievements

Low temperature laser sintering of Polyamide 12 (PA12) on a commercial, unmodified laser sintering system (EOS P396) is investigated to create the basis for Low Temp LS of high temperature materials. First results by changing the exposure parameters and by fixing parts on a building platform show a processing of PA12 at a build chamber temperature at 80°C and less instead of standard approximately 175°C.

PROJECT OVERVIEW

RESEACHER

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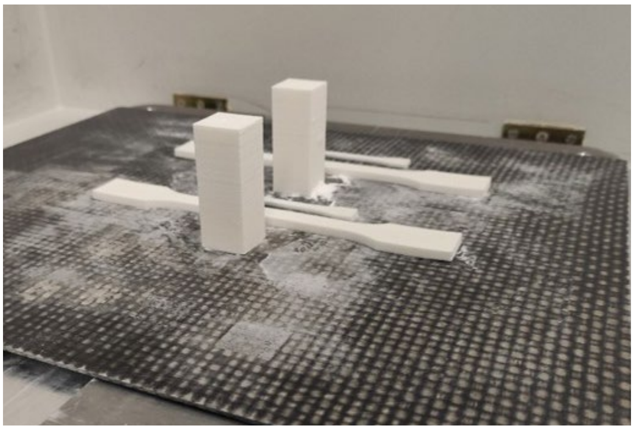

FIGURE 1 Low Temp LS of different test specimen

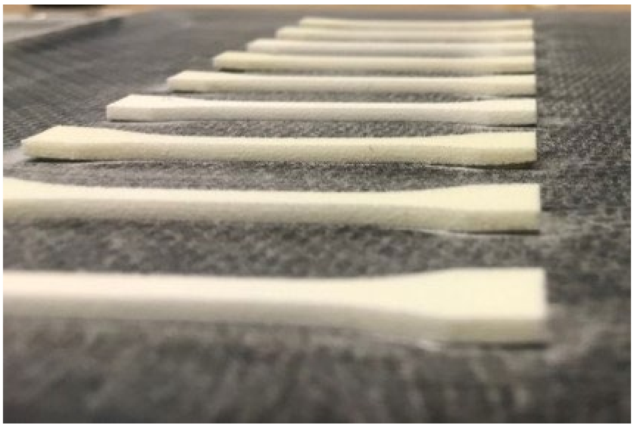

FIGURE 2 Tensile bars directly built on building platform

MODELLING OF TEMPERATURES AND HEAT FLOW WITHIN LASER SINTERED PART CAKE

PROJECT OVERVIEW

PARTNER

Indian Institute of Technology Bombay, Powai, Mumbai, India

RESEACHER

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

Research Assistant
Dr.-Ing. Stefan Josupeit
Lavish Ordiac

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.

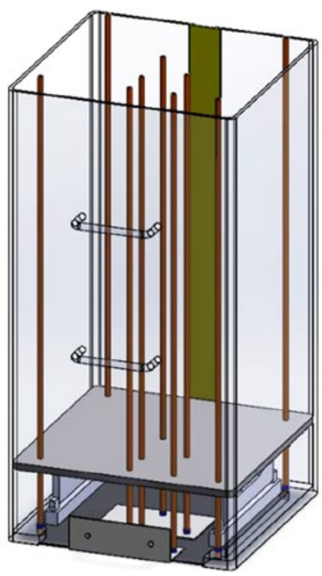

FIGURE 1 EOS P395 Frame with installed temperature measurement system

OPTIAMIX – MULTI-TARGET-OPTIMIZED AND AUTOMATED PRODUCT DESIGN FOR ADDITIVE MANUFACTURING IN PRODUCT DEVELOPMENT PROCESS

BMBF Project OptiAMix

The collaborative project OptiAMix, funded by the BMBF, was initiated for multi-target optimized and continuously automated component development for additive manufacturing processes in the product development process. To accelerate the spread of additive manufacturing in the industrial environment, the process capability, the economic efficiency and the reliability of the processes has to be improved. To solve these challenges, the companies Krause DiMaTec, EDAG Engineering, Hirschvogel Tech Solutions, INTES and WP Kemper as well as the Direct Manufacturing Research Center conducted collaborative research and developed solutions to overcome existing barriers.

Rear wing bracket Wing3D

For the optimization of a rear wing bracket, the research results were used to produce a high-quality, application object. For this purpose, the Wing3D rear wing bracket developed by EDAG Engineering was manufactured from aluminum using the SLM process.

The rear wing bracket has an integrated hydraulic system that allows the rear wing to be adjusted continuously between 6° and 42°. This allows the realization of a rear wing setting adapted to the driving situation and an aerodynamic braking function. A 3D printed plain bearing insert reduces friction and enables maintenance-free kinematics. In addition, the cabling for the integrated taillight and a sensor cable have been integrated into the rear wing bracket. The high degree of functional integration and the complex, bionic shape could only be realized using additive manufacturing. In addition, the geometry created a lightweight design that simultaneously withstands the high mechanical loads of the application. An aerodynamic and visually appealing, high-quality design could also be realized and optimized by an elaborate finishing process.

The rear wing bracket is designed in such a way that it can be offered for small series production for sports vehicles factory-supplied or as an aftersales part. The Wing3D thus combines lightweight design, active aerodynamics, function integration and a visually appealing design with the aid of additive manufacturing.

PROJECT OVERVIEW

PARTNER

- EDAG Engineering
- WP Kemper
- Hirschvogel Tech Solutions
- Krause DiMaTec, INTES

RESEACHER

Research Leader
Prof. Dr.-Ing Rainer Koch
Prof Dr.-Ing. Detmar Zimmer

Research Assistant
Anne Kruse
Stefan Lammers

FIGURE 1 Rear wing bracket “Wing3D” [Source: EDAG Engineering]

FIGURE 2 Structure of the integrated hydraulics [Source: EDAG Engineering]

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

PROJECT OVERVIEW

RESEACHER

Research Leader
Prof. Dr.-Ing. Gunter Kullmer

Research Assistant
Dr.-Ing. Jan-Peter Brüggemann

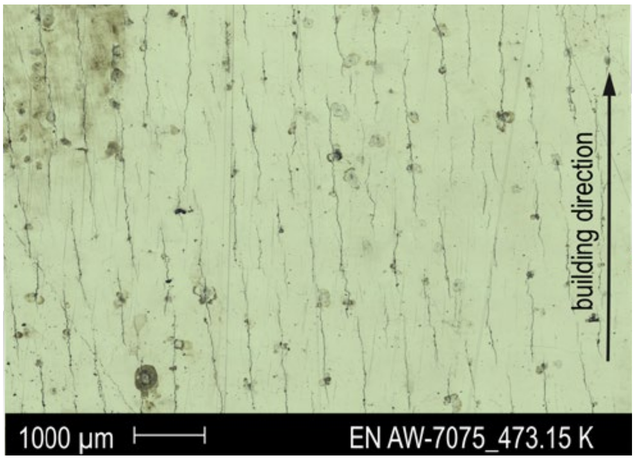

FIGURE 1 Optical micrographs of the specimen after SLM processing EN AW-7075 manufactured with a 473.15 K pre-heated building platform

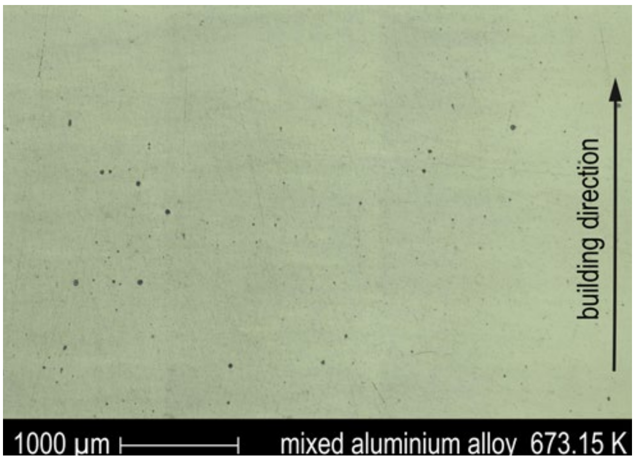

FIGURE 2 Optical micrographs of the specimen after SLM processing mixed aluminum alloy manufactured with a 673.15 K pre-heated building platform

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.

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

RESEACHER

Research Leader
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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.

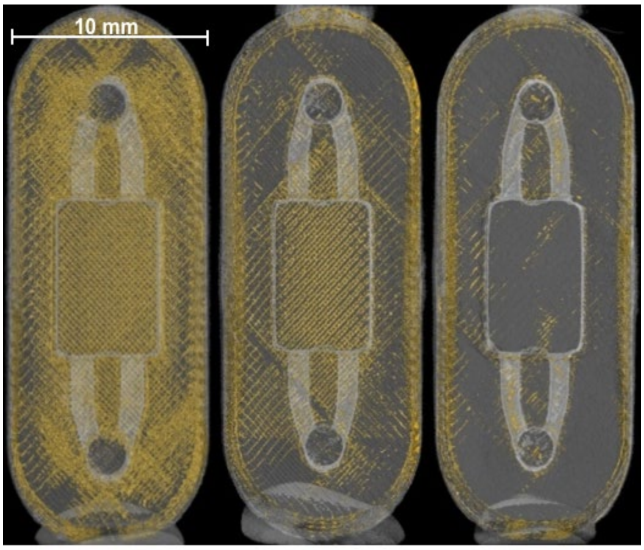
The cell culture reservoirs have the purpose to absorb, store and pass the microfluidic into micro physiological systems. Therefore, the tightness of the whole system is crucial to ensure the functionality. The structure is generated by applying single polymer droplets, so that cavities are formed between 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.



FF 1.48 BT 80 °C | FF 1.40 BT 80 °C | FF 1.40 BT 100 °C

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

POLYMER POWDER SPREAD PROCESS MONITORING SYSTEM

PROJECT OVERVIEW

RESEACHER

Research Leader
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Research Assistant
Helge Klippstein, M.Sc.

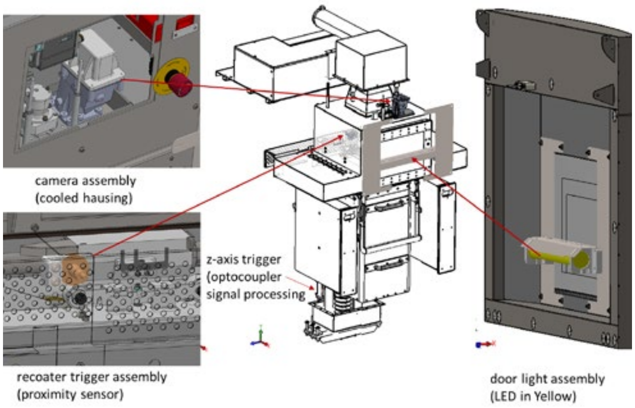

FIGURE 1 Process monitoring assembly unites

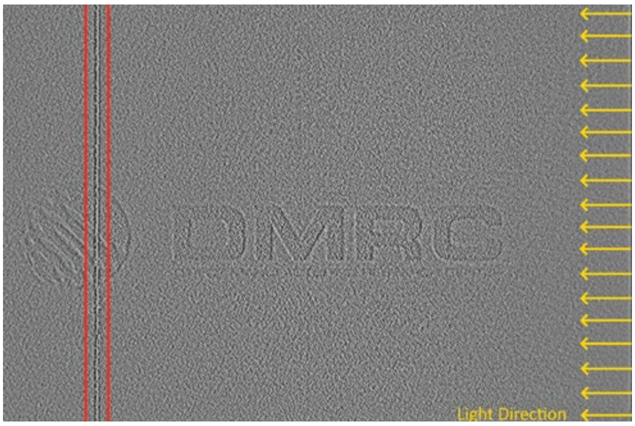

FIGURE 2 Critical powder spread flaw within the exposure area of a part

DMRC Project – Low Cost Process Monitoring

Machine and part qualification are always based on the information gathered. For a proper qualification and for confidence gaining in the LS technology the process itself should be observed and monitored as precisely as possible. Within this DMRC project a high-resolution images-based powder spread monitoring system for the laser sintering process has been developed. For each layer an image is captured and fed to a Region Based Convolutional Neural Network (Mask R-CNN) feature detection software, where it is analysed for powder spread flaws. The software is capable to detect point, line and area flaws within the powder spread and can differentiate those from the exposure area of the parts. The process monitoring system is therefore able to alert the operator, if the powder spread went wrong in a critical way, affecting the part quality. With this information the part can be directly rejected, set to no exposure or the job can be stopped to save powder material, time and costs.

Hardware

The developed system is a retrofittable system, containing four assembly unites plus the processing unit for the software. First the relevant process information as recoater position, preheating phase and exposure areas are collected. A light positioned in front of the process chamber door increases the shadow casting of the powder surface topology. Powder spread flaws tend to cast much more concise shadows, which helps to identify those imperfections. The image detection software is than able to identify critical areas and highlight the flaws. Additionally, the failure severity, hence the expected intensity of the failure, is rated with a score. This allows to differentiate between minor powder spread imperfections and critical flaws, which show an impact on the part optical and haptical or the mechanical properties.

Achievements

This system is the first powder spread monitoring system for the laser sintering technology, which is running fully automatically and gives in detail insides on the importance of the powder spread process.

QUALIFICATION OF NEW FDM MATERIALS BASED ON THE WELD SEAM STRENGTH

Introduction and Objectives

A component is created in the Fused Deposition Modeling (FDM) process by depositing a polymer strand layer by layer. Due to thermal fusion, the deposited material bonds with the layer below. This leads to the characteristic welded seams of the FDM process. Therefore, an essential part of the qualification of new materials for the FDM process is the evaluation of the processing suitability by means of the weld seam quality. The aim of the research in cooperation with DMRC industrial consortium is to drive forward the material qualification of high-performance polymers.

Procedure

In the investigations, an innovative methodology developed at the Direct Manufacturing Research Center (DMRC) is used to test the achievable weld seam quality, which enables an assessment of the processing suitability of materials in the FDM process. The tests are carried out on a parameter-open high temperature machine in order to be able to demonstrate the significance of various processing parameters for the processing of high-performance polymers in FDM. Main part of the methodology is the manufacturing of single-strand test specimens with the aim of determining the mechanical strength values of the individual weld seams based on tensile tests.

Achievements

The investigations demonstrated the suitability of the methodology for high-performance polymers and process parameter optimizations were successfully carried out. In particular, the nozzle temperature and the build chamber temperature have a major influence on the weld seam quality. The following materials were qualified for the FDM process:

- Polyetheretherketone (PEEK), carbon fiber-reinforced PEEK, thermally conductive PEEK
- Polyphenylsulfone (PPSU)
- Polypropylene (PP) with 30 % glass fibers

PROJECT OVERVIEW

PARTNER

- Industrial Consortium of DMRC

RESEACHER

Research Leader
Prof. Dr.-Ing. Elmar Moritzer
Research Assistant
Julian Wächter, M.Sc.

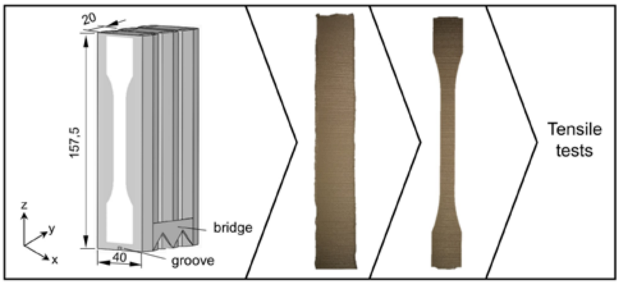

FIGURE 1 Process procedure for determining the weld seam quality

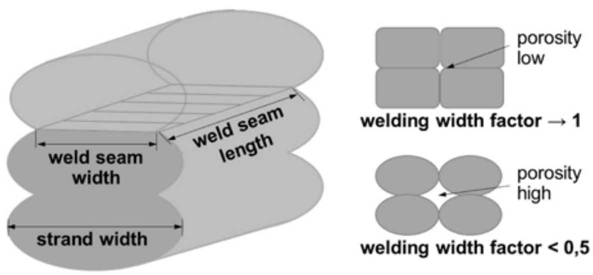

FIGURE 2 Factors for the assessment of weld seam quality

SLM FABRICATED DIE INSERT FOR PRESS HARDNEING

PROJECT OVERVIEW

RESEACHER

Research Leader
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Research Assistant
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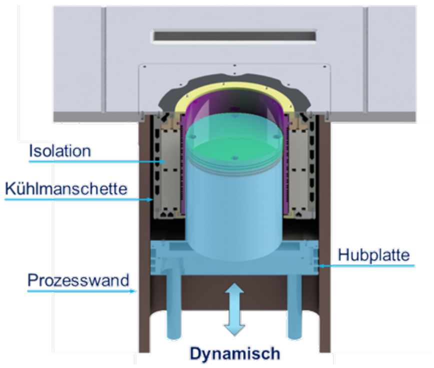

FIGURE 1 Warmformbacke

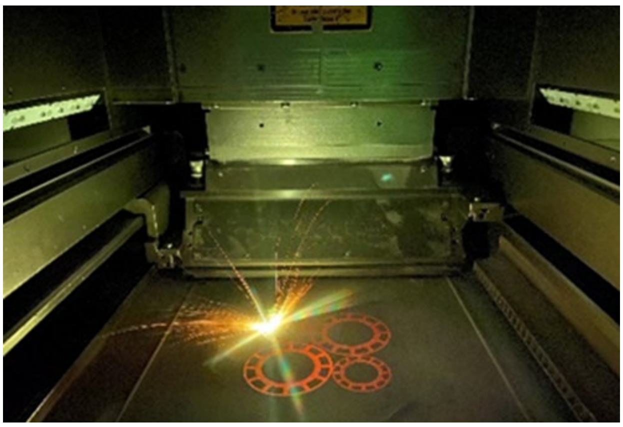

FIGURE 2 Topology-optimized die insert

UPB & Benteler AG, Apex Generative Design

Selective laser melting (SLM) is a powder bed-based additive manufacturing process for the production of metallic, highly complex components. With regard to tool manufacturing for forming production (e.g. extrusion, deep drawing), an almost unrestricted freedom of design enables the integration of cooling channels close to the contour in order to reduce hot spots, so that the component distortion of the semi-finished product is minimized, the service life of the tool is extended and the process time is shortened. As a result of the near-contour filigree production, machining can also often avoided.

Achievements

The process parameter study required for this includes the targeted variation of the volume energy density using a design-of-experiment approach. The achievable relative density is analyzed using cube samples with dimensions of 10 × 10 × 10 mm3. In addition to the relative density of > 99.99 %, the process speed and the surface roughness are defined as target parameters. Increased coating thickness has a significant effect on process time, so that coating thicknesses of 100 µm and 150 µm are targeted instead of the standard 25 µm to 50 µm. Following the determination of the process parameters, the surface roughness is addressed in order to set a low roughness for the uppermost two layers through a targeted parameter adjustment.

In parallel to the development of the process parameters, the topology of a tool insert for hot forming with integrated near-contour cooling is optimized. An existing conventional mold, for which the load cases and the thermal input are known, is used as a demonstrator.

With the generated results of both project focuses, an economic efficiency analysis is finally carried out with regard to the conservation of resources.

SURFACE FINISHING

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

- Walther Trowal Gmbh & Co. KG

RESEACHER

Research Leader
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Prof. Dr.-Ing. habil. Mirko Schaper

Research Assistant
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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

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.

PROJECT OVERVIEW

PARTNER

Industrial Consortium of DMRC

RESEACHER

Research Leader
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Research Assistant
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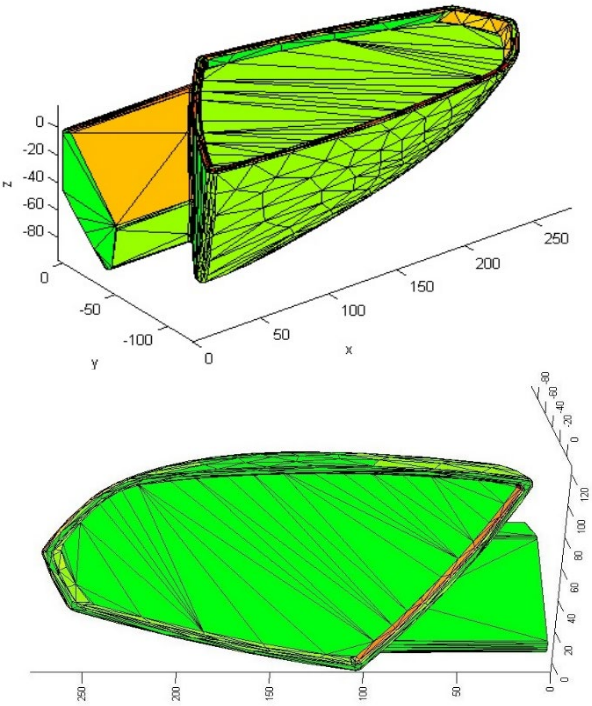


FIGURE 1 EOS P395 Frame with installed temperature measurement system

EDUCATION

CONTENT

EDUCATIONAL PROGRAMME

DMRC – AM LESSONS

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

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

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

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

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

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

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

DMRC – SEMINARS FOR INDUSTRY

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

DGM seminar

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

DGM seminar - advanced

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

Additive Manufacturing Specialist VDI

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

Participants will complete the course with a recognized VDI certificate. 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 have started 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/

STUDENTLAB3D – STUDENT LABORATORY

We want every student to have the opportunity to come into contact with additive manufacturing and to use "3D printing". We have come one step closer to this goal through close collaboration with the Department of Art, for which we won the 2014 Förderpreis für Innovation und Qualität in der Lehre (Award for Innovation and Quality in Teaching). In order to make the technology accessible to all students in all departments outside of lectures and seminars, our doors are open three days a week. Every student is welcome to learn about engineering, create and build their own idea, and challenge their mind because the question is, "How far can you imagine?"

PROJECT OVERVIEW

PARTNER

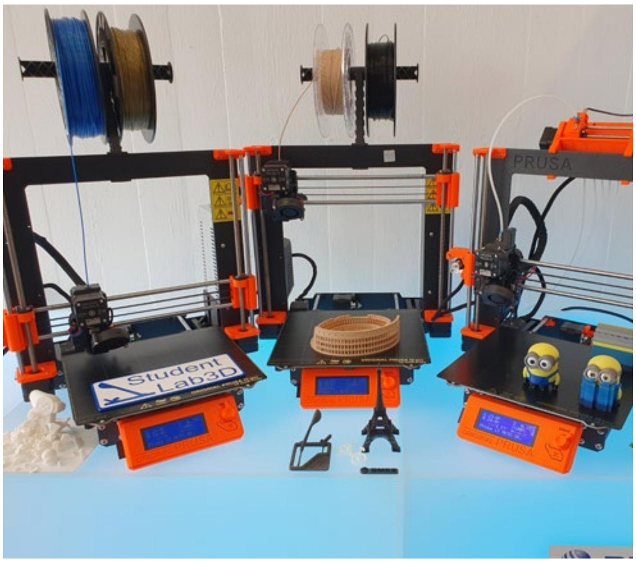
Paderborn University

RESEACHER

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

Research Assistant
Christine Driediger M.Sc.
Dennis Menge, M.Sc.

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



StudentLab3D at the Paderborn University

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.

Equipment

The StudentLab3D has 12 desktop printers with three different additive manufacturing processes. The main focus is on fused deposition modeling, but a resin printer and a laser sintering system are also available. Furthermore, we also have three 3D-scanners with different resolutions.

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.

CHAIRS AND INSTITUTES

CONTENT

FACULTY OF MECHANICAL ENGINEERING

FACULTY OF SCIENCE

FACULTY FOR COMPUTER SCIENCE, ELECTRICAL ENGINEERING AND MATHEMATICS

COMPUTER APPLICATION AND INTEGRATION IN DESIGN AND PLANING

» 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 C.I.K. (Computer Application and Integration in Construction and Planning) investigates and works on innovative approaches to the optimization of construction and planning processes using information technologies. The knowledge gained is applied in the construction and planning of products, as well as in the field of civil defense and disaster control of the Federal Republic of Germany and the European Union.

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 organizations, additional end user groups and other project partners from industry and science. The scientific field is extended by industrial research in projects in the field of additive manufacturing. The gained expertise, from completed and current research projects, is the basis for our ideas, systems and technologies in connection with planning, coordination, training, decision and integration support. Today, eight research assistants and up to ten student assistants work at the C.I.K. and contribute knowledge from the fields of engineering, economics and computer science.

ADDITIONAL EQUIPMENT OF THE CHAIR

Hardware

- Ultimaker 3 incl. Dual Extruder
- Ulitmaker S5 incl. Air Manager
- Prusa MKi3
- BigRep STUDIO
- BigRep ONE

Software

- 3D Systems - Geomagic Freeform incl. 3D Systems touch haptic device
- msc apex generative design

STAFF

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Integration of AM as a serial production process

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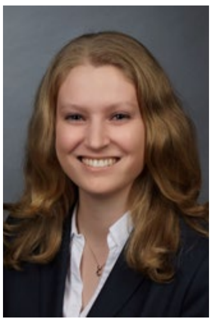

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INSTITUTE OF APPLIED MECHANICS

FAM

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

Prof. Dr.- Ing. Gunter Kullmer

INTRODUCTION

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

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

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

ADDITIONAL EQUIPMENT OF THE CHAIR

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

STAFF

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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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HEINZ NIXDORF INSTITUTE – 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 of 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 are anticipated in addition to articulated customer requirements. Our product understanding includes both material core product and related services.

Model Based (Systems) Engineering

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 Model Based (Systems) Engineering, 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 and Realisation

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 "Industry 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 Digitalization 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. In our Smart Innovation Laboratory, we observe engineering collaboration and human computer interaction with latest digital technologies.

ADDITIONAL EQUIPMENT OF THE CHAIR

Smart Automation Laboratory

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

Smart Innovation Laboratory

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

Software Tools

- CAX (SolidWorks, Matlab,...)
- Modelling (MagicDraw,...)
- Management (esp. Siemens Teamcenter)

Equipment for Digitalization (incl. VR/AR devices)

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

STAFF

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DESIGN AND DRIVE TECHNOLOGY

University of Paderborn
Design and Drive Technology

» The application of additive manufacturing for the production of highly functional and complex structures has developed rapidly in recent years. Nevertheless, there are economic obstacles for many fields of application, starting with the design, through additive or hybrid manufacturing, to the generation of functionally high-quality final components by finishing processes. «

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 of 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 there are 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

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KUNSTSTOFFTECHNIK PADERBORN

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

Prof. Dr.-Ing. Volker Schöppner

INTRODUCTION

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

The two professorships of the KTP ensure a broad range of knowledge transfer:
- Polymer Engineering, Prof. Dr.-Ing. Elmar Moritzer
- Polymer Processing, Prof. Dr.-Ing. Volker Schöppner

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

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

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

- Fused Deposition (FDM) or Fused Layer Modeling (FDM)
- Arburg Plastic Freeforming (APF)

ADDITIONAL EQUIPMENT OF THE CHAIR

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

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

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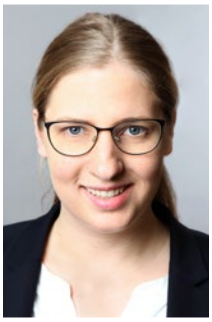

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AUTOMOTIVE LIGHTWEIGHT CONSTRUCTION

www.Leichtbau-im-Automobil.de

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

Prof. Dr. Thomas Tröster

INTRODUCTION

Research Activities

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

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

Equipment

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)
- High Speed tensile test equipment – Zwick HTM8020

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

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SLM Performance Parameter

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CHAIR OF MATERIALS SCIENCE

LWK
Lehrstuhl
für Werkstoffkunde

» 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 disequilibrium 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.

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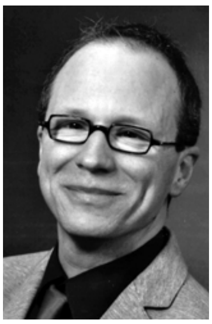

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Alloy development;
AM for biomedical applications

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ADDITIONAL EQUIPMENT OF THE CHAIR

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

PARTICLE TECHNOLOGY GROUP

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

Prof. Dr.-Ing. Hans-Joachim Schmid

INTRODUCTION

Particle technology is a specialization in process engineering. We investigate the properties and further the production, conditioning and manipulation of particulate systems as well as their characterization. Such particulate systems may consist either of solid, liquid (i.e. droplets) or even gaseous (i.e. bubbles) particles in a matrix which might be either gaseous or liquid. These systems show a complex behavior, sometimes called the 'fourth state of aggregation'. Principally, if particles become smaller and smaller particle-particle interactions become dominant for the behavior of such systems.

The Particle Technology Group is involved in fundamental and applied research in the field of particle technology. We have a strong focus on understanding the behavior of particulate systems and to learn how to produce a requested particulate property in a final product. Therefore, doing fundamental, publicly funded research is considered to be equally important as cooperations with companies on very specific projects, to develop solutions in the field of particle technology. The Particle Technology Chair performs research and offers expertise in the following fields:

- Particle synthesis
- Aerosol particle formation
- Characterization of particles and dispersed systems
- Polymer laser sintering (SLS) process analysis
- Quality management systems for SLS processes
- Qualification of polymer material for SLS 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

Particle size analysis

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

Rheometry

- Pressure - Driven Capillary Rheometer Rosand Rh-7
- Viscometer - Ubbelohde
- Rotational Rheometer - Anton Paar MCR501
- Torque Rheometer - Rheodrive 7
- Melt Flow Tester - Zwick Mflow
- Revolution Powder Analyzer – REVOLUTION PS Prozess-technik

Crushing

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

Other

- Multi-Process-Machine – MPU 50 ATP Hosokawa

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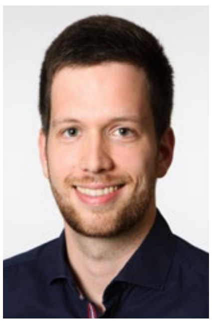

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TECHNICAL AND MACROMOLECULAR CHEMISTRY (TMC)

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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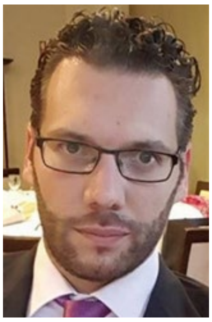

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Dr. Juan Carlos Calderón Gómez

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SOFTWARE INNOVATION LAB (SI-LAB)

» We need and do research on data-centric, software-based ecosystems in different application domains like energy supply, e-commerce, future work or additive manufactoring. Our research is based on established software engineering concepts enhanced by machine learning-based techniques and solutions. «

Prof. Dr. Gregor Engels

INTRODUCTION

A nowadays great challenge of modern service platforms and architectures is beside qualitative development to systematically capture and integrate diverse requirements in complex software systems. To overcome these challenges from software side, 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 a systematization of the development process. Models for software development are therefore central research topics of the database and information systems group (DBIS).

The growing complexity of these digital services and their value-added service networks demand a broadly collaboration support of involved stakeholders in each connected knowledge domain. Innovative data-centric and software-based ecosystems additionally need a strong link between application domains and related research domains.

The cooperation model SICP – Software Innovation Campus Paderborn delivers this demand including several scientific competences at Paderborn University. It enables close cooperation between business and science and transfer of research results into marketable, software intense innovations. On science side the central scientific institution SI-Lab – Software Innovation Lab of SICP identifies the inter- and transdisciplinary research activities. More than 30 university teachers from Paderborn University of different faculties are involved in the fields of computer science, electrical engineering and information technology, economics, business informatics and cultural studies. With their expertise and the competencies of their disciplines, they manage the necessary scientific and interdisciplinary know-how, which is composed in projects according to requirements.

Currently, SI-Lab has five competence areas, each of which is scientifically led by a director (university teacher) and operatively directed by a manager. The Centres of Competence (CoC) are oriented towards the needs of companies and society. These areas of expertise are Cyber-Physical Systems, Digital Business, Digital Security, Smart Systems and Software Engineering. The DBIS group mainly exports its expertise to the Software Engineering Centre of Competence. In person, Prof. Dr. Gregor Engels is the director of the CoC Software Engineering and the Chairman of the Board of SI-Lab. Eventually, the SICP offers the interface and key success factor in the transfer of research results into marketable, software-intensive innovations.

Within the collaboration of the DMRC, we are connecting both competence hubs and strengthen the cooperation between mechanical engineering and informatics. By now we are developing digital services integrating machine learning approaches to extend and optimized processes in additive manufacturing.

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CONTENT

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