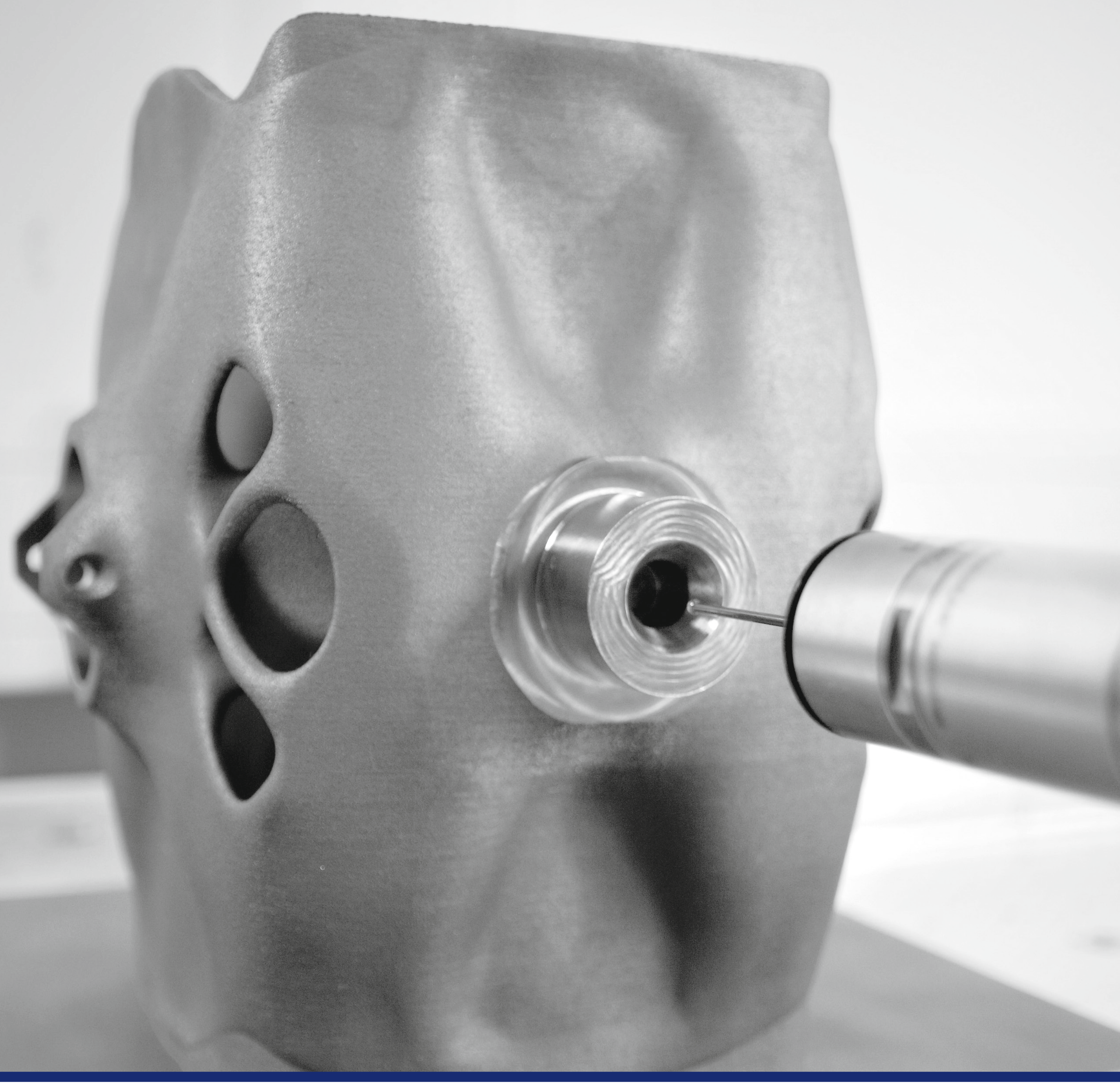
DMRC

DIRECT MANUFACTURING RESEARCH CENTER

RESEARCH
INNOVATION
EDUCATION

Annual Report 2017



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FOREWORD

Dear Members and Friends of the Direct Manufacturing Research Center,

another year in the rapidly evolving world of Additive Manufacturing has passed by. The market has seen many exciting developments with new players and new technological possibilities evolving. The constant development in the area of Additive Manufacturing and the according short innovation cycles and the constant growing application fields make research so interesting for us. AM is our passion and so we thrive to help to developing Additive Manufacturing as an industrial established production process.

Seeing a lot of movement in the market, 2017 was a very interesting and very intensive year for the DMRC. This now is already the sixth edition of the DMRC annual report, in which we would like to share some of our past research activities, some important news, impressions and achievements with you. Some of the important developments include:

- In 2017 the DMRC research community once again has grown stronger. We were happy to welcome the companies AKG, Danfoss, Klaeger 3D-Cut, Mettler Toledo as well as Porsche as new members.
- In the Year 2017, the overall budget available for additive manufacturing research increased to a rough budget of 3 million Euros.
- In January of 2017 the two BMBF funded research projects OptiAMix and KitkAdd were launched. The kick-off for both projects took place at the Paderborn University.
- The DMRC has continued to strengthen its network and started the collaboration with AM-Motion, Mobility goes Additive e.V..Furthermore, the DMRC has started to contribute to the AM working groups of the VDMA (mechanical engineering industry association) and the BDLI (German aerospace industries association).
- A one-year additive manufacturing lecture was introduced at the Paderborn University to educate the AM engineers of tomorrow. Over 170 students already attended the lecture from the university.
- In the role as Managing Director Dr.-Ing. Christian-Friedrich Lindemann has succeeded Dr.-Ing. Guido Adam.

We wish you much joy reading this report and sincerely thank you for your continued support. For the latest news, follow us on LinkedIn (https://www.linkedin.com/company/dmrc) or on our website.

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MOTIVATION AND AIM

Additive Manufacturing processes create parts in layers and without using formative tools. Thereby, they transfer three-dimensional manufacturing challenges into two-dimensional ones. In addition, for many additive manufacturing processes, the material properties of the additively manufactured part arise during the manufacturing process as a function of the raw material and the used manu-facturing parameters. From these manufacturing characteristics results that additive manufacturing offers lots of freedoms, 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.
- 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. Two 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.
- 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 by means of internationally outstanding contributions in terms of research, innovation and teaching.

Situation of additive manufacturing regarding its...

advantages

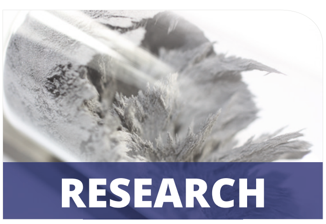
- Great design freedoms
- Great material freedoms
- Great economical possibilities
- ...

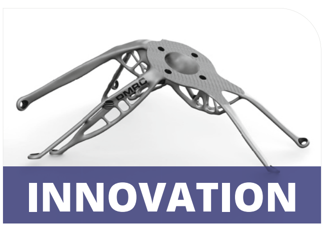
spreading and usage

- Usage in research institutes & technology leading companies
- Advantages often unknown
- Risks often unknown

AIM

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





STRUCTURE OF THE DMRC

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

Both, the various different disciplined be handled as well as the changing research and development focus, clearly define two mayor goals that the structure of the DMRC needs to meet:

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

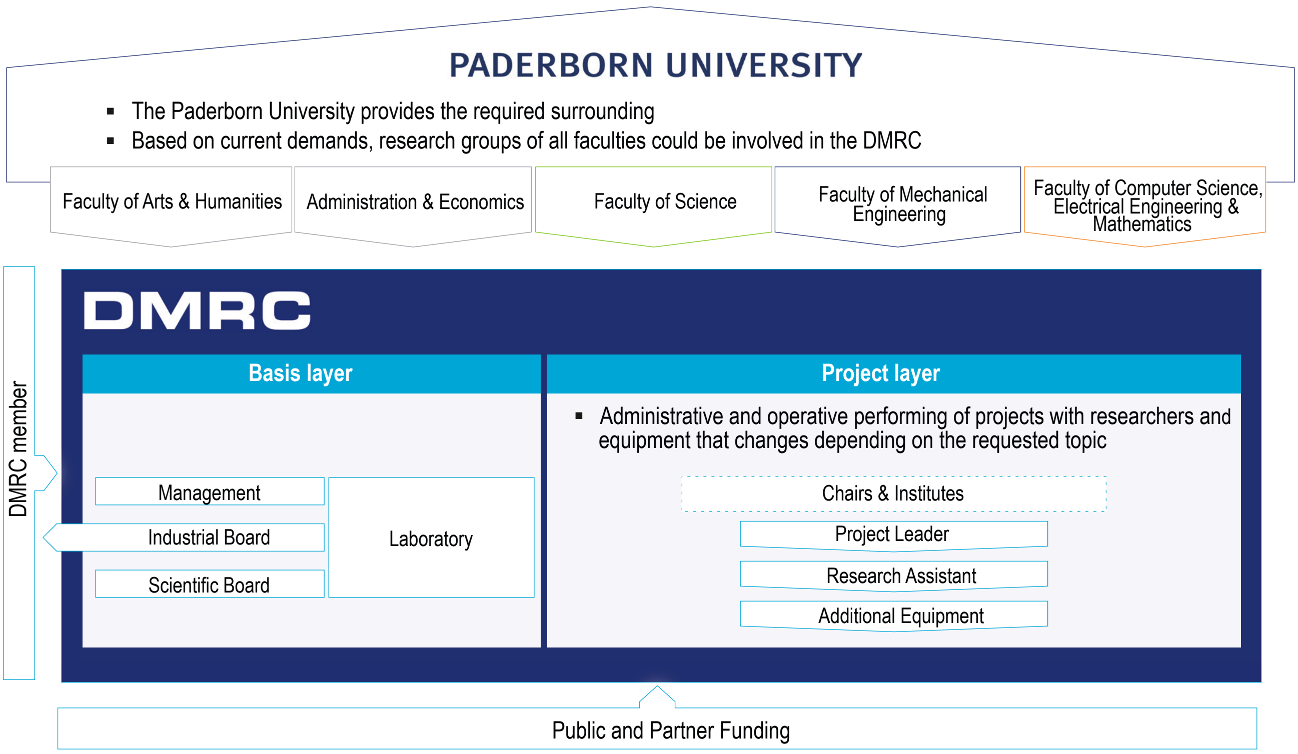
In order to fulfill these requirements, the DMRC is structured in different layers:

Basic Layer: This layer contains the management of the DMRC, the industrial and the scientific board as well as the laboratory. The DMRC Basic Layer has the task to steer the DMRC and to create an appropriate surrounding to perform research and innovation.

Project Layer: Within this layer, projects are performed. Therefore, each project consist of the project leaders, who are send by both the industry and scientific board, the research assistants and, if required, additional equipment. Project tasks and budgets are defined in the DMRC Basic Layer. Based on the described tasks, the individually required personals are then invited to join the DMRC Project Layer to perform the projects. Once a project is fully finished, further research needs influence, if the expert remains in the DMRC Project Layer and continues the work or if other experts from other disciplines join.

Paderborn University: The surrounding and the third layer for the DMRC forms the Paderborn University with its five faculties. Located in this surrounding, the DMRC can invite experts from Arts and Humanities, Business Administration and Economics, Natural Science, Mechanical Engineering, Computer Science, Electrical Engineering and Mathematics to join the DMRC and work on projects.

FIGURE 1 Structure of the DMRC



STANDARDIZATION COMMITTEES

Additive Manufacturing technologies and applications are becoming more and more mature. The DMRC is supporting this progress on different levels. Doing fundamental and applied research along different disciplines, technologies and research fields on the one hand. On the other hand, there is an increasing need of standardization and the DMRC is actively participating in different standardization committees to foster this process.

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

Furthermore, the DMRC is part of the VDMA Additive Manufacturing – Automation. The superordinate committee targets at the whole chain of production and brings together industry and research institutes. The overall goal is to develop standards and technical requirements to support the ongoing extension of Additive Manufacturing application. DMRC activities are focused on aspects regarding the automation of Additive Manufacturing processes.

Another standardization committee the DMRC is part of is the FVA AK Geregelter Elektroantrieb and FVA AK Additive Manufacturing. It aims at uncover new application potentials of Additive Manufacturing in the field of drive train applications. FVA AKGEA is focused on applications regarding controlled electric drives, while FVA AKAM has a broader perspective and targets

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

COMMITTEES

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

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

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

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

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

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

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

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

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

INVOLVED CHAIRS AND INSTITUTES

FACULTY OF MECHANICAL ENGINEERING

Automotive Lightweight Construction

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

Chair of Material Science

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

Chair of Fluid Process Engineering

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

Computer Application in Design an Planing

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

Design and Drive Technology

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

Heinz Nixdorf Institute

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

Heinz Nixdorf Institute

Prof. Dr.-Ing.
Jürgen Gausemeier
Head of Chair -
Strategic Planing and
Systems Engineering

Institute of Applied Mechanics

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

Institute of Applied Mechanics

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

Particle Technology Group

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

Kunststofftechnik Paderborn

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

Kunststofftechnik Paderborn

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

FACULTY OF SCIENCE

Technical and Macro Molecular Chemestry

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

FACULTY OF COMPUTER SCIENCE

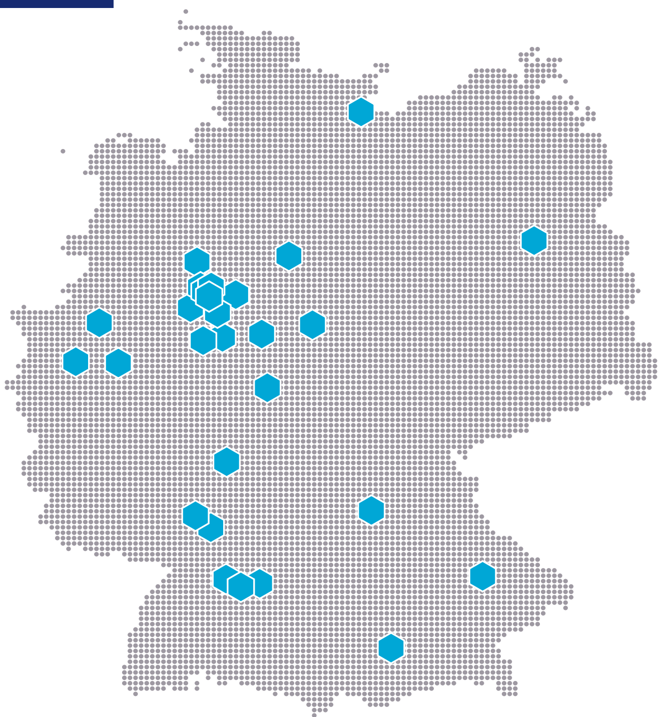
Chair of Database and Information Systems

Prof. Dr.
Gregor Engels
Head of Chair

PARTNERS 2017

INTERNATIONAL

NATIONAL



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

USA

DENMARK

SWISS

GERMANY

LABORATORY

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

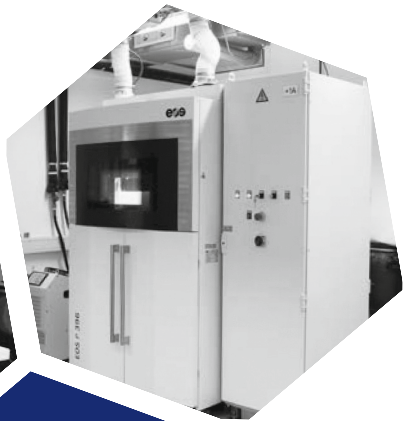
This equipment will continuously be updated and increased. In 2017 the DMRC has e.g. invested into test rigs to investigate further aspects of the future electro mobility, into an optical scanning head for the coordinate measurement machine, and further equipment for the preparation of our test specimens.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

And, in case the DMRC equipment is still not sufficient for a specific task or request, the DMRC can utilise all equipment, which is available at the chairs that work together in the DMRC. This chair equipment comprises a very wide field of different testing machines, microscopes, test rigs and even computer tomography. Summarizing this, the total accessible equipment opens up the opportunity for the DMRC partners to get access to a very wide spectrum of different additive manufacturing machines and testing equipment.

To get an overview about the manufacturing machines and the testing equipment, which is installed in the DMRC, please check the tables listed on the next pages. The additional equipment of the chair is listed in the section “Chairs and Institutes”.

EQUIPMENT

EOISINT P396



EOISINT P395

Laser Sintering

SLM 280HL

Laser Melting

Fused Layer Modeling

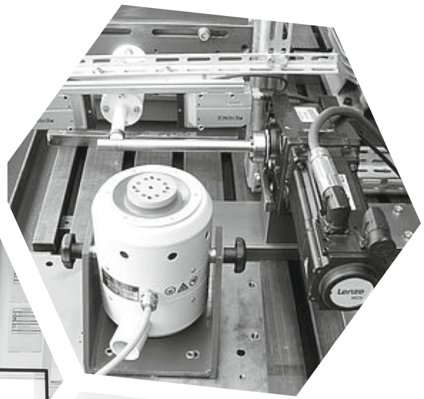
SLM 250HL

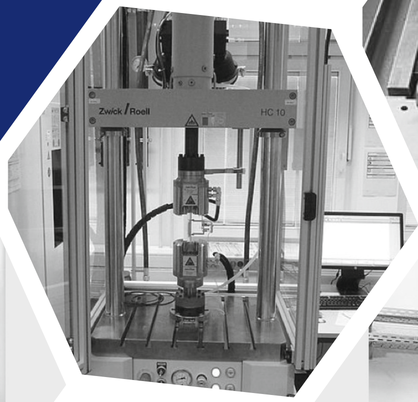
FORTUS 400 mc

FREEFORMER

Mechanical Analysis

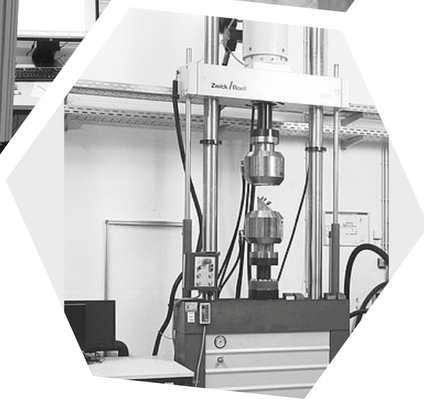
TEST RIG FOR
BENDING VIBRATIONS





ZWICK HC 10

INSTRON 5569



ZWICK HB 250

Optical Analysis

3D MEASURING
MACROSCOPE

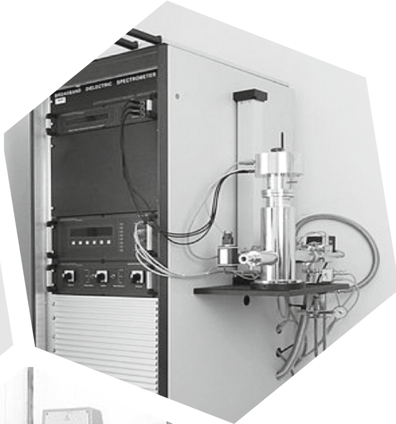
SCANNING ELECTRON
MICROSCOPE (SEM)

3D SCANNING
kolibriMulti

THERMAL IMAGING
CAMERA P60, FLIR

PARTICAL SIZE ANALYSER
MASTERSIZER 2000

DIELETRIC
SPRECTROMETER



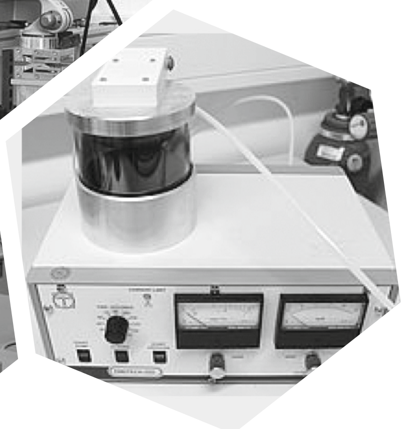
PRECISION BALANCE

MOISTURE MEASUREMENT
AQUATRAC

Geometrical Analysis

RHEOMETER
PHYSICA MCR 501

EXTRUSION PLASTOMETER
MFLOW



SPUTTER COATER
SC7620

Geometrical Analysis

HOMMEL ETAMIC
T80000

NIKON ALTERA 8.7.6

DIRECT MANUFACTURING RESEARCH CENTER (DMRC)

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

INTRODUCTION

Field of research

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

Research leads to innovation

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

Education at the DMRC

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

EQUIPMENT OF THE DMRC

Laser Sintering

- EOSINT P395
- EOSINT P396

Fused Layer Modeling

- Fortus 400mc
- Freeformer

Laser Melting

- SLM 250HL
- SLM 280HL

Optical Analysis

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

Geometrical Analysis

- Nikon Altera 8.7.6
- Hommel Etamic T8000
- Particle size analyser Mastersizer 2000
- Thermal imaging camera P600, FLIR

EQUIPMENT OF THE DMRC

Physical and chemical Analysis

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

Mechanical Analysis

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

DMRC STAFF

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Research

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ADDITIVE MANUFACTURING OF MEDIUM CARBON STEELS AND A COCR-ALLOY

The project addresses the fabrication and analysis of three challenging materials via selective laser melting (SLM). Two medium carbo steels and a high carbon content CoCr-alloy are chosen in order to expand the material spectrum available for SLM. During this one-year project, thorough parameter-studies will be conducted to determine suitable parameter-sets. Additionally, preliminary microstructural and mechanical results will be obtained.

PROJECT OVERVIEW

DURATION

01/2017 – 12/2017

PARTNER

- Direct Manufacturing Research Center (DMRC)
- Voestalpine
- Baker Hughes
- Porsche

FUNDED BY

Industrial Consortium of DMRC

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

With regard to the latter material group, the martensitic steel H13 (1.2344) is widely known for the additive manufacturing of components, primarily tools. Despite this, medium carbon steels obtain a limited hot hardness, which is of utmost importance during molding or hot forming operations. Thus, another martensitic steel is needed qualified for SLM processing, which satisfies this expectation. In this project, the microstructure will be investigated, and mechanical properties will be characterized. This tool steel is suited for applications in which highest toughness and hot hardness is needed, i.e., in cold work, hot work, and plastics tools.

One further medium carbon steel group, which has rarely been investigated, can be identified as quenched and tempered (QT) steel. These steels exhibit high toughness accompanied by high strength. Thus, QT steels are employed in machinery and structures in which an increased yield strength and an abrasion resistance is demanded, e.g., as gears, cutting edges, or camshafts.

Both steels possess medium carbon contents of approximately 0.5 wt.%, which has not successfully been processed at larger diameters, e.g., >50 mm. Evolving high residual stresses lead to numerous cracks during SLM fabrication. A promising approach to avoid the undesired cracks is the modification of the scan-strategy in combination with the variation of the build platform temperature up to 400 °C.

The third material selected within this project is the CoCr-alloy with a high carbon content. Generally, these materials possess superior tribological and corrosion properties under aggressive conditions. Until now, these materials are processed by casting methods or powder metallurgy. Nonetheless, based on the processing technologies available, the geometrical freedom is restricted, and the machining is extremely challenging.

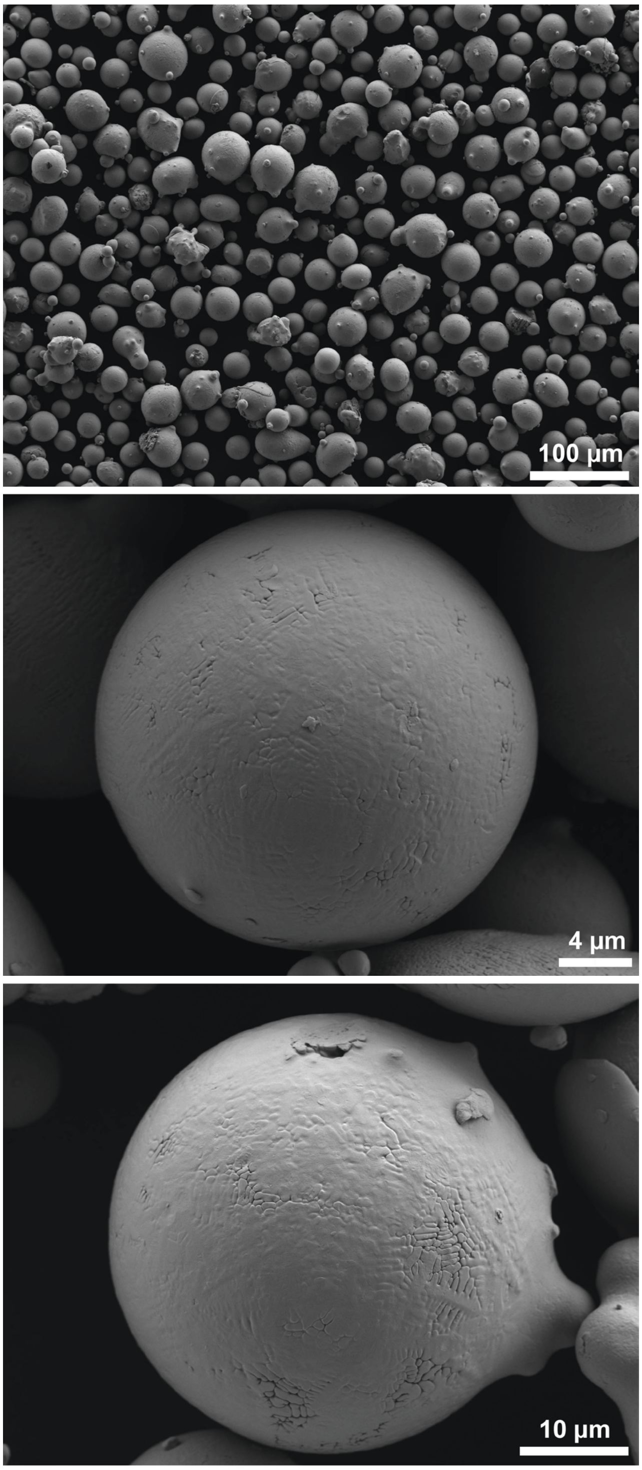

FIGURE 1 Powder morphology and particle analysis

CONCEPT AND CASE STUDIES 2017

To enable the use of AM in broad industrial practice, specific tools are required. Function-orientated active princip-les 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".

PROJECT OVERVIEW

DURATION

01/2017 – 12/2017

PARTNER

Industrial Consortium of DMRC

FUNDED BY

Industrial Consortium of DMRC

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Prof. Dr.-Ing. Rainer Koch (CiK)

Research coordinator
Stefan Fischer (John Deere)

Research assistent
Sebastian Magerkohl, M.Sc. (KAt)
Thomas Reiher, M.Sc. (C.i.K)

WEBSITE

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

Objectives

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 as a long term objective, starting in 2017 with:

- heat transfer
- structural optimization

The results show potentials of additive manufacturing in terms of heat transfer and structural optimization and can be used to inspire design engineers and to emphasize the technical benefits using AM.

Procedure

The procedure is divided into three phases (Figure 1). The first step 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, thus making it possible to focus on relevant approaches in a meaningful and well-founded manner. 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 identification of suitable active principles. In the process already known and new approaches are considered. In some cases simulations were performed to estimate the influence

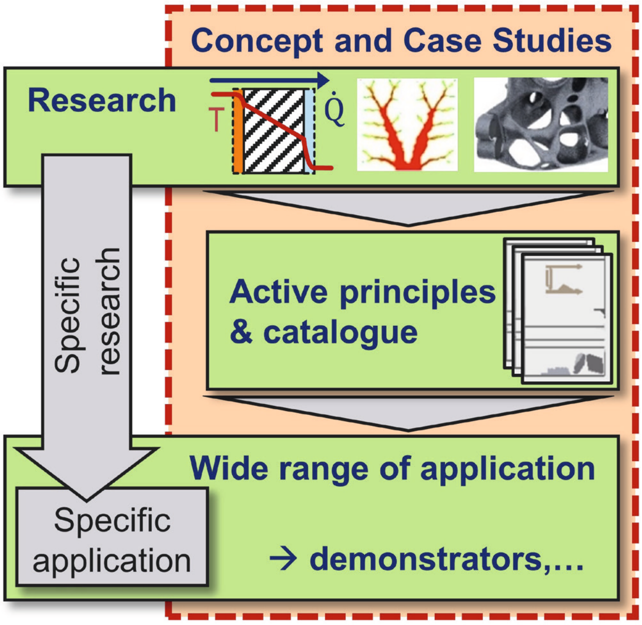

FIGURE 1 Project concept and process phases

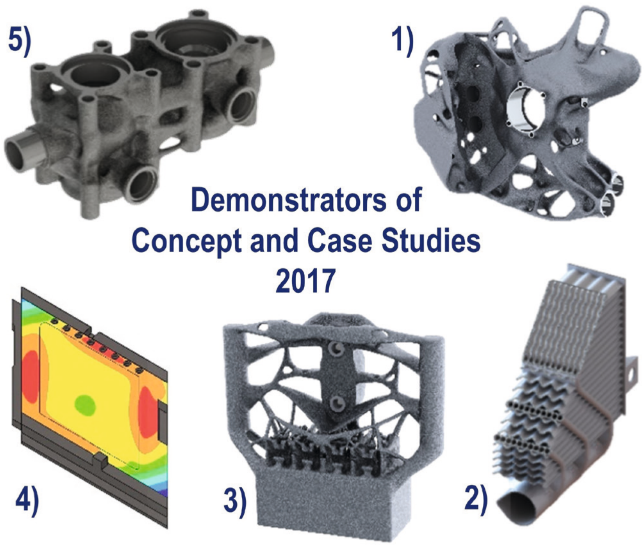

FIGURE 2 Demonstrators for heat transfer and structural optimization

on performance data. With a focus on the application in the design process, a clear and uniform form of presentation was important. Accordingly, all active principles were recorded in a uniform table form which, in addition to a graphic illustration, contains descriptions of practical relevance as well as application examples and their quantitative impact on the performance development. The tables are presented in a catalogue which contains the active principles as well as application examples.

In the concept phase of the design process, promising concepts must be selected, which are to be examined in greater detail. To support the decision in this early phase, experience is helpful. In order to make that available for the corresponding subject area, industrial demonstrator components are optimized using a design for AM (Figure 2). These components can be used to verify and demonstrate the applicability of the active principles for heat transfer (2 & 4), structural optimization (5) and combinations of both topics (1 & 3).

Due to the generic approach and the use of function-orientated active principles, the application of the results is not limited to the demonstrators. The active principles allow a broad applicability and can be used in further components.

Results

In the field of heat transfer, a large number of applications are available, which are bound to special requirements. In order to achieve reliable results, the focus has been limited to one area that is present in a variety of products, the heat transfer between a solid and a flowing medium. For this purpose, different structures are examined and analyzed with regard to their heat transfer properties. It could be shown, that there is a high potential especially in complex applications due to the design freedom of AM; however, this can only be exploited taking the respective boundary and process conditions into consideration. Additively manufactured heat transfer structures can be specifically adapted to the respective application and used efficiently. Therefore, the design freedom can be used to improve the technical implementation of the function.

The potential of AM components in terms of structural optimization is also considered. This is a major advantage, particularly in the field of lightweight design, which is exploited by increased application in the aerospace industry. The full potential can only be achieved if, in addition to the mechanical load capacity, other functions are integrated as well. The project focuses on the combination of multi-objective optimization. Due to the topics, this was carried out specifically in connection with heat transfer.

Potential resulting from AM can be demonstrated in every field, particularly though in the combination of heat transfer and structural optimization.

Outlook

The basic idea and the results of the „Concept and Case Studies 2017" project have been positively evaluated. The practical form of presenting the results supports the application of AM in the design process. The basic idea will be pursued in 2018, considering the topics „magnetic flux" and „structural damping".

HIGH TEMPERATURE PROCESSING OF METALLIC SLM POWDERS

The aim of this project is to reduce the high residual stresses and the shrinking of the material caused by the high cooling rate during the building process, which leads to crack formation. In this project, a heated building platform helped to reduce the temperature gradient, which leads to certain microstructural changes that made these materials processable with selective laser melting.

PROJECT OVERVIEW

DURATION

01/2017 – 12/2017

PARTNER

Industrial Consortium of DMRC

FUNDED BY

Industrial Consortium of DMRC

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Objectives

In most industrial applications, the lightweight design and the development of individual, functional customized products have been and still are of major interest for material development. Therefore, materials such as aluminum-, titanium-, nickel-based alloys, as well as steels came into focus due to their specific, aligned density and mechanical characteristics. In view of these aspects, high strength aluminum alloys, e.g., EN AW 7075, have not been considered yet for additive manufacturing due to their inferior processability. Aluminum is only given as an example to emphasize the need for research and to discern the effects of a heated building platform concerning the resulting mechanical and microstructural properties. With regards to the future microstructural and mechanical tests, a tool steel (H13, X40CrMoV5-1) was chosen since this material is a commonly applied steel in industrial applications. Moreover, this steel is difficult to process via SLM without further processing modifications. The second analyzed material was the aluminum alloy AA7075. Due to the occurring hot cracks, a heated platform up to 400°C represents a promising solution to avoid these defects.

Results

In the first period of this project, cuboidal blocks were built on a small building platform at different temperatures (RT; 100°C; 200°C; 300°C; 400°C). Here, two criteria for a stable production and analyzing of samples were considered. The first criterion is the residual stress, which increases during the manufacturing for H13 . The main reason for the residual stress is the high cooling rate encountered during the process. The rapid cooling leads to a fast phase transformation from gamma iron into alpha iron (martensite). The second criterion is the geometry of the sample to ensure that the influence of each parameter set of the building process can be analyzed. For all of these samples, hot cracking has been detected. The pre-heated samples with a temperature of 100°C and 200°C show the largest and thickest cracks. The cracks in the other samples (300°C, 400°C) are have been very thin and a lower porosity. The 300°C samples had more cracks compared to the 400°C sample. The influence of the pre-heating of the platform was not successful to prevent hot cracking. The size of the melting pool had a higher

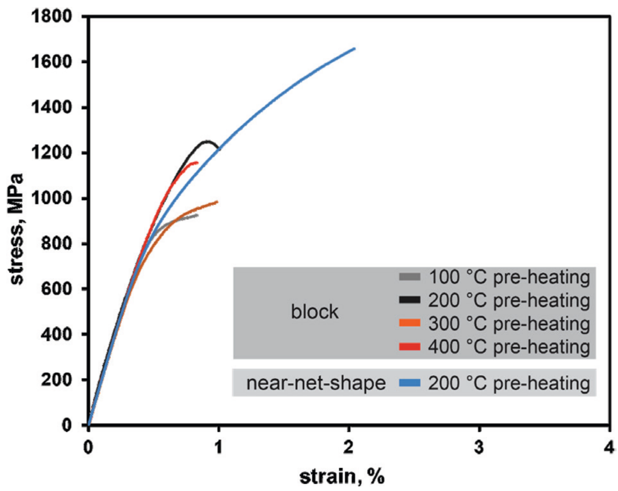

FIGURE 1 Quasi-static properties of H13 samples

impact on the crack formation.

Tensile tests of pre-heated H13 samples built with a layer thickness of 50 µm were compared with near-net-shape samples from a previous project. These samples were built with the SLM 250HL with a layer thickness of 30 µm. Figure 1 shows that the pre-heated specimens do not reach the values known from the literature, and, additionally, do not meet the tensile strength values of the near-net-shape sample, which are comparable to values obtained for the conventional processed material.

The microstructure of the 100°C and 200°C samples are shown in Figure 2. On the top, the IPF image shows a typical martensite structure for this material after a fast quenching. The phase image (bottom) depicts the information concerning the amount of retained austenite (green), which had been detected in prior investigations as well. During the tensile test, the retained austenite transforms into martensite, which leads to a hardening effect, thus employing a higher mechanical strength. The strain values collected in the tensile tests showed very little evidence of changes between the variable build platform temperatures. At a preheating temperature of 400 °C, based on a quasi-iso-thermal conditions, a martensitic to bainitic microstructure developed.

Conculsion

The approach to increase the pre-heating temperature above the Ms-temperature of H13 does not avoid hot cracking of the material. Based on results obtained from the near-net-shape specimens built with a smaller layer thickness, it is assumed that a higher energy density will result in a reduction or removal of hot cracking. Therefore, it is proposed that, in order to increase the energy density, the melt pool area should be reduced via a reduction of the hatch distance. Based on the energy density relationship, this should alleviate the hot cracking problem.

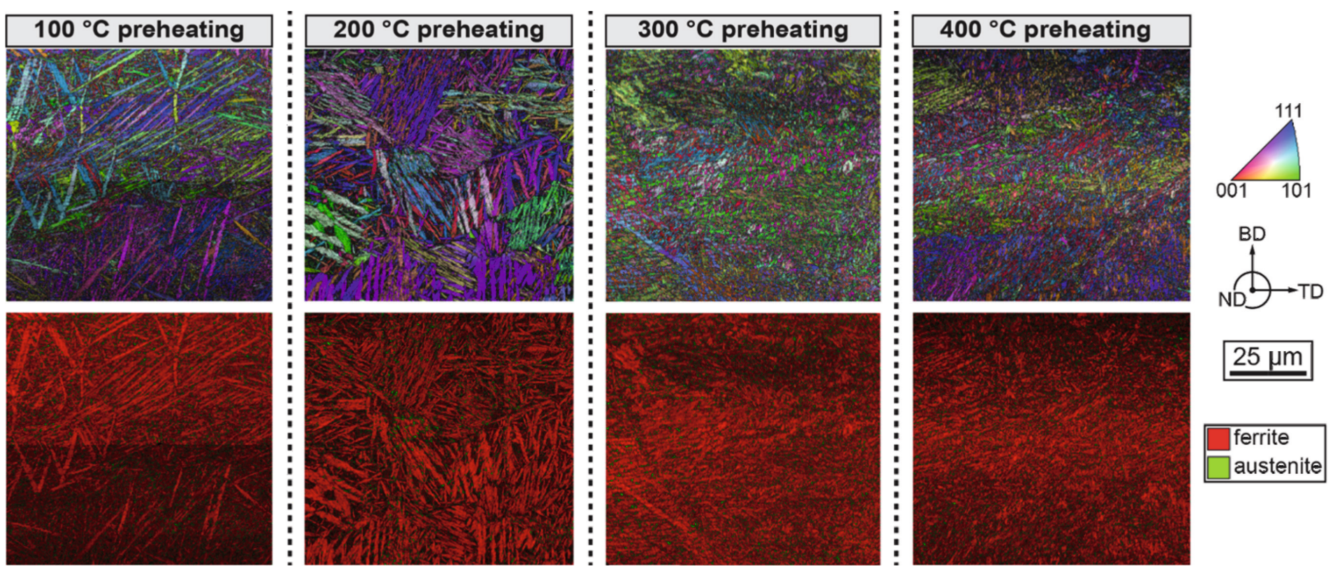

FIGURE 2 Electron Backscatter Diffraction (EBSD) mapping depicting a martensitic microstructure by means of Inverse Pole Figures (IPFs) and the respective phase-mappings in which martensite is displayed in red and austenite is displayed in green

INFLUENCE OF DIFFERENT POWDER PROPERTIES ON THE MATERIAL CHARACTERISTICS

Ti6Al4V is the most commonly used alloy, because of its well-balanced property profile. Different heat treatments allow to tune microstructure and properties for different requirements and applications. During the use phase of powder, effects like out-washing of fine fractions, pick up of oxygen as well as enrichment of splashes change powder characteristics. In addition, there is a possibility of powder decomposition due to the powder handling process. Therefore, the powder quality permanently changes during the manufacturing process. Another point is the lot to lot variation of the powder quality inside the specified ranges. Scope of this project was to investigate the influence of relevant changes of powder characteristics on material as well as part properties.

PROJECT OVERVIEW

DURATION

01/2017 – 12/2017

PARTNER

Industrial Consortium of DMRC

FUNDED BY

Industrial Consortium of DMRC

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Objectives

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

Procedure

The project aim is the investigation of the powder material with its specific influencing factors during the use-phase. Of particular interest thereby is the lot to lot variation of the powder quality inside specified ranges. Because of that, it is necessary to investigate how a shift of the median value x50 affects the material properties. The approach is to shift the median value as near as possible to the range limits of the particle size range. The first generated size distribution is in the range between 45 – 66µm with an median value of d(0.5) = 45µm (upper limit). The second generated size distribution is in the range between 21 – 54µm with an median value of d(0.5) = 30µm (lower limit). The artificial aging process takes place inside a climate chamber with standard atmosphere condition. In this regard a temperature of 300°C is provided, because from this temperature the titanium powder absorbs oxygen very easily. Since the aging process is executed under standard atmosphere, the nitrogen content

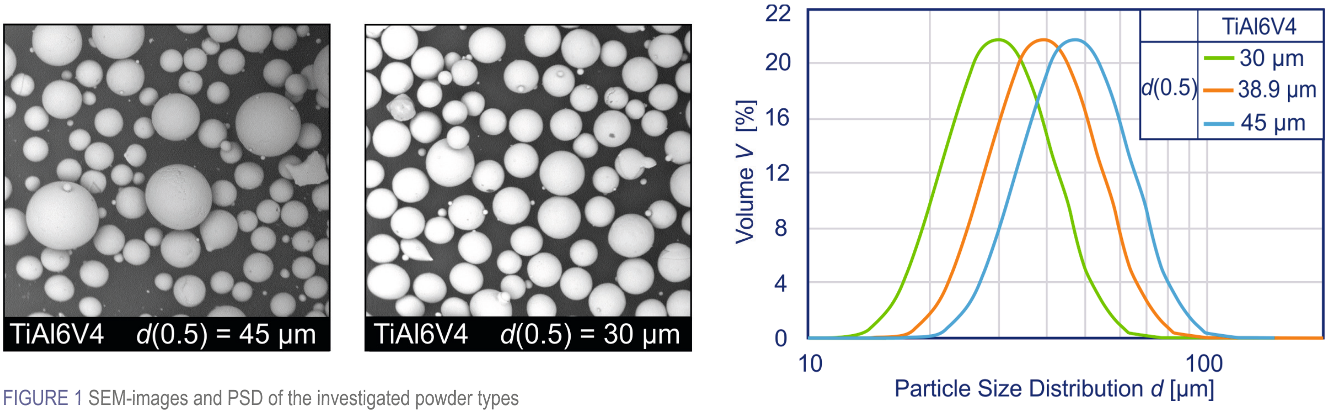

FIGURE 1 SEM-images and PSD of the investigated powder types

of the powder must also be investigated. At first, processing times of one, four and eight hours were evaluated to analyze how the oxygen and nitrogen content develops and to identify meaningful aging times. Based on this, the oxygen and nitrogen content of the manipulated titanium powder were determined through LECO analysis. For a complete powder characterization different test procedures are necessary. In particular, three different material tests are carried out. For all three types of experiments it is necessary to manufacture test specimen with the virgin and the manipulated powder. All specimens were built on the SLM 280HL under an argon inert gas atmosphere. Earlier investigations have shown, that the material characteristics of titanium in the as built condition are significantly worse. For this reason, all specimen are subjected to a heat treatment at 800°C in an argon inert gas atmosphere for two hours. Finally, tensile and fatigue tests are carried out to determine the tensile and fatigue strength. Furthermore crack propagation experiments are designated in order to establish crack propagation curves for all different powder states.

Results

The results of the aging process show that there is a fast increase of the oxygen content after a short time period and that there is an approach to an oxygen saturation. Furthermore, it can be seen, that the maximum allowed oxygen content is reached after approximately four hours (0.199%). Compared to these results there is only a small increase of the nitrogen content even after a longer aging time (0.028%). In summary, it can be said that there is a meaningful aging time for the virgin powder of four hours because a high oxygen content is reached but it is still below the maximum allowed limit.

Tensile and fatigue tests

The impact on the tensile strength and the elongation of the aged material is very high for both PSDs. The comparison between both virgin conditions shows that the ultimate strength is in the same range, but the elongation to fracture for the larger PSD is lower. The aging treatment has an effect on the tensile strength which is reduced for both PSDs. The elongation to fracture is significantly reduced by the aging treatment, especially, for the higher PSD. The virgin material has a higher fatigue strength for both PSD. The larger PSD is severely influenced by the aging treatment. With a smaller PSD the aged material shows a poorer fatigue behavior.

Fatigue crack growth experiments

The results for the tests with different PSD show, that for the examined powders the crack propagation curves have almost the same curve progression, especially in the threshold area and in the middle region. Only in the fracture toughness region some slight differences are observable. In summary it can be said, that there is obviously no significant influence on the crack propagation curve or the threshold value when using different PSDs.

In case of an aged powder, the PSD has a significant influence. For the powder with the larger median value, the aging process leads to a barely noticeable change in the threshold value as compared with the virgin condition. In contrast, an aging process of the powder with smaller median value leads to a significant decrease of the threshold value. The fundamental reason for this result can be the smaller particle size. Due to the smaller particle size, there is a larger surface, which is more influenced by the aging process. Therefore, the potential oxygen uptake of the powder is higher with smaller sized particles. With regard to a fracture mechanical analysis, it can be said that in the presence of an aged powder, a powder with a larger average particle size has less influence on the fracture mechanical properties.

Outlook

Further investigations could be tensile, fatigue and fracture mechanical experiments with a mean PSD from the same powder lot. In addition, the influence of different heat treatments, the building direction or the powder humidity could be investigated.

LONG-TERM PROPERTIES OF A HIGH TEMPERATURE FDM MATERIAL

Information about the mechanical properties are essential for designers in order to design products for application. Particularly for a dynamical application, like in the automotive industry or aircraft, the fatigue and creep behavior of the parts has to be known, so that the parts fulfill the calculated product life cycle. In this project, the fatigue behavior of Fused Deposition Modeling (FDM) components built with Ultem 9085 and Ultem 1010 is investigated. The dynamic properties of the material Ultem 9085 are tested at low and higher temperatures and Ultem 1010 is analyzed at higher temperatures. In further proceedings of the project, investigations on the deformation behavior of the materials at higher temperatures will follow.

PROJECT OVERVIEW

DURATION

01/2017 – 12/2017

PARTNER

Industrial Consortium of DMRC

FUNDED BY

Industrial Consortium of DMRC

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Objectives

The main objective of this project is to characterize the fatigue behavior for FDM parts built with Ultem 9085 and Ultem 1010 by using the FDM standard parameters. The long- and short-term properties of Ultem 9085 will be identified for different build orientations at different temperatures. For that purpose, dynamic properties must be tested at low and higher temperatures. The aim is to detect S-N curves for the chosen FDM materials Ultem 1010 and Ultem 9085. With this information, it will be easier for designers to calculate the lifetime of a FDM part, for example an air duct, at low and high temperatures. In addition, short-term deforming tests are done at higher temperatures. Additionally, tests will be performed at a sample part which will be provided by the DMRC or by DMRC partners.

Procedure

Information about the mechanical properties are essential for designers in order to design products for application. In practice, the knowledge about the fatigue properties is crucial for a reliable component design, in addition to the static material properties. Many components are not only statically loaded because in the area of application components are also dynamically loaded. An example for this case is a fastening element of an airplane. During turbulence or take-offs and landings, the components are exposed to certain vibrations in addition to the actual static load, which leads to load peaks. Reliable statements about the relationship between the number of cycles and the load can be made with the help of S-N curves so that the risk of an unexpected component failure is significantly minimized.

The proceeding of the project is divided into different work packages. The first work package includes the fatigue tests at five different temperatures for the build orientations X, Y and Z. In the first part of this project, tensile bars are produced on a Stratasys Fortus 400 mc FDM system and they

are dynamically tested to determine temperature specific fatigue curves. The tensile bars are conditioned according to ASTM 618 before they are tested. Figure 1 shows the S-N curves for different build directions X, Y, and Z for Ultem 9085. The aim of this work package is to detect S-N curves for the chosen FDM material Ultem 1010 and Ultem 9085. With this information, it will be easier for designers to calculate the lifetime of a FDM part at low and high temperatures. Dynamic testing of plastics is associated with some peculiarities due to the plastic-specific material behavior. For metallic materials dynamic test can be performed with a frequency of e.g. 100 Hz. However, plastics reach the softening temperature range at high test frequencies because of internal friction of the molecules with simultaneously bad heat conduction and low temperature resistance. This leads to a premature failure of the specimens in comparison with the metallic materials. Therefore, the dynamic testing of the thermoplastic components has been performed at a significantly reduced test frequency which leads to an increase of the test duration.
In the next work package, short time deformation tests at higher temperatures will be performed to analyze the deformation behavior because fatigue tests in a range of pulsating tensile stresses lead to additional creep effects. In general, amorphous thermoplastics have a very low creep behavior, however, creep or deformation effects will increase with higher temperatures. In order to analyze the deformation behavior, short time deformation tests will be performed at the same positive temperatures which are used for fatigue tests. In addition to work package 1, the fatigue behavior of a real part will be analyzed in a further work package. Fatigue tests of a sample part should deliver the information how well or badly S-N-curves can be used for application.

Latest results

In the past project year, the fatigue behavior of Ultem 9085 at different temperatures as well as the fatigue behavior of Ultem 1010 was investigated. The results of preliminary tests show that the temperature has a significant influence on the static mechanical properties. In the following fatigue tests the temperature also has a significant influence on the fatigue behavior.

Outlook

In this project, the fatigue behavior of Fused Deposition Modeling (FDM) components built with Ultem 9085 and Ultem 1010 is analyzed. The dynamic properties of material Ultem 9085 are tested at low and higher temperatures and Ultem 1010 is analyzed at higher temperatures. In further proceedings of the project, investigations on the deformation behavior of the materials at higher temperatures will be continued. Finally, the results will be validated with an example part.

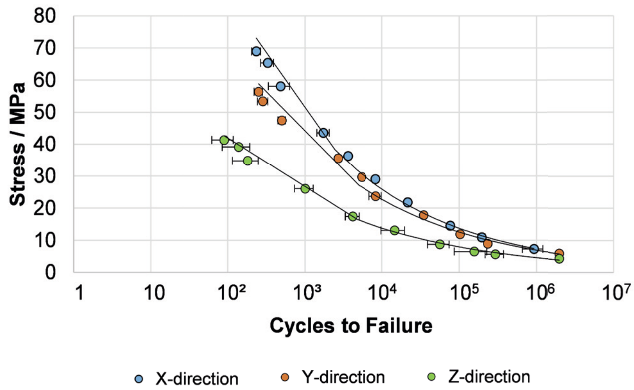

FIGURE 1 S-N curves for Ultem 9085

LS POLYAMIDE FOR HIGH TEMPERATURE APPLICATIONS – PROCESSING AND PROPERTIES OF PA613

The availability of high performance LS materials is still limited to mainly polyamide 11 and polyamide 12 powder. However, these materials do not match to requirements of some advanced applications, for example in the electronics or automotive industry where higher material strengths and temperature resistance is required. The motivation of this project is to robustly process a new material – PA613, delivered by Evonik – and to specify its powder and resulting part properties. Since the material can be processed on regular "low temperature" LS systems like EOS P39x machines, PA613 material promises a great increase of application fields using already industrially established machine types.

PROJECT OVERVIEW

DURATION

01/2017 – 12/2017

PARTNER

Industrial Consortium of DMRC
especially EVONIK and EOS

FUNDED BY

Industrial Consortium of DMRC

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Objectives

The new material PA613 is a polyamide especially developed by Evonik for the laser sintering process and therefore not known for conventional manufacturing processes. The advantage of the material in comparison to the standard LS material polyamide 12 is the processing and therefore the assumed application temperature. In this way the application field of laser sintering will be increased. Particularly automotive, electronics and aircraft industries require high temperature polymers where the properties of polyamide 12 are not sufficient. But beside the temperature resistance of the laser sintering systems appropriate polymer powders have to be available. PA613 is a laser sintering powder with high potential for high temperature applications but first of all it has to be processed robustly on a laser sintering machine..

Procedure

The proceeding of the project starts with investigations of the processability of PA613 in general where recoating of the powder is tested and machine parameters are adapted. To reach high quality build parts further parameters, especially laser exposure parameters, are developed in a further procedure. Another topic is the recyclability of used powder. Ageing effects are investigated to get a first hint to the recyclability in general and, if possible, to a suitable refresh strategy. When the material is processable on the LS system and suitable parameters are found, achievable standard part properties of PA613 are tested and an analysis of advanced characteristics demanded by the aimed applications is done.

Latest Results

In the first part of this project the processability of the new laser sintering material PA613 was investigated and suitable process instructions concerning powder recoating, tempe-

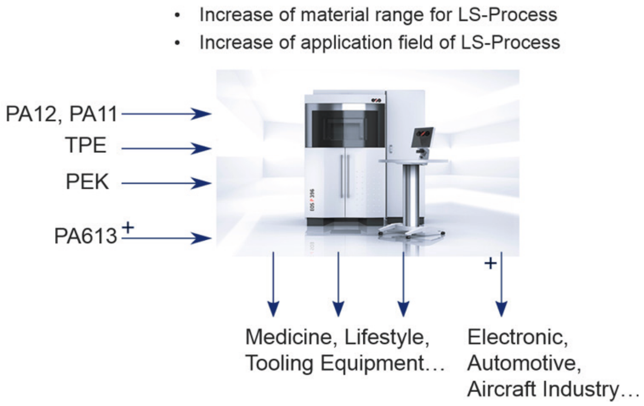

FIGURE 1 Motivation of the project

rature settings and machine modifications were found. A smooth and homogenous powder surface can be generated due to good flowability which was detected by powder characterization. Furthermore, the temperature window, which allows building parts without process failures, is quite high.

In a second step laser exposure parameters were correlated to mechanical properties and it became clear that tensile properties are quite constant for a wide range of laser energy density but can be maximized especially in z-build direction by optimization of contour parameters. The latter might be investigated in a deeper detailed work in the future. For this project, a final laser exposure parameter set could be found which works robustly and was used for further investigations.

Beside build parameters ageing effects of the material were investigated with regard to recyclability of the material. The recyclability of used powder is usually limited due to ageing effects during the manufacturing process. The material is kept at high temperatures for a long time period. To ensure a constant material quality, mixtures of recycled and virgin powder are commonly used for established LS materials. Within this project ageing effects could be found, but which refresh rate is suitable to gain high quality parts is not clarified completely. However, different PA613 part characteristic are determined for virgin powder. PA613 achieves about 25% better tensile properties than standard LS material PA12 and shows high potential to be implemented in industrial applications.

Outlook

In a follow up project in 2018 the recyclability will be investigated further with the aim to find a suitable refresh strategy and will supplement the material-dependent process instruction already found. Together with defined process parameters further information about achievable part quality especially application relevant characteristics will set the base for an application of the new material in industry. As PA613 is not known in conventional manufacturing, it is important to classify the material within the range of engineering plastics to become a new high performance material in industry. For this purpose, more information about part properties have to be generated in the future.

Research

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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.

PROJECT OVERVIEW

DURATION

01/2016 – 6/2016

PARTNER

- Liebherr-Aerospace Lindenberg GmbH
- The Boeing Company

FUNDED BY

Federal Ministry of Economic Affairs and Energy (BMWi)

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Objectives

The aim is to develop a decision support scheme for future applications during the product engineering process and to elaborate the fundamentals for an Additive Manufacturing material database based on lightweight and composite structures, besides solid material properties. Moreover, investigations working on improving the process through topology optimization, 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, will be acquired. The intention is to reduce the processing time in every stage of the process chain, particularly in the Additive Manufacturing process.

Procedure

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 will be developed with a complete description of process chain mapping possibilities and influencing factors for the process.

Figure 1

The second work package works on the development of lightweight structures and composite structures and their mechanical properties for several target functions. Moreover, the mechanical properties of solid material built with various adjusted parameter sets will be determined. The gained knowledge of the previous working steps will be merged in topology-optimized components to demonstrate the possibilities of Additive Manufacturing as a key technology of the future.

Latest Results

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 trade-off

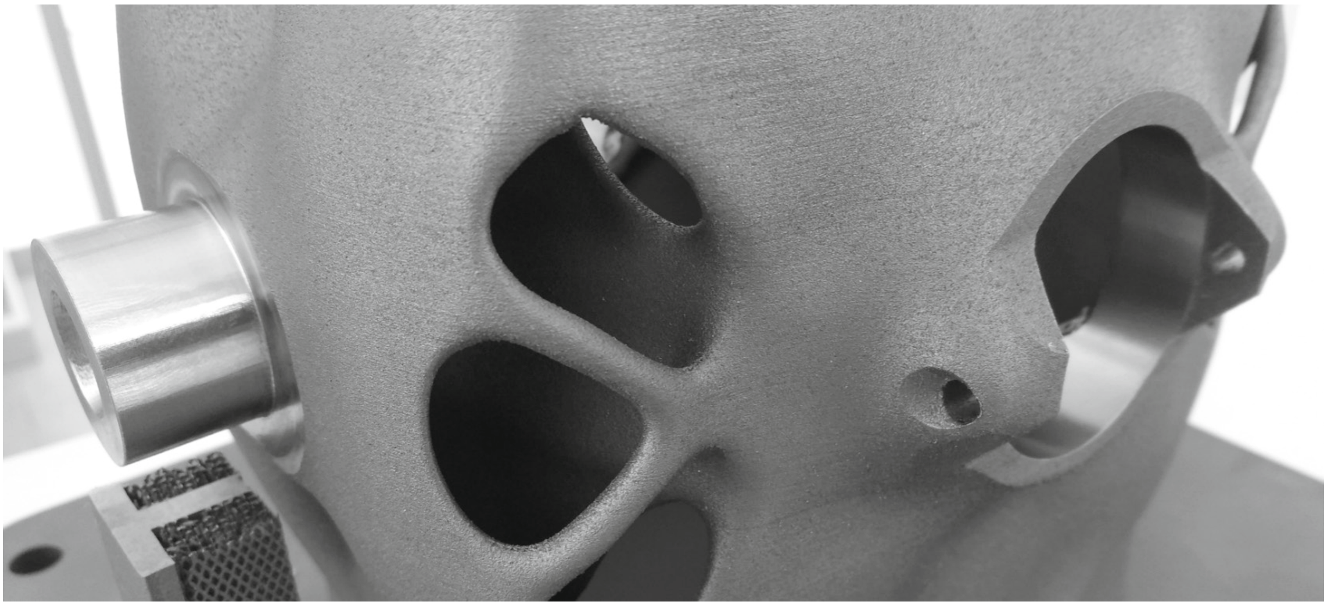

FIGURE 1 Topology optimized component with finished interface surfaces

methodology tool has started. Furthermore, the initial steps for the determination of mechanical properties of the structures to be examined were done.

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 and for increasing the building speed through parameter optimization has been done. The results are shown in figure 2.

Outlook

The next working steps are further investigations on the topics mentioned above. The whole project is an iterative process and the gained knowledge during the project will be used for topology optimized parts. Moreover, additional and extensive investigations on increasing the building speed while at least holding the properties and on combining different materials in composite structures will be examined finally.

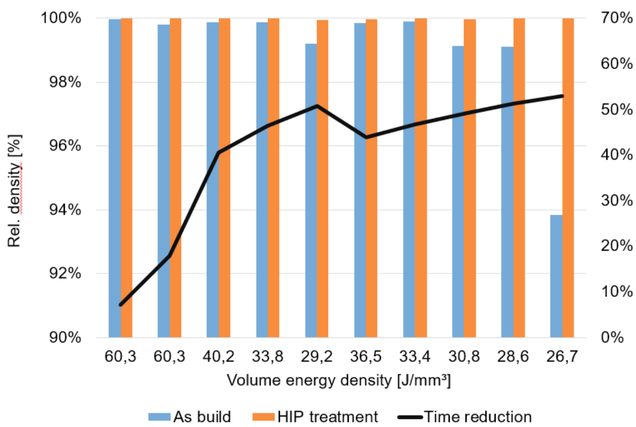

FIGURE 2 Optical density analysis of cross section images (x-z-plane) before and after HIP-process

DEVELOPMENT AND OPTIMIZATION OF ADDITIVELY MANUFACTURED TOOL COMPONENTS FOR A HIGH-SPEED FORMING PROCESS (ZIM – RUPTURE DISCS)

This project is about the ability how to use AM components for forming processes. Innovative rupture discs shall be produced with a high-speed forming process called HGU (German: "Hochgeschwindigkeitsumformung – HGU"). The challenge is to ensure a stable application even with small nominal sizes of the rupture discs. A significant innovation is the insertion of predetermined breaking points by secondary form elements 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

09/2016 – 12/2018

PARTNER

- Poynting GmbH
- Rembe GmbH
- Paderborn University – Department of Forming and Machining Technology (LUF)
- Paderborn University – Kunststofftechnik Paderborn (KTP)

FUNDED BY

- Federal Ministry of Economic Affairs and Energy (BMWI)
- ZIM (Zentrales Innovationsprogramm Mittelstand)

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Objectives

The field of application of rupture discs as pressure protections is limited due to the restricted geometry as well as the inflexible production (cf. Figure 1). A challenge by the application of very small nominal diameters (of the rupture disc) combined with a low pressure range, is the reliable and stable operation in terms of the response behavior. Furthermore, many process steps are required for the manufacturing of these types of rupture discs. The aim of the project is to develop a new rupture disc (Rembe GmbH) with a small diameter, which shows a very good response behavior even at very low pressures. A significant innovation is the implementation of secondary form elements as weakening geometries. These should be integrated as metallic inserts into a thermoplastic die manufactured with Fused Deposition Modeling (FDM). The aim is a defined weakening of the material during the forming process, so that a suitable forming process is necessary. Fine geometries of the required quality can be achieved by means of a high-speed forming processes (Poynting GmbH). This results in another project goal, since the use of the HGU should save process steps. Therefore, the development of a tool system with additively manufactured components (die and plunger) is planned for the production of rupture discs. This will combine the advantages of a quasi-static and high-speed forming in an innovative, efficient and unique tool system.

Procedure

The development of tool components is based on two different sections. On the one hand a plunger is developed which is responsible for the pressure translation within the high-speed forming process. 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. For this purpose, two concepts are made with of titanium (TiAl6V4) and aluminum (AlSi10Mg) in the Selective Laser Melting (SLM) process. The manufactured components could be successfully used in the HGU. It was possible to achieve a weight saving of over 50 % compared to a conventionally produced component (turning, milling). The weight savings could be achieved by consistent lightweight design which was realized by topology optimization.

The other research focus is on an additively manufactured die through FDM. The aim of this process is to produce thermoplastic dies which satisfy the mechanical loads of the HGU process. The big advantage of complex component design trough 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 Fig. 2).

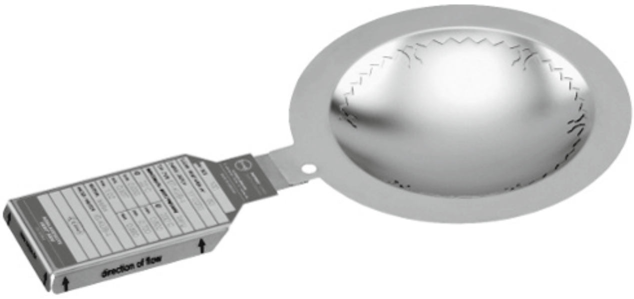

FIGURE 1 Rupture Disc (Reverse Acting Rupture Disc KUB® by Rembe)

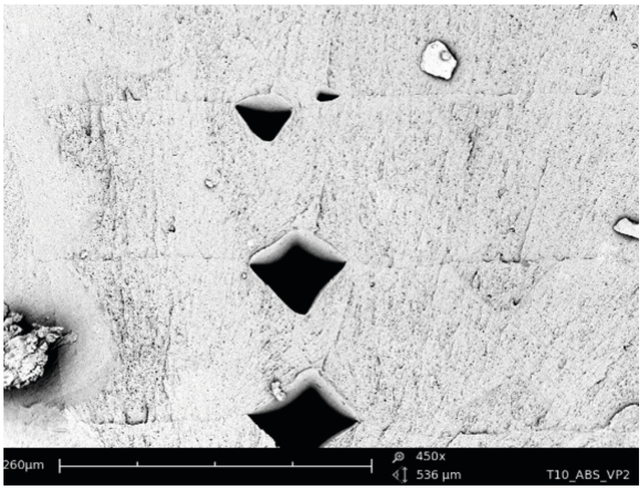

FIGURE 2 SEM-Image of a FDM Structure Shows Process-Related Porosity

Latest Results

The process-related porosity is analyzed by using computed tomography (CT). For this purpose, specimens are manufactured with different materials, orientations and toolpath parameters. Investigations showed that the parameter "air gap" has the highest influence on the porosity and that it can be used to change the porosity in a defined manner. The lowest porosity results for a negative air gap of -5 % and amounts 3.74 % for the material Ultem 9085 (cf. Fig. 3). To determine the correlation between porosity and venting, an air permeability test setup was developed. FDM samples are tested with 10 bar air pressure and the pressure drop is measured over time. The results from this test can be used to develop a certain area in an FDM part which should have a defined air permeability. This function integration can have an additional value to FDM components.

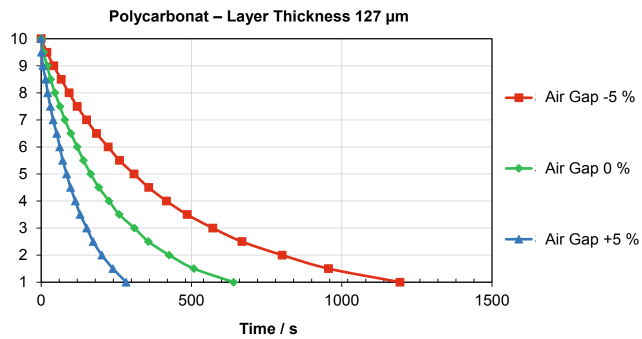

FIGURE 3 Air Gaps Air Permeability of Ultem 9085 Specimens as a Function of the Parameter Air Gap

As mentioned above, the rupture discs shall have defined weakening geometries. By implementing metallic inserts in the FDM structure, these can occur as secondary form elements. For example sharp-edged metal inserts can achieve a targeted thinning of the formed product. For this reason, design rules are developed how to implement metallic components into FDM structures. Defined pausing of the FDM process allows an easy intervention and insertion of metallic parts. 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.

FDM-STRUCTURES FOR THE PARTIAL REINFORCEMENT OF HYBRID STRUCTURES

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

PROJECT OVERVIEW

DURATION

01/2015 – 12/2018

PARTNER

Kunststofftechnik Paderborn (KTP)

FUNDED BY

Deutsche Forschungsgemeinschaft (DFG)

RESEARCHER

Research leader
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Research assistent
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Objectives

This project aims to determine design and process guidelines for FDM-reinforcement-structures, which are aligned for specific load cases and shall be used for a partial reinforcement of lightweight parts. The reinforcement structure shall provide maximum increase of strength and stiffness with minimum increase of weight. To realize the maximum increase of the mechanical properties the inner structure is adjusted to the specific load case by using different parameters for the layer generation. In addition to this, the design of the FDM-part will be varied to achieve a weight increase as minimal as possible. The used material for the FDM-reinforcement-structure is Ultem 9085.

Procedure

The strength and stiffness for various inner part structures will be determined for the different load cases by using mechanical tests (tensile, compression, flexural, impact and torsional strength). As a result, a list of load specific designs and process guidelines for the FDM-structure will be compiled. Additionally a modeling of the mechanical strength of FDM-parts will be developed. The strength is modeled as a function of the inner part structure which is directly depending on the process parameters. The modeling shall support the strength analysis of the different load cases.

At last, the design and process guidelines will be verified on a real lightweight part. This part will consist of two components, a GITBlow-part and the FDM-reinforcement-structure (Figure 1). To realize a joint between both parts, the FDM-structure is inserted to the injection mold first. Then the GITBlow-preform is inflated and adheres to the FDM-structure. The gain structure is only added to the thin-walled area of the GITBlow-part. For that hybrid component, different mechanical tests will be carried out.

Latest Results

In preliminary investigations, the manufactoring boundary conditions for the FDM-reinforcement-structure are investigated. The minimal negative air gap without an overfilling of the specimens and the maximum positive air gap for sufficient stability are determined. The Investigations show that interactions between the different process parameters and the positioning of the seam out of stressed areas need to be taken into account. The highest mechanical properties can be achieved with the flat orientation of the FDM-reinforcement-structure in the build chamber. For the following investigations the flat orientation is used.

The investigations show that the mechanical properties of the FDM-reinforcement-structure depends on the filling parameters. For all load cases (tensile, compression, flexural, impact and torsional strength) a significant influence of the raster to raster air gap is detected. With a positive raster to raster air gap about 0.5 mm there is no force transmission in the component structure (Figure 2). This results in a failure of local stressed strands. Higher mechanical properties can be achieved by a negative raster to raster air gap about -0.03 mm caused by the force transmission through the layers.

The experimental investigations show influences of the other parameters and interactions between them. Furthermore the FDM process parameters have an effect on the part weight and the lightweight potential of the reinforcement structure.

Outlook

In addition to the variation of process parameters, the design of the FDM-reinforcement-structure shall be adapted. The aim is a topology-optimized construction (FEM-analysis, Figure 3). The process principle of the Fused Deposition Modeling is the deposition of polymer strands in layers. As a result of this process characteristic the properties of FDM-parts are heavily depending on the fill pattern and the deposition orientation. This anisotropic material behavior has to be considered in the FEM-analysis. Moreover, extended strength verifications with dynamic tests are planned and the development of specific load design and process guidelines for the FDM-reinforcement-structure shall be continued

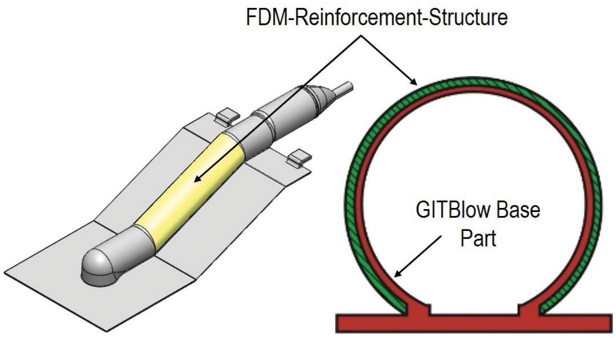

FIGURE 1 GITBlow part with FDM-reinforcement-structure

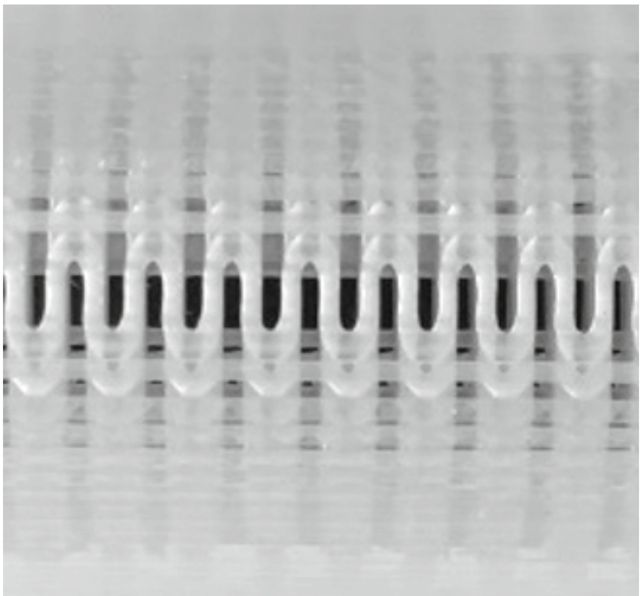

FIGURE 2 Positive raster to raster air gap: 0.5 mm

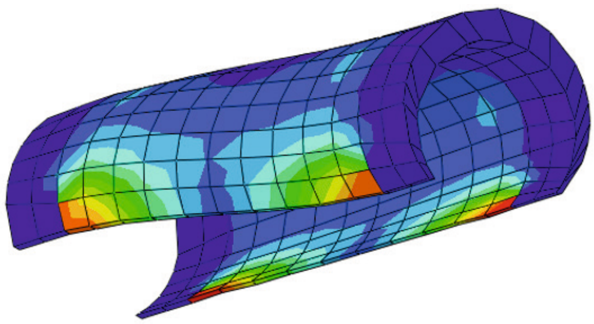

FIGURE 3 Topology-Optimization of the FDM-reinforcement-structure

HIGH TEMPERATURE FATIGUE BEHAVIOR OF NICKEL BASED SUPERALLOYS MANUFACTURED BY SELECTIVE LASER MELTING

The motivation of the project is to attain a comprehensive understanding of the variation of microstructure and mechanical properties of Ni-based superalloys processed by selective laser melting (SLM). Based on these results a robust processing routine for components made from Inconel 718 will be developed, showing high geometric complexity and an optimized microstructure for high temperature loading. In order to reduce the porosity, hot isostatic pressing (HIP) is highly interesting. Thus, a promising approach for the further improvement of the material properties is functional encapsulation by means of physical vapour deposition (PVD), which uses an electric arc to evaporate a target material.

PROJECT OVERVIEW

DURATION

05/2013 – 07/2017

PARTNER

Technical University of Dortmund
Institute of Materials Engineering,
Dortmund, Germany

FUNDED BY

Deutsche Forschungsgemeinschaft (DFG)

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Microstructural characterization

The microstructure of additively processed material strongly influences mechanical properties such as strength, ductility, hardness etc. and consequently has to be thoroughly studied. In this project, microstructure evolution was characterized using various techniques including optical microscopy, electron backscatter diffraction and X-Ray diffraction. The microstructure of IN 718 specimen (built vertical to the building platform) in different conditions, e.g. as-built (a), solution annealed (b) and hot isostatic pressed (c) are shown in Figure 1. The images obtained from the as-built and the solution annealed conditions are very similar. Compared to the as-built condition, the microstructure is different after HIP (Fig. 1c), which is attributed to the effect of recrystallization during HIP treatment. Especially, the microstructural stability under high temperature quasi-static loading as well as fatigue loading is very important for high temperature applications.

Mechanical Testing

Mechanical experiments were performed under different loading conditions. In a first step, the characterization of the behavior under quasi-static load at ambient temperature shed light on the role of process-induced microstructure, i.e. the general impact of grain shape and texture. In the following, the tests were extended to different sample and loading conditions. Clearly, an artificially aged condition needs to be characterized thoroughly, as only this condition shows good properties in the high temperature regime. The focus was the characterization of the alloy performance under cyclic loading at elevated temperatures to show what the reason of crack initiation is, i.e. where cracks start, and in which ways cracks evolve during further loading.

Summery

Detailed knowledge regarding the fatigue behavior is crucial if cyclic loading is applied to parts at high temperatures. Therefore, the microstructure and mechanical properties of

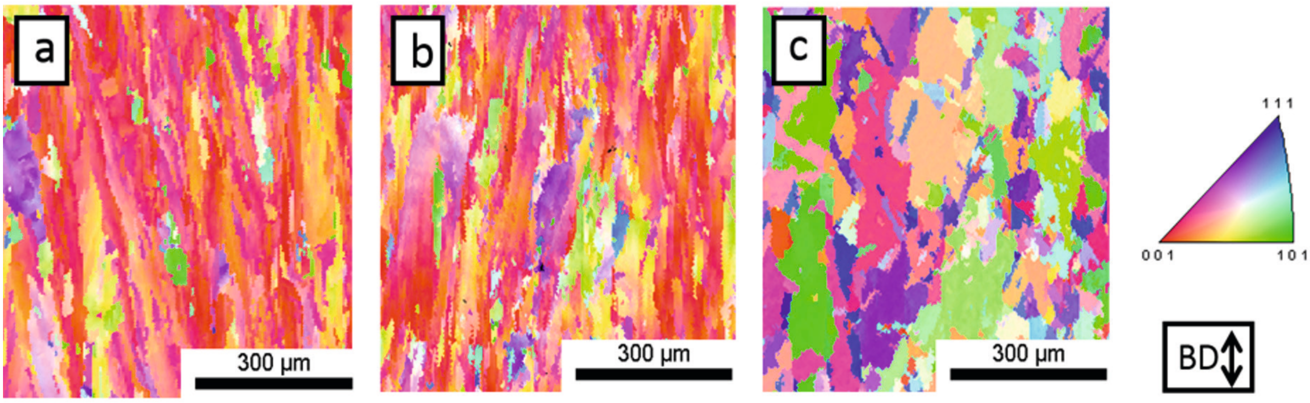

FIGURE 1 EBSD inverse pole figure maps for the gage length of (a) as-built, (b) the solution annealed and (c) HIP conditions.

a SLM processed Inconel 718 superalloy has been investigated. The results helped to identify an adapted material performance for applications at high temperatures. Furthermore, the effects of the hot isostatic pressing on the SLM material were characterized. Moreover, the functional encapsulation of laser melted Inconel 718 by Arc-PVD for post compacting by hot isostatic pressing was improved. On view of these aspects, the results can be summarized as follows:

- SLM processing of Inconel 718 shows a columnar-grained microstructure.
- All aging treatments improved the ultimate tensile strength and yield strength due to the formation of precipitates.
- HIP leads to recrystallization of the SLM processed IN 718 alloy. As a result, the achieved mechanical properties seem to be more influenced by the microstructure. Prior PVD coating does not have a significant effect on the microstructure.
- Precipitation hardening is essential for high temperature application.
- Argon measurements showed an Ar-content of 0.3 ppm. It was concluded that the cavities are in parts filled with argon. The argon could be entrapped during the SLM process or embedded in the powder particles.
- The post-treatments solution annealing, PVD coating and HIP reduced the hardness values of the SLM processed IN 718 specimens. This fact can be explained by the dissolution of precipitates already introduced by SLM processing.

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

The overall objective for iBUS is to develop and demonstrate by 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 guide-lines, 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

- UNIVERSITY OF LIMERICK
- FÁBRICA DE JUGUETES SL,
- JUGUETTOS CENTRAL DE COMPRAS SCOOP
- AVRO TECH / LeFabShop
- MCOR TECHNOLOGIES LTD,
- MANOPT SYSTEMS LTD / Entellexi
- Dassault Systemes UK LTD
- UNIVERSITY PADERBORN
- AIJU
- CARTAMUNDI DIGITAL
- SDRUZENI PRO HRACKU A HRU
- OCEAN PRINT LIMITED
- MAHER O'ROURKE LIMITED

RESEARCHER

Research leader
Prof. Dr.-Ing. Rainer Koch

Research assistant
Dipl.-Ing. Ulrich Jahnke
Anne Kruse, M.Sc.

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

Objectives

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

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

Procedure

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

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

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

Main participation of DMRC is in the WP3 "Customised

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

Latest results

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

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

Outlook

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

FIGURE 1 Customized toy car bodies meeting european safety requirements

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

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

PROJECT OVERVIEW

DURATION

01/2017 – 12/2019

PARTNER

- 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)
- Projektträger Karlsruhe - PTKA - at the Karlsruher Institut for Technology (KIT)

RESEARCHER

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Prof. Dr.-Ing. Detmar Zimmer

Research assistent
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https://kitkadd.de/

Due to the dynamic competitive environment in the 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. Selective Laser Melting (SLM) as an additive 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.

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 can not 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.

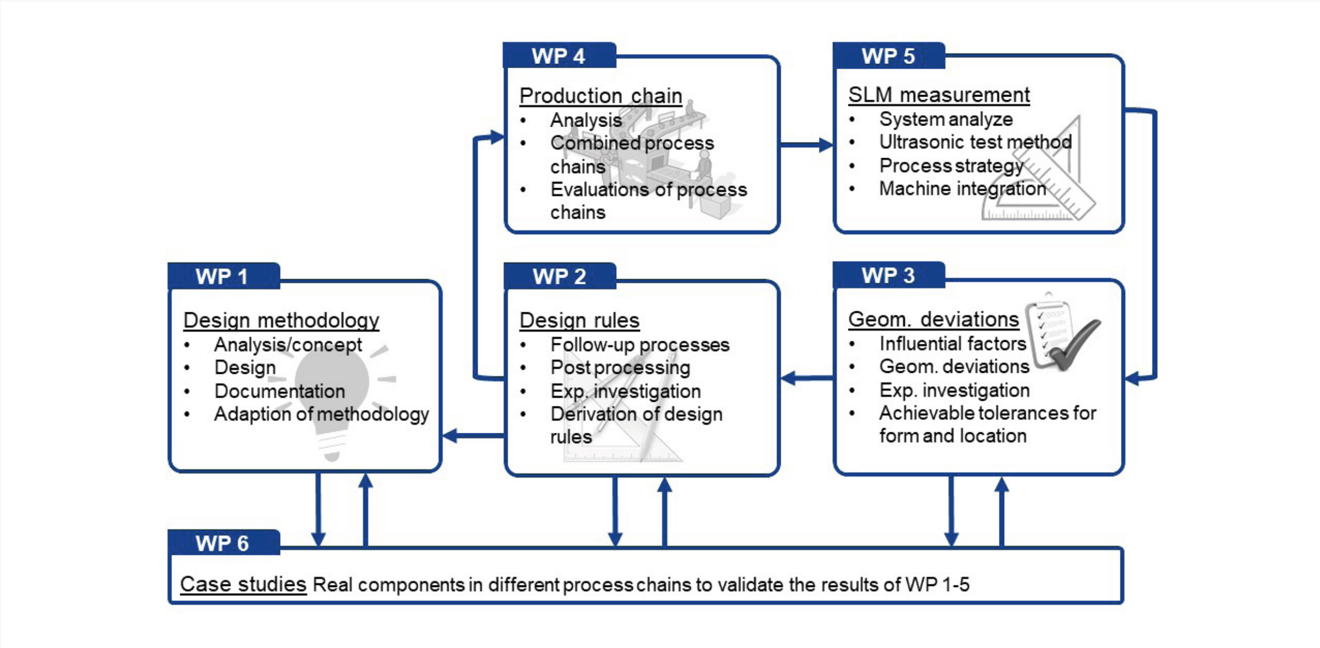

FIGURE 1 Work packages

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

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

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

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

MATERIAL DEVELOPMENT OF POLYMERS FOR EXTRUSION DEPOSITION ADDITIVE MANUFACTURING

The aim of this project is to investigate the requirements for materials and semi-finished products which are processed in extrusion deposition 3D printing processes. By gainig a better understanding of these processes, 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 under 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 – 06/2018

PARTNER

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

FUNDED BY

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

RESEARCHER

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Objectives

The to be examined extrusion deposition additive manufacturing processes are among the most commonly used additive manufacturing processes. For example, they are known by the terms Fused Deposition Modeling (FDM), Fused Layer Modeling (FLM) or Fused Filament Fabrication (FFF). In this methods, the semi-finished product, commonly a wire of a thermoplastic polymer, is melted 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 with this method as, for example, in the profile extrusion or injection molding technology. Therefore, the processing suitability of any thermoplastic polymer should be estimated based on the material properties or characteristics in advance of the processing. This is currently not possible because, in contrast to conventional methods, only little is known about the required and desirable material properties for the processing in extrusion deposition additive manufacturing processes.

Procedure

In this project, the requirements for materials, semi-finished products and processes are investigated by the means of example polymer types. For this purpose, different types of polyamide 6 (PA6) will be systematically extruded into monofilaments and then a supervised processing in an extrusion deposition additive manufacturing machine will follow. By varying important material properties, such as the viscosity, the material properties should be connected to the processing properties.

To reach that aim the processability in extrusion deposition additive manufacturing processes has to be defined so that

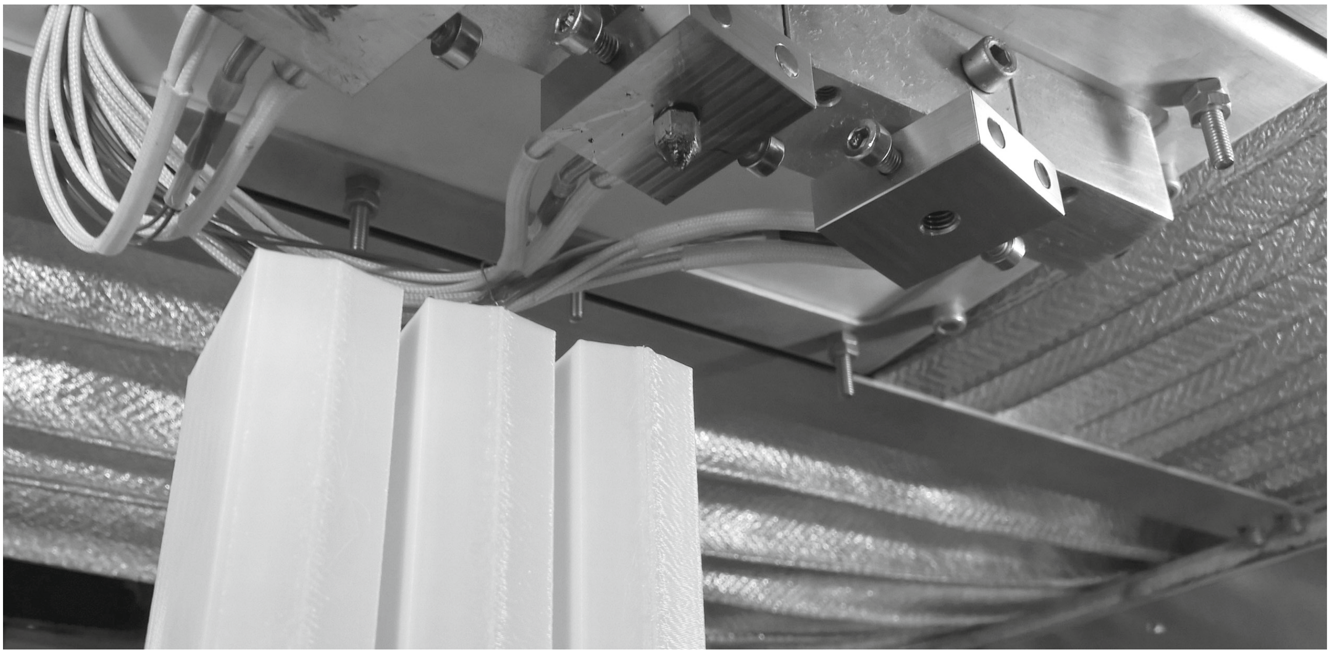

FIGURE 1 Custom built specimen produced by a FDM-machine

it is evaluable for different materials. Therefore custom-built specimens are created to investigate some significant characteristics like tensile strength of the welding seams or process specific warpage. Other factors like machine quality or data processing should have no or minimal influence. For that reason machine and process specific influences are considered to create custom-built specimens.

After the specimens have been verified on known materials, series of tests should be run for each characteristics. Suitable material properties are identified by rating the processability as a function of the varied material properties. Those are supervised during the whole project by methods like differential scanning calorimetry or high pressure capillary rheometry.

Outlook

Some characteristics like tensile strength of the welding seams or process specific warpage are currently in testing for different material types. Additional types of materials with different material properties should be tested and additional characteristics should be investigated for all tested material types. At least a polymer should be identified that shows an optimal processability. This polymer should be reinforced with fibers. Then the processing of fiber-reinforced materials should be examined. It is assumed that the procedural generation of components by juxtaposing many strands enables the influence of fiber orientation.

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

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

PROJECT OVERVIEW

DURATION

01/2017 – 12/2019

PARTNER

- University Paderborn (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)

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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 the derivation of design rules“ and „Tool for automated and multi-target optimized component design“, the chairs KAt, LiA and CIK first developed, produced and tested resilient test specimens for the development of design guidelines for the areas “load”, “post processing”, “cost” and “production”. From this design guidelines were derived, which will serve as the basis of the optimization tool. The KAt researchers implemented the first guidelines as machine-readable forms in a database, which the tool developed by INTES will later access.

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 next 1 ½ years of the project will be used to fully develop the tool for automated and multi-target optimized component design and to finalize the method for the integration of additive manufacturing in companies. In addition to the various sub-goals, different support tools will be created for manufacturing documentation as well as for accompanying the product development.

Project Information

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

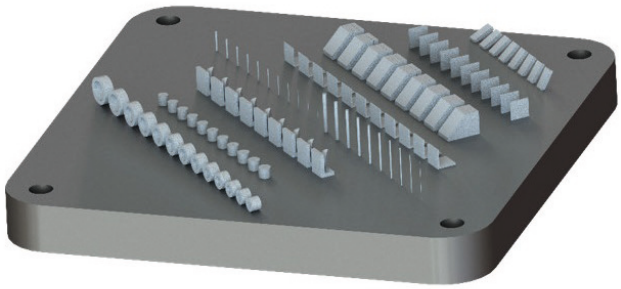

FIGURE 1 Test specimens for the development of design guidelines

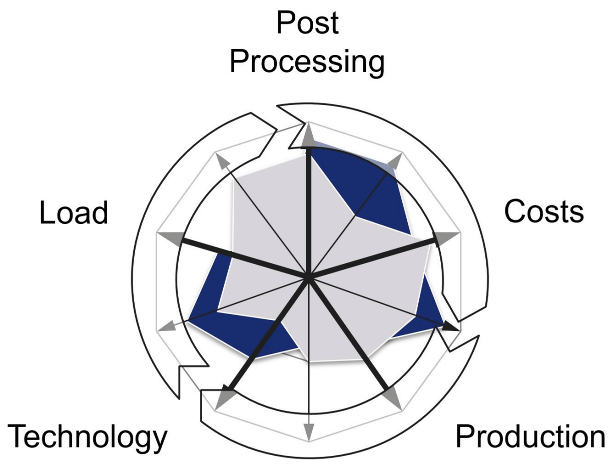

FIGURE 2 Multi-target optimized component design

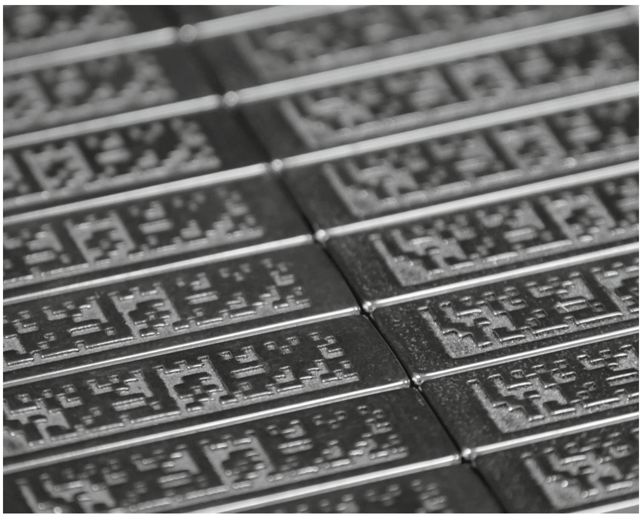

FIGURE 3 Test specimens for component marking

STUDY OF THE EFFECT OF RESIDUAL STRESSES AND SURFACE ROUGHNESS OF ADDITIVELY MANUFACTURED COMPONENTS ON THE COATABILITY AND FATIGUE STRENGTH OF THE COMPOSITE SYSTEMS

By employing additive manufacturing (AM) in general and selective laser melting (SLM) in particular, it is possible to produce metallic parts and components of high complexity. In order to reach the efficiency of conventionally manufactured parts, additively produced parts must fulfil at least the same requirements. Therefore, basic investigations for coating and composite systems are essential to obtain a comprehensive understanding of the process-microstructure-mechanical properties of IN 718 and 316L alloys processed by SLM.

PROJECT OVERVIEW

DURATION

04/2017– 03/2020

PARTNER

Technical University of Dortmund, Institute of Materials Engineering, Dortmund, Germany

FUNDED BY

Deutsche Forschungsgemeinschaft (DFG)

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Surface quality after SLM

Surface quality of SLM process is still a key issue during the fabrication of the metallic parts. The surface roughness depends not on the process parameter itself, but also on the orientation of the parts in the building chamber. The surface roughness of AM parts has been in the focus of several studies. However, only little research has been performed to characterize the impact of the surface roughness on the coatability of AM parts as well as on the fatigue strength of the overall composite system. Therefore, a deep understanding of the surface properties after SLM is required in determining their effects on the mechanical properties and in designing components with improved performance.

Residual stresses

In order to apply AM components under conditions comparable with conventionally produced components in the future, equivalent prerequisites must be created with regard to the post-treatment and the further manufacturing process steps. Most of the metallic components used in high performance conditions, under heat, wear, or corrosive load, are enhanced by adapted heat treatments (e.g. hardening) or (protective) coatings. Through targeted surface functionalization by means of coatings and the adaptation of the layers to the substrate material, the performance characteristics of the entire component are decisively influenced. Most of the components produced by SLM are intended for applications with high mechanical, thermal or corrosive loads. Residual stress can be found in components manufactured by SLM. Therefore, in this project the reason for the evolving of residual stresses and their influence on the coatability of AM parts are explored. Different SLM specimens will be coated by means of High Velocity Oxy-Fuel (HVOF) spraying, Physical Vapour Deposition (PVD) as well as Atmospheric Plasma Spraying (APS). Afterwards, experimental methods are used to measure the residual stress profiles in a set of test specimens with different conditions.

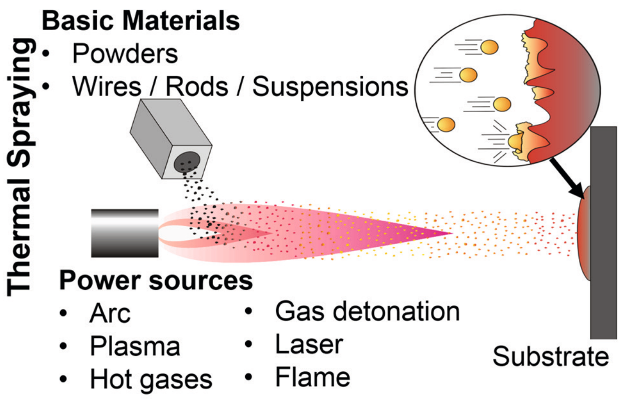

FIGURE 1 Diagram of high velocity oxy-fuel (HVOF) spraying

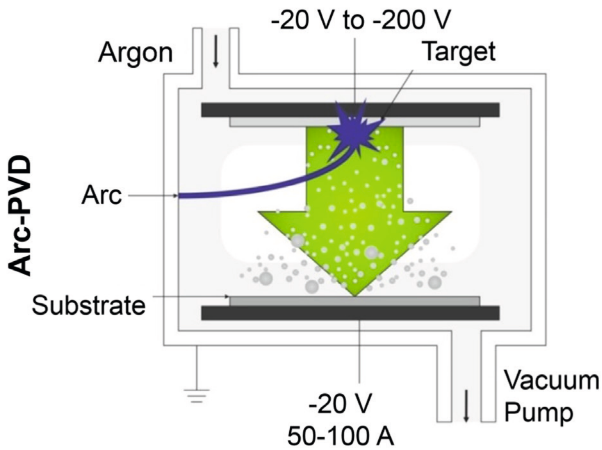

FIGURE 2 Diagram of physical vapour deposition (PVD)

Microstructural characterization

The microstructure evolution in SLM material strongly influences the resulting mechanical properties such as strength, ductility, hardness etc., and consequently has to be thoroughly studied. Especially, the microstructure stability under high temperature quasi-static and cyclic loading for IN 718 is of high interest, as their stability is crucial for the envisaged applications. The stability is significantly influenced by precipitates formed artificially by aging or during thermo-mechanical testing.

Mechanical Testing

Mechanical testing will be performed under different loading conditions. In a first step, the characterization of the residual stresses profiles in various specimen conditions will be defined. Consequently, the mechanical tests will be extended to different coated specimen and loading conditions. The main focus will then be in characterization of the overall composite system under cyclic loading at elevated temperatures. It will be of high of interest to clearly show the influence of residual stresses and surface roughness on the crack initiation.

SOFT MAGNETIC ALLOYS FOR ADDITIVE MANUFACTURING OF ELECTRIC MOTORS

Two soft-magnetic materials, a ferro-silicon alloy and a ferro-cobalt alloy, were processed with selective laser melting (SLM). Both alloys are used in the electrical industry for different applications due to their increased specific resistance, in particular regarding the FeSi alloys. The conventional production methods of electrical steel sheets have been extensively researched and optimized in terms of cost-effectiveness. Therefore, new production techniques have to be taken into account to increase the efficiency of motor components, e.g., rotors.

PROJECT OVERVIEW

PARTNER

Forschungsvereinigung Antriebstechnik e.V. (FVA)

FUNDED BY

Forschungsvereinigung Antriebstechnik e.V. (FVA)

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In this study, two soft-magnetic materials, a FeSi alloy with a Si content of 2.9 wt% and a FeCo alloy having a Co content of 50 wt%, were selected for processing with Selective Laser Melting (SLM). In the electrical industry, both alloys are widely used as sheet material due to their increased specific resistance, in particular in the FeSi alloys. The conventional production methods of electrical steel sheets have been extensively researched and optimized for cost-effectiveness. Therefore, new production techniques have to be taken into account to increase the efficiency of motor components, e.g., rotors. Both alloys were gas-atomized in a nitrogen atmosphere. The particles produced were spherical in shape and showed the desired particle size distribution of 10 µm - 45 µm. In this investigation, the samples and rotors were generated using a SLM 280HL machine, supplied by SLM Solutions Group (Lübeck, Germany), equipped with a 400 W ytterbium fiber laser. Furthermore, the targeted variation and adaptation of the laser parameters during the SLM process enabled a suitable parameter window for the processing of both selected materials. In particular, the FeCo alloy was characterized by a relative density above 99.9% as compared to FeSi alloy, which had a relative density of 99.5%. The microstructural evolution of both alloys is typical for SLM-processed iron-based materials without a phase transformation in the solid state. The EBSD micrograph in Figure 1 shows an epitaxial grain growth in building direction as well as the structure of melt pools along the scan direction of the laser. The high temperature gradient, as well as the high solidification velocity of the melt pool, evokes a columnar epitaxial grain morphology along the building direction. The resulting mechanical properties directly after the manufacturing process are slightly anisotropic. For reducing the residual stresses, and to improve the magnetic properties, a heat-treatment (900 °C, 2 h) was conducted. The mechanical characteristics for both materials are above the required

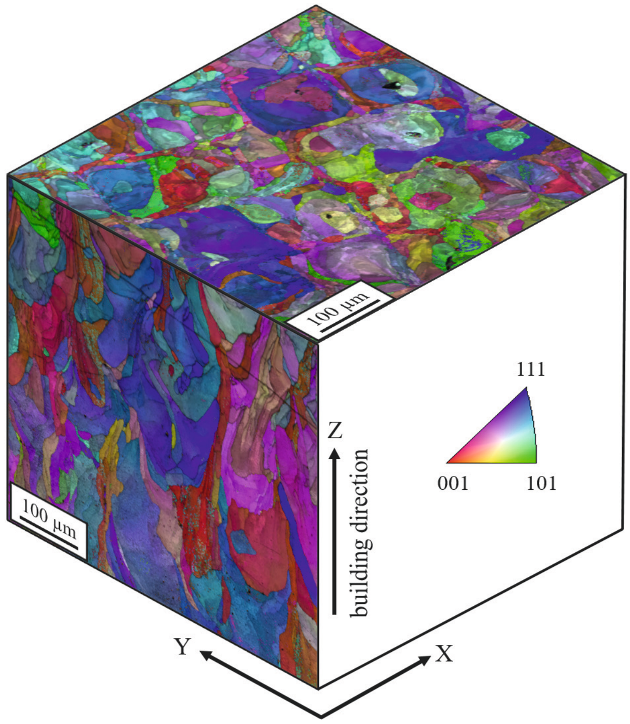

FIGURE 1 EBSD inverse pole figure (IPF) map for the FeSi alloy after heat-treatment (900°C, 2h)

yield strength of 400 MPa (FeSi: YS > 450 MPa; FeCo: YS > 500 MPa). In particular, the FeSi alloy is characterized by a lower anisotropy. Due to the selected heat-treatment a significant increase in the maximum permeability ($\mu max = 3{,}000$) for the FeSi alloy in comparison to the initial, as-built condition ($\mu max = 950$) was achieved. A reduction in the re-magnetization losses (eddy current and hysteresis losses) was also observed.

In summary, the application of a soft magnetic ferro-silicon alloy in an additively manufactured PMSM rotor active part and shaft could be proven successfully. Therefore, the additively manufactured rotor was tested and compared to a conventionally laminated rotor. Inserting lightweight lattice structures into the shaft region, the rotor mass could be reduced by 21% unaffecting mechanical strength. Besides that, additional rotor coils were added to improve the self-sensing performance of the machine, which is an alternative to a meandering wire directly positioned in the q-axis. The experimental results show that the magnetic anisotropy could be improved by adding short-circuited wires underneath the magnets considering the aforementioned boundary conditions. The resulting deviations between the conventionally produced rotor, the additively manufactured rotor and the simulation results could be explained by the increased air-gap, the production tolerances and the rotor coils. Using the present tool chain, a fast determination of the machine characteristics was possible if three-dimensional effects or production tolerances could be neglected.

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 created. Based on a case study several parts or assemblies have been selected and were optimized for lightweight, function and assembly integration or change in material. Finally, demonstrator parts are build and verified based on performance requirements as well as cost, time and quality.

PROJECT OVERVIEW

DURATION

04/2016 – 07/2019

PARTNER

- Diehl Service Modules GmbH
- Diehl Aerospace GmbH
- Diehl Aircabin GmbH,
- AOA Gauting GmbH
- Boeing Research & Technology Europe

FUNDED BY

- Federal Ministry of Economic Affairs and Energy (BMWI)
- VERONIK

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Objectives

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

Procedure

The DMRC participates in two work packages of the collaborative project VERONIKA. In the first work package – Process Chain of Rapid Engineering – two different studies were worked out. The first study deals with the different AM processes and their processable materials. The second study is about part selection and design rules for parts generated by AM. Furthermore, material properties are determined and FE models are developed. A production instruction based on quality management will be prepared for the selected aircraft cabin components from WP2. Finally, a validation of the process chain shall be performed. In the second work package – Application of Additive Manufacturing – the project partners submitted several components of the aircraft cabin, which are parts for conventional manufacturing, and filled out a specification sheet template which was provided by the DMRC. Subsequently, several parts of the submitted cabin parts were selected by using a trade of methodology. Enabling factors for the selection are for instance highly complex parts, a high buy-to-fly ratio for conventional production, several contact points to surrounding parts or the possibility to integrate functions. The aim for the selected parts is then to

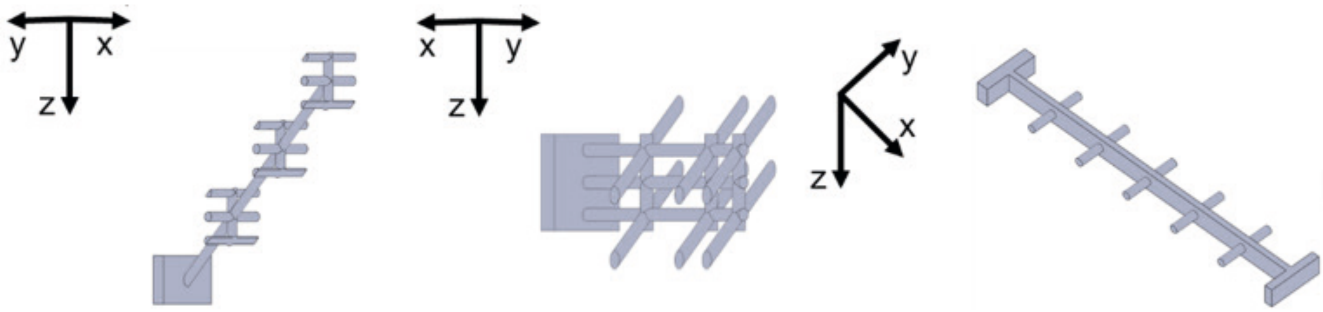


FIGURE 1 Different unit cells for lattice structures used for heat transfer

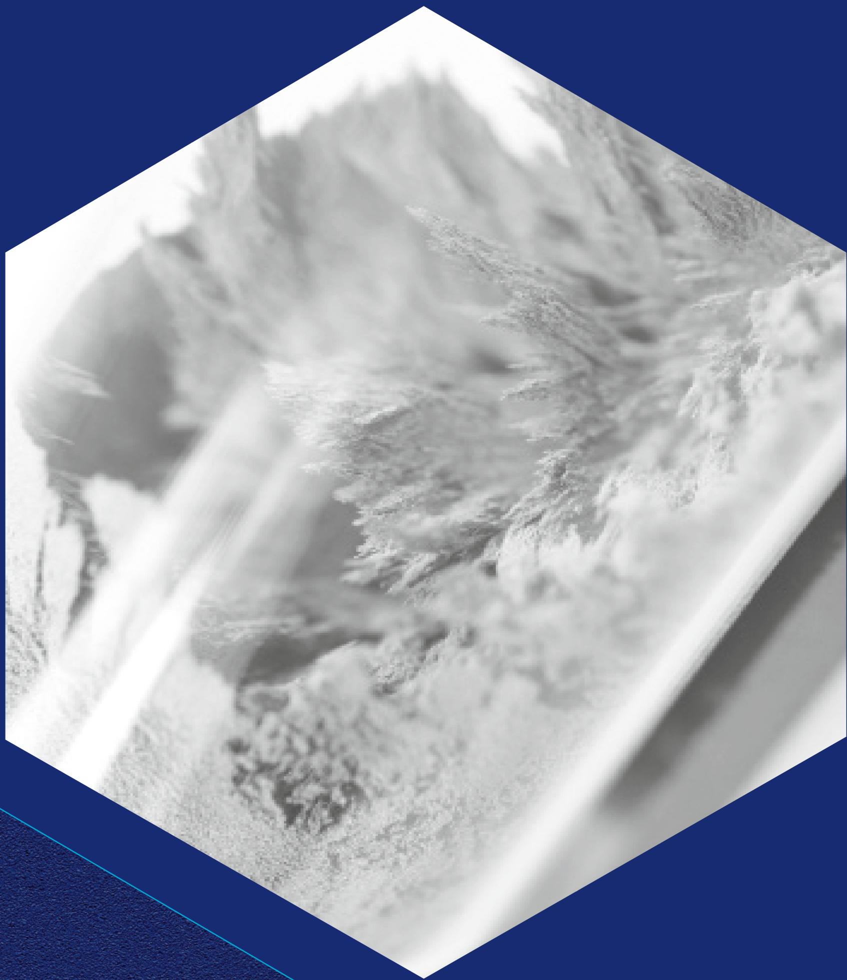
perform a change into an AM compliant design and an optimization regarding material change, weight, part integration or function integration by e.g. topology optimization. Thereupon, process parameters shall be defined and demonstrators shall be produced. Further, the demonstrators shall be verified 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 is optimized regarding function integration in form of heat transfer (see figure 1). Further, a bracket is optimized concerning weight and part number reduction. The weight can be reduced drastically by up to 70 % and the number of parts can be decreased from two to one part. Part integration, material change and weight reduction were performed in another case study assembly. The number of parts were reduced from four to one part and only one material was used instead of two. Within this optimization procedure the manufacturing technology of laser sintering and laser melting were applied. First tests of the parts has been conducted on those prototypes.

Outlook

Upcoming, the other parts shall be extensively verified and further optimization iterations shall be run. Production instructions will be developed and prepared. A validation of the total process chain shall be followed. Finally, demonstrators of the optimized parts shall be build.



Innovation

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INNOVATION

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

PROJECT OVERVIEW

PARTNER

Additive Marking – Produktionsintegrierte Kennzeichnung GbR (additive-marking.de)

RESEARCHER

Research leader
Dipl.-Ing. Ulrich Jahnke

Introduction

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

Objectives

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

Achievements

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

Promising Applications

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

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

FIGURE 1 Additive Marking – efficient solutions made by creative minds

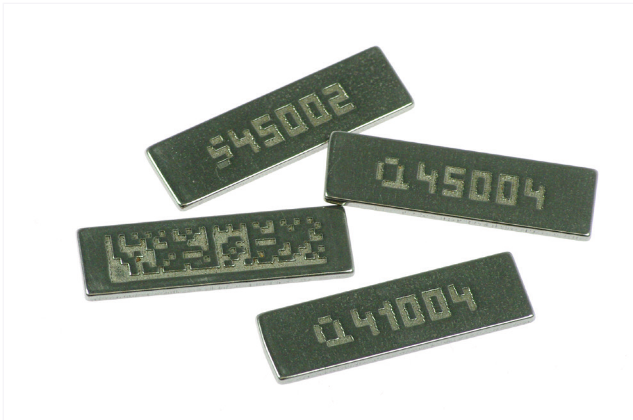

FIGURE 2 Individual markings directly produced during Selective Laser Melting

AIRCRAFT BRACKET CASE STUDY

PROJECT OVERVIEW

PARTNER

H&H GmbH

RESEARCHER

Research leader
Prof. Dr.-Ing. Dettmar Zimmer

Research assistent
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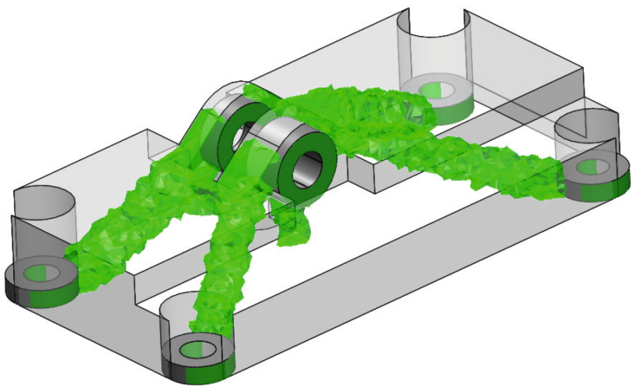

FIGURE 1 Topology Optimization of the bracket

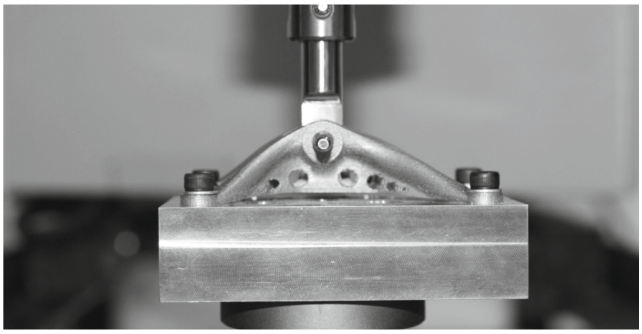

FIGURE 2 Testing of the manufactured bracket

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

European Space Agency (ESA)

RESEARCHER

Research leader
Prof. Dr.-Ing. Rainer Koch

Research assistent
Thomas Reiher, M.Sc.

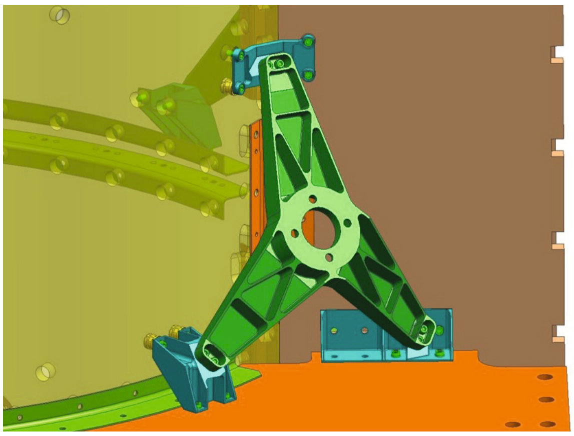

FIGURE 1 Traditional design of Reaction Wheel Bracket mounted in Exo Mars satellite

FIGURE 2 AM Designed Reaction Wheel Bracket

AMendate – INNOVATIVE AM OPTIMIZATION

PROJECT OVERVIEW

PARTNER

AMendate

RESEARCHER

Research leader
Thomas Reiher, M.Sc.
Gereon Deppe, M.Sc.

AMENDATE
INNOVATIVE AM OPTIMIZATION

FIGURE 1 AMendate – An automtaed and integrated topology optimization for Additive Manufacturing

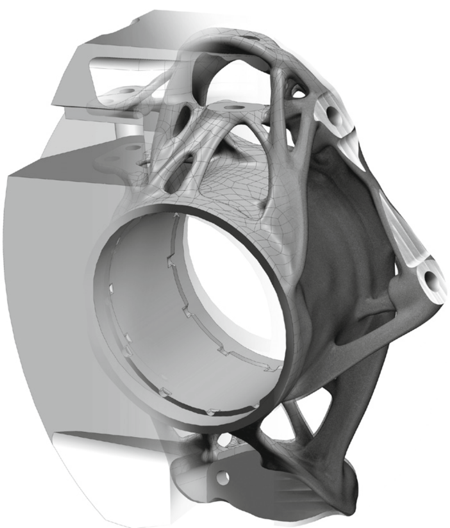

FIGURE 2 Optimization from CAD to CAD in 6 hours combined in one automated software

Objectives

In order to save resources and adapt parts better to their requirements, companies are focusing on part optimization for lightweight design. Unfortunately, the existing software for topology optimization is characterized by several shortcomings: Modeling is a lengthy, labor-intensive process, the computing time is long and extensive expertise and manual reworking is required. Usually several software tools are needed to achieve a satisfying result. However, these software tools are not aligned to an AM-specific design and the transition between the various tools results in errors and reduces the quality of results.

The aim was therefore to develop a dedicated software solution for automated topology optimization with integrated retransition into proper, additive manufacturable geometries. The result is a software called AMendate, which will soon be available on the market and offers topology optimization, automated in one single solution, from CAD to CAD..

Procedure and Achievements

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

This makes AMendate a significant step towards the automated design of optimized parts, which will promote the introduction of additive manufacturing in other industries.

BIPOLARPLATES USING FDM-MOLD

Partner

This Innovation was developed together with Eisenhuth GmbH & Co. KG. Eisenhuth is SME located in Germany, Osterode am Harz, and has three main competencies: Mold making, small and medium series of thermoplast, 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 has to be 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 on orientation angles for optimal canal depths and shapes.

Highlights:

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

PROJECT OVERVIEW

PARTNER

Eisenhuth GmbH & Co. KG

RESEARCHER

Research leader
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Frederick Knoop, M.Sc

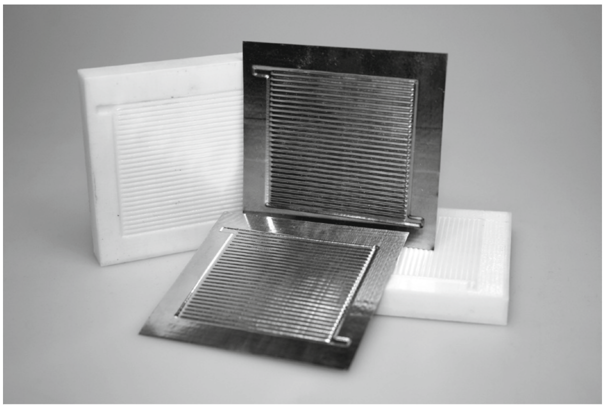

FIGURE 1 Pressed sheet metal

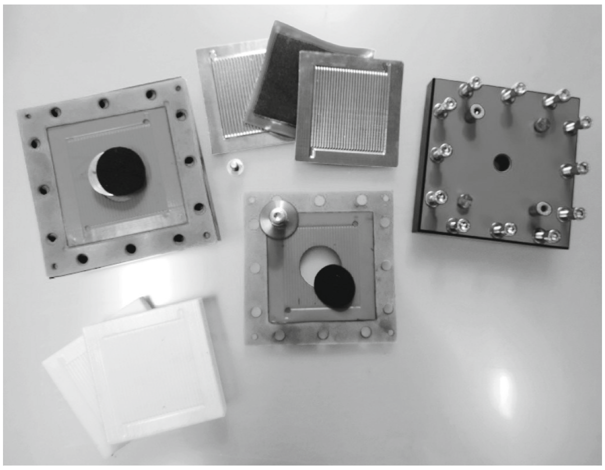

FIGURE 2 Experimental setup of the fuel cell

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

PROJECT OVERVIEW

RESEARCHER

Research leader
Prof. Dr.-Ing. Detmar Zimmer

Research assistent
Thomas Künneke, M.Sc.

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.

FIGURE 1 Test rig used for sound pressure level tests

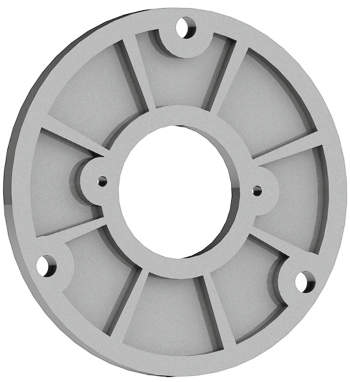

FIGURE 2 Sectional view of the cavities inside the damped armature plate

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 machining requirements. Our divisions PRODUCTION MOD-ULES and XL MANUFACTURING SYSTEMS stand for different machine concepts and machin-ing solutions for various industry sectors.

Objectives

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

Procedure

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

Achievements

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

- Weight reduction:- 58 %

PROJECT OVERVIEW

PARTNER

ELHA-MASCHINENBAU Liemke KG

RESEARCHER

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Prof. Dr.-Ing. Rainer Koch

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Thomas Reiher, M.Sc.

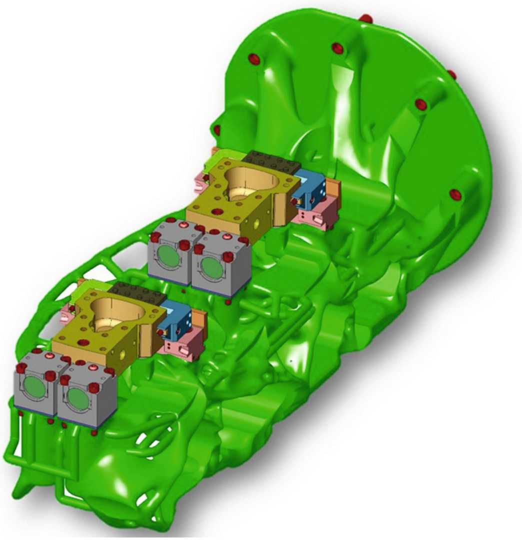

FIGURE 1 Topology optimized clamping device

LIGHTWEIGHT ROTOR SHAFT FOR PMSM

PROJECT OVERVIEW

PARTNER

Siemens, Wittenstein, Porsche, VW, Wilo, IAL (University of Hanover) and the IAM (Karlsruher Institute of Technology).

RESEARCHER

Research leader
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Research assistent
Stefan Lammers, M.Sc.

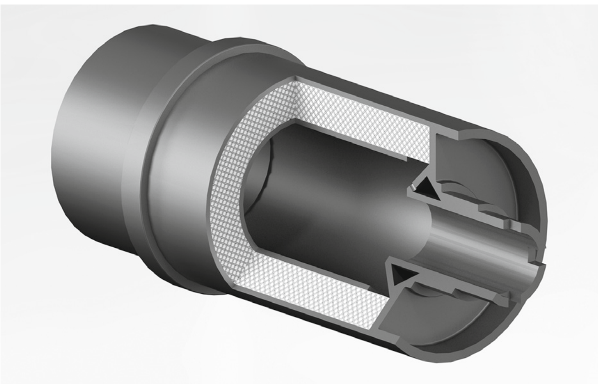

FIGURE 1 Optimized rotor shaft with lattice structures for a lightweight design

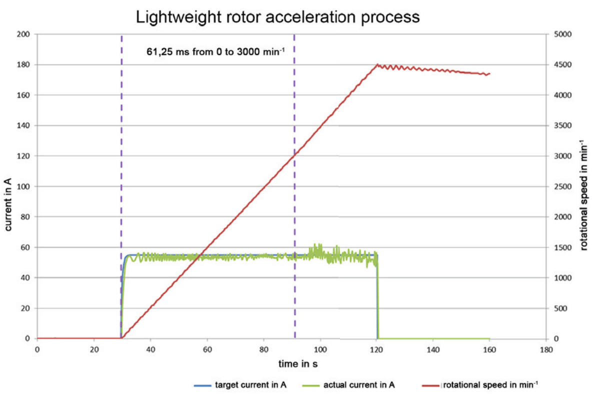

FIGURE 2 Results of the motor characteristics investigations.

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.

MODELLING OF TEMPERATURES AND HEAT FLOW WITHIN LASER SINTERED PART CAKE

PROJECT OVERVIEW

PARTNER

Indian Institute of Technology
Bombay, Powai, Mumbai 400076, India

RESEARCHER

Research leader
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Research assistent
Stefan Josupeit, M.Sc.
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.

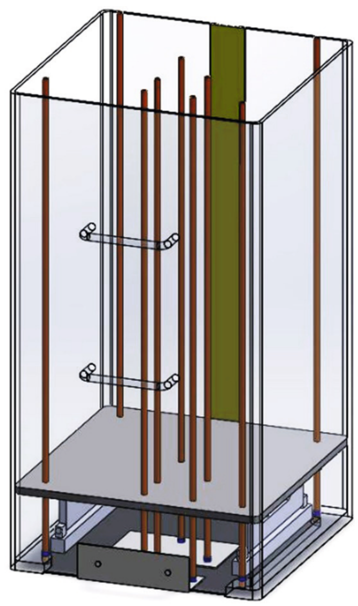

FIGURE 1 EOS P395 Frame with installed temperature measurement system

PLASTIC FREEFORMING OF LIQUID-TIGHT MICROFLUIDIC COMPONENTS

PROJECT OVERVIEW

PARTNER

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

RESEARCHER

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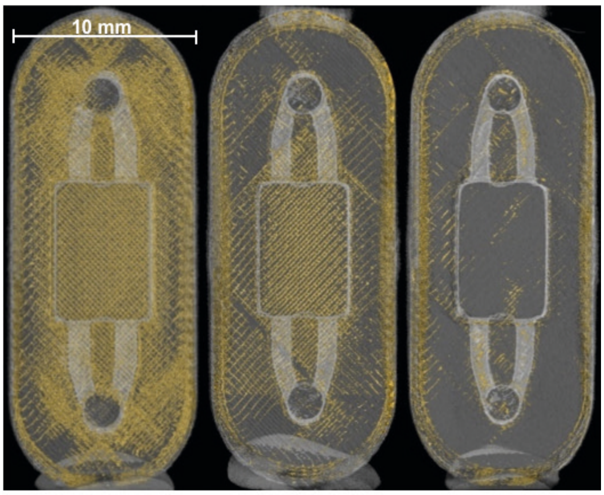

FIGURE 1 Computer tomographic pore volume analysis with varied form factors (FF) and build chamber temperatures (BT)

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 and be printed directly. 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 temperature (material preparation and build chamber temperature) is 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.

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 1a / 1b).
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

Direct Manufacturing Research Center (DMRC)

RESEARCHER

Research leader
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Research assistant
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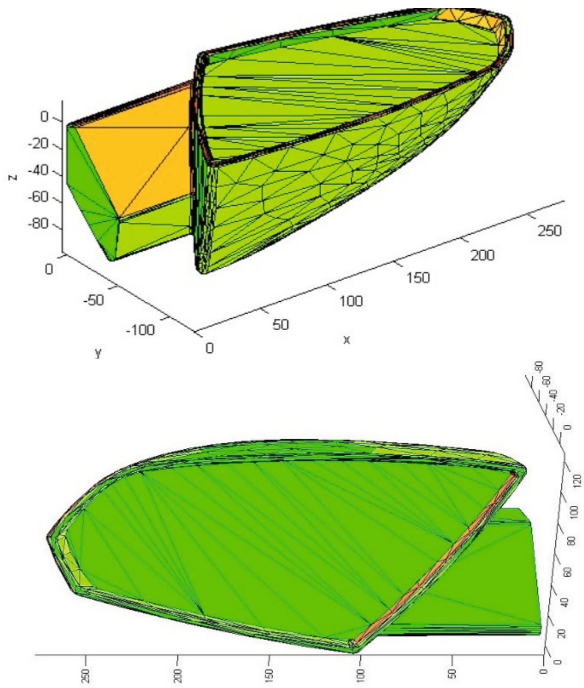

FIGURE 1 EOS P395 Frame with installed temperature measurement system

Education

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DMRC - AM LESSONS

Education is one of the most important factors for the development of additive manufacturing towards an industrial established and production capable manufacturing technology. With this motivation, the DMRC is active in many teaching and training measures in terms of additive manufacturing. Thereby, different task groups are addressed: students, teachers/trainers as well as technology beginners and experts from the industry. In terms of academic teaching, the Direct Manufacturing Research Center steadily strives to implement additive manufacturing contents in the lessons at the Paderborn University.

An important milestone was achieved few years ago by setting up an elective module “Additive Manufacturing” within the master’s degree course in mechanical engineering. The elective module consists of the compulsory lecture “Additive Manufacturing” and of at least two other selectable courses. In 2017, over 170 students took part in the compulsory lecture “Additive Manufacturing” and learned 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.

DMRC – INDUSTRIAL SEMINARS

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

Haus der Technik: Direct Manufacturing In cooperation with Ostwestfalen-Lippe University of Applied Sciences the DMRC performed two basic seminars on additive manufacturing. The seminars were held in Berlin and Paderborn. Within this two-day seminar, participants learned fundamental information with regards to additive manufacturing.

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.

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.

Additive Manufacturing Specialist VDI: In 2017, the DMRC and VDI Wissensforum GmbH, the training provider of the Association of German Engineers (VDI) have agreed to collaborate in a practice-oriented qualification course developed by VDI WF together with experts from the additive manufacturing industry. Participants will complete the course with a recognized VDI certificate. The certificate course is technically coordinated by Dr.-Ing. Stefan Bindl (AM Ventures Holding GmbH) and Dr.-Ing. Christian Lindemann (DMRC) and VDI WF. First courses will start in 2018. Within the seminar series the DMRC will educate in the area “Design for additive Manufacturing”

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

STUDENTLAB3D - STUDENT LABORATORY

3D printing offers big advantages such as design freedom, short production time and fast prototyping. In order to leverage the 3D printing technology apprenticeship is needed. Some of the important questions are: How to get a high quality 3D model? How to reduce support structures and is a part capable of 3D printing or not? With the StudentLab3D the Paderborn University and the DMRC offers practical teaching for all students and the staff of the Paderborn University. The aim is to enable students to work with 3D printing and related technologies. In the StudentLab3D the theoretical knowledge can be extended by practically experiences.

PROJECT OVERVIEW

PARTNER

University Paderborn

RESEARCHER

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

Research assistent
Christian Schumacher, M.Sc.
Dennis Menge, M.Sc.

WEBSITE

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

Started in 2014

The project was funded by the Paderborn University in 2014. The Direct Manufacturing Research Center won the “Award for Innovation and Quality in Teaching 2014”. With this financial support, three affordable 3D printers and a handheld 3D scanner have been purchased. In the meantime the equipment was extended by additional 3D printers, 3D scanners and software.

Teaching and workshops

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

Additionally, the teaching staff of all faculties of the Paderborn University is invited to implement 3D printing into their lessons and lectures. Among the integration in the engineering faculty and the master module additive manufacturing, the StudentLab3D cooperates with other faculties. For example, 3D printed sculptures are designed in a cooperation with the art faculty and scaled mannequins of reallife students for tailoring purposes are manufactured in a cooperation with the textile and fashion faculty.

Achievements

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

Chairs and Institutes

CONTENT

FACULTY OF MECHANICAL ENGINEERING

Computer Application and Integration in Design and Planing (C.I.K.) 78

Institute of Applied Mechanics (FAM) 84

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FACULTY FOR COMPUTER SCIENCE, ELECTRICAL ENGINEERING AND MATHEMATICS

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

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

INTRODUCTION

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

Bridging the gap between science and industry

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

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

Civil safety and Additive Manufacturing projects

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

ADDITIONAL EQUIPMENT OF THE CHAIR

Software

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

Hardware

- Makerbot Replicator 5th Generation
- Ultimaker 3 incl. Dual Extruder

STAFF

HEAD OF CHAIR

Prof. Dr.-Ing. Rainer Koch

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Field of research
IT-driven Design Optimization

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CURRENT RESEARCH PROJECTS

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

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 manufacturing 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.

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

RESEARCH LEADER Prof. Dr.-Ing. Rainer Koch

ASSISTENT Dipl.-Ing. Ulrich Jahnke

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FUNDED BY

OptiAMix - Multi-target optimized Product Development for Additive Manufacturing

In January 2017 the research project "OptiAMix" started at the Paderborn University, funded with 2.54 Mio. Euro by the Federal Ministry of Education and Research (BMBF) by a total volume of 4.4 Mio. Euro.

The aim of this project is the multi-objective and continuous, automated component development for the additive manufacturing process in the whole product development process. In order to achieve a multi-objective optimization with regard to diverging factors, such as low costs or load-balanced design, a new software tool for production-oriented, post-processing-oriented, load-balanced and cost-effective design of components will be developed and combined with existing tools. Thus, increasing product complexity can be mastered and a high level of data security will be ensured.

RESEARCH LEADER Prof. Dr.-Ing. Rainer Koch

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FUNDED BY

Bundesministerium
für Bildung
und Forschung

CaCS 2018 - Concept and Case Studies 2018

One of the limiting factors in the adoption of AM are design studies with relevant empirical data that show performance enhancements. The idea of this project is to develop generic design studies that are relevant to the industries 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.

The areas for consideration in 2018 are:

- influencing magnetic flow
- optimizing damping properties

After clarification of tasks, for both areas research will be done on fundamental effects and the implications of using additive manufacturing. Experimental tests as well as simulation models will be set up to determine the best possible use of the new possibilities of AM.

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FUNDED BY DMRC DIRECT MANUFACTURING RESEARCH CENTER

FINISHED RESEARCH PROJECTS 2015-2017

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

In a fast moving age manufacturers of innovative products and products of exceptional quality are often victims of product piracy. Imitators enter the market just copying extensively developed products and reducing the deserved turnover of the original creators. As part of the technology network "Intelligent Technical Systems" OstWestfalenLippe (it's OWL) funded by the Federal Ministry of Education and research (BMBF) the project "It's OWL 3P: Prevention of Product Piracy" focuses on raising the awareness that legal measures are not the only way to protect innovations and products against product piracy.

The main objective of the DMRC's part of this project is to show potentials of Additive Manufacturing to protect product from being copied.

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FUNDED BY Bundesministerium für Bildung und Forschung

CURRENT RESEARCH PROJECTS

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

The aim of the project NewStructure – initiated and funded by the ESA – is to examine the ability of using Additive Manufacturing for producing structural metallic parts mainly used in actual telecommunication satellites.
In a first step a trade-off methodology to be used in the project has been developed. This procedure helps to rate actual structure elements in a very objective way to identify parts most promising for AM (technically and economically). Typical relevant parts have been those with a high buy-to-fly ratio and time-consuming or complex fabrication steps. Demonstrators of structural elements have been built in SLM either with or without redesign especially for AM. The resulting improvements gained by changing the manufacturing process with or without a redesign on costs and weight have been figured out.

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FUNDED BY esa

RepAIR - Future RepAir and Maintenance für Aerospace industry

The goal of this research project with twelve partners from all over the world has been the onsite maintenance and repair of aircraft by integrated direct digital manufacturing of spare parts. AM is ought to make the maintenance, repair and overhaul of aircrafts more efficient and effective. Therefore it is necessary to reduce the aircraft's downtime; this has to be achieved not only for the regular maintenance but also for urgent repairs. The challenge is to design cost efficient and lightweight parts but additionally ensure a high robustness and reliability of the parts. AM offers a high potential for these requirements. The overall aim of the project is to shift the 'make-or-buy' decision to 'make' with respect of an on-site production. Spare parts should be manufactured completely or damaged parts should be repaired.

RESEARCH LEADER Prof. Dr.-Ing. Rainer Koch

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Dr.-Ing.Christian Lindemann
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FUNDED BY

Know AM - Knowledge about Additive Manufacturing

The project KnowAM deals with the processes of cost efficient design and planning regarding the use of Additive Manufacturing technologies. Costing structures of AM technologies and planning tools for early phases of the product development are part of the research. Based on best practices from product development case studies, a methodology for cost efficient design and planning is derived.
The following goals are targeted in the project:

- Enhancement of costing framework developed in the Project CoA2MPLy "Costing Analysis of Additive Manufacturing over Product Lifecycle"
- Achievement of comparability between machines and technologies regarding costing aspects and particularly building rates
- Derive best practices for cost efficient design and planning

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FUNDED BY DMRC DIRECT MANUFACTURING RESEARCH CENTER

INSTITUTE OF APPLIED MECHANICS (FAM)

> Additive Manufacturing is the key for the development and optimization of individual products.
>
> Prof. Dr.- Ing. Gunter Kullmer

INTRODUCTION

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

"Strength optimized and rupture safe design of components" deals with the dimensioning and optimization of components and structures with respect to the practically oriented advances of the FEM standard software and its efficient use in various applications. In this relation the applied tools are stress and deformation analyses as well as notch stress tests and fracture mechanical tests including fatigue crack growth experiments. The propagation behavior of fatigue cracks in many cases determines the life time of the components and technical structures. To predict the crack growth behavior and to prevent damage, various crack growth simulation programs were created and are in use at the institute. The area "Biomechanical analysis of the human musculoskeletal system" covers the simulation of courses of movement up to the development of intelligent healing aids. The aims are the evaluation of injury risks and the avoiding of resulting injuries. In order to provide an optimal rehabilitation process, medical devices are frequently required to be individually fitted to the patient's physical condition. So, additive manufacturing grows to become an attractive approach in medical engineering, e. g. for orthoses, implants and prostheses. The third area of research "Optimization and new development of products in cooperation with industrial partners" deals with the solving of specific problems which occur in practice by implementing the above mentioned core competences.

ADDITIONAL EQUIPMENT OF THE CHAIR

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

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CURRENT RESEARCH PROJECTS

Influence of different powder properties on the material characteristics

Ti6Al4V is the most commonly used alloy, because it has a well-balanced property profile and different heat treatments allow to tune microstructure and properties for different requirements and applications.
During the use phase of powder, effects like out-washing of fine fractions, pick up of oxygen as well as enrichment of splashes change powder characteristics. In addition, there is a possibility of powder decomposition due to the powder handling process. Therefore, the powder quality permanently changes during the manufacturing process. Another point is the lot to lot variation of the powder quality inside the specified ranges.

Scope of this project is to investigate the influence of relevant changes of powder characteristics on material as well as part properties.

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Changes of stainless steel powder

There is high market potential for the production of metal parts using Additive Manufacturing (AM) technologies: In many applications, stainless steel (1.4404) with a good corrosion resistance is widely used. For serial production, deep knowledge on the robustness of part properties against variation of powder characteristics is required.
During the use phase of powder, effects like out washing of fine fractions and pick up of nitrogen change the powder characteristics.Therefore, the powder quality permanently changes during the manufacturing process. Another point is the lot to lot variation of the powder quality inside the specified ranges. Within the specified limits for particle size and particle chemistry there is a lot of freedom.

The scope of this project is to investigate the influence of relevant changes of powder characteristics on material as well as part properties.

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FINISHED RESEARCH PROJECTS 2015-2017

Fatigue strength properties of SLM components

Detailed knowledge regarding the fatigue behavior is crucial if cyclic loadings are applied to components. Therefore, in the scope of this project, the behavior of SLM-processed materials under fatigue loadings have been investigated. For this purpose, process-induced defects have been characterized and optimization strategies have been developed in a first step. Subsequently, fatigue tests and fracture mechanical studies for SLM-processed materials with different post-treatments have been performe was found. This enables a fast and stress optimal design.

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Fatigue Life Manipulation

A defined arrangement of crack retardaition elements optimizes the life of Selective Laser Melting parts that are under fatigue loading, thus ensuring safe use in an industrial environment. For this purpose, examinations are carried out on specimens containing different arrangements and geometries of crack retardation elements and their influence on service life is tested by means of experimental and numerical methods. Fracture mechanical characteristics, like influence of crack retardation elements on crack initiation and crack deflection behavior are the results of this project in order to generate an optimal design for cyclically loaded components.

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New Member

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.
>
> Dr.-Ing. Nicole Lutters

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

ADDITIONAL EQUIPMENT OF THE CHAIR

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

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FINISHED RESEARCH PROJECTS 2015-2017

Concept and Case Studies 2017 (CaCS 2017)

"Concept and Case Studies 2017" addresses the two issues of "thermal management" and "structural optimization and light weight design", as well as the development of suitable forms of catalogue presentation.
Therefore, active principles or design aids are visualized appended by illustrative demonstrators and collected in a design catalogue. In this way, the designers are to be given the opportunity to use a uniformly designed reference work during development in order to achieve an efficient use of additive manufacturing.
FVT investigated innovative rib geometries for a demonstrator of the industry partner John Deere. This demonstrator represented a condenser for an air conditioning system. Thanks to the FVT contribution, the rib geometry was optimized and, consequently, the condenser size was reduced.

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HEINZ NIXDORF INSTITUTE (HNI) - PRODUCT CREATION

HEINZ NIXDORF INSTITUT
UNIVERSITÄT PADERBORN

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

INTRODUCTION

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

Strategic planning and Innovation Management

Synergies in the 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 the competitive situation. Taking future scenarios into account, we define search fields for product innovations. Thus, promising product ideas meet a high demand at market entry. Future implicit wishes of untapped customer groups will be anticipated in addition to articulated customer requirements. Our product understanding includes both material core product and related services.

Systems Engineering and Engineering Management

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

Production Management

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

Digital and Virtual Engineering

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

ADDITIONAL EQUIPMENT OF THE CHAIR

Smart Automation Lab

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

Equipment for Digitalization (incl. VR/AR devices)

- Oculus Rift
- HTC Vive
- Microsoft Hollowlens

Development Software (CATIA, Matlab, …)

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CURRENT RESEARCH PROJECTS

FOCUS – Active Strategy Implementation and Advancement

The aim of FOCUS is to update our strategic knowledge base, to adapt facilitation and continuous improvement tools as well as to advance service and training offers – change from passive into active strategy focus and make corresponding knowledge available for DMRC partners.
FOCUS supports managing roles to sharpen the scientific profile; actively engage and liaise with German, European and international communities; monitor and enhance potential synergy effects between research interests of both scientific and industrial partners. The DMRC will gain an outline of the competitors' strategies, clear USPs and demanded research fields in AM. The roll-out and implementation process will ensure sustainability of the project, handing it into the regular structures and processes of the DMRC.

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OptiAMix - Multi-target optimized Product Development for Additive Manufacturing

Additive Manufacturing offers various potentials for functional integration and lightweight construction. Methods for the analysis of requirements of the additively manufactured components are developed by members of the Chair for Product Creation. Requirements management during
product development and in later phases of the product life cycle is one of the key pitfalls and potential cost driver. For instance, in case of changes in one manufacturing process, the implications of subsequent modifications to the design or to the manufacturing process of other parts or modules must be identified and considered. These risks are handled by the OptiAMix software tool. .

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FINISHED RESEARCH PROJECTS 2015-2017

DynAMiCS - Development of an Additive Manufacturing Potential Check System

Object of DynAMiCS is the development of a procedure in order to identify business opportunities for AM in a company. A procedure was consolidated to a holistic, but scalable AM potential check system that was validated in workshops with external companies and DMRC partners. The check system draws on findings from the project "Strategy" and empowers the DMRC to become a leading institution acting at the intersection of technology and market research. Finally, the check system was further developed to a service offer that attracts companies to get in contact with the DMRC, and to join the DMRC as a partner in a further step. This increases visibility and reputation of the DMRC. The results of the project are summarized in a confidential study. Additionally, a public study is published and available on *DMRC homepage*.

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Domain specific requirements for Additive Manufacturing and identification of potentials

The objective was the identification of potential application fields and domain specific requirements for AM in a large-scale industrial context. Activities included the identification of specific requirements for AM in various markets, of key drivers for future AM business and the potential future key challenges (in general and domain specific) which had to be addressed by the customer.
Based on a literature study, key capabilities and their correlation to AM technologies and materials were deduced. In specific markets, application fields and part types were identified. These were related to the available AM materials. Based thereon, specific requirements for these were derived.

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University of Paderborn
Design and Drive Technology

DESIGN AND DRIVE TECHNOLOGY (KAt)

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

INTRODUCTION

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

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

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

Key aspects in the field of electromechanical drive technology are the

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

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

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

ADDITIONAL EQUIPMENT OF THE CHAIR

Equipment (test rigs)

- high-speed friction
- multi-motor drive system
- torsion vibration
- wear resistance of profiled shaft joints with sliding seat
- condition monitoring of rolling bearings
- bearing damage
- damping
- heat transfer

Software

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

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CURRENT RESEARCH PROJECTS

KitkAdd: Combination and integration of established technologies with additive manufacturing processes in a process chain

The aim of KitkAdd is to reduce the production costs by combining AM with established manufacturing processes such as machining, sintering, and casting. First, demonstrators of participating companies, for instance a turbine blade for gas industry, are analysed to identifying part sections that can significantly improve the part properties through AM. The remaining part sections are manufactured by an established process. Design rules and tolerances are prepared for the parts. For the resulting combined process chains, future concepts are designed for production facilities with additive manufacturing for large-scale production. Quality control is improved by an innovative ultrasonic measuring principle assuring a reduction of residual stresses in the component during additive manufacturing.

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FUNDED BY Bundesministerium für Bildung und Forschung

Concept and Case Studies 2018 (CaCS 2018)

One of the limiting factors in the adoption of AM are design studies with relevant empirical data that show performance enhancements. The idea of this project is to develop generic design studies that are relevant to the industries 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.

The areas for consideration in 2018 are:

- influencing magnetic flow
- optimizing damping properties

After clarification of tasks, for both areas research will be done on fundamental effects and the implications of using additive manufacturing. Experimental tests as well as simulation models will be set up to determine the best possible use of the new possibilities of AM.

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OptiAMix: Multi-objective-optimized product design for additive manufacturing

The core objective of this collaborative project is the multi-objective optimization of additively manufactured components, the requirements and divergent goals set for a suitable component have to be determined, such as load capacity, costs and production costs, are weighted in advance and automatically taken into account by a design-supporting software tool. For a successful solution of the project objective the sub-steps of the PEP are considered. It is important to develop methods and tools for the strategic-technical component selection as well as for automated and multi-target optimized component design. Furthermore, multi-objective optimized design rules are methodically and experimentally established, and the interdisciplinary cooperation of the divisions and product protection are promoted.

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FINISHED RESEARCH PROJECTS 2015-2017

Direct Manufacturing Design Rules (DMDR)

Additive manufacturing provides new design freedoms that can provide great benefits to users. In order to make these design freedoms and design restrictions accessible, the DMDR project has the aim to develop design rules for additive manufacturing.
A method for the development of design rules was worked out. The basis for this method is given by standard elements. These are geometrical objects which often reoccur by designing technical parts.
Based on defined standard elements, design rules have been methodically developed. These are function independent, completely focused on geometry and thereby easily transferable on individual part designs.
The developed rules were summarized in a design rule catalogue. This catalogue creates a basis for a practical knowledge transfer to users from industry and science.

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FUNDED BY
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Dimensional Tolerances for Additive Manufacturing

The freedom of design provides great benefits to users of additive manufacturing processes. In order to profit from these benefits, it is necessary to know and to take into account the manufacturing limits of the processes. This applies in particular to the geometrical accuracy of the components. At time, neither the reasons for the occurrence of deviations nor the tolerances to limit the deviations are known.
Thus, the project has two different aims. First dimensional tolerances will be systematically determined. Secondly, it will be considered, how dimensional deviations and the derived tolerances can be reduced.

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Additive Manufactured Function Integrated Damping Structures (AMFIDS)

In technical systems mechanical vibrations are usually undesirable. They lead to increased stress on the components and thus to a reduction in lifetime. In addition, mechanical vibrations harm the function and lead to audible noise emission. Within the project it will be investigated, how damping functions can be integrated into existing structures by additive manufacturing processes. Further on it should be analyzed, how the damping function can be adjusted to different mechanical vibrations in order to obtain an optimum damping effect. Based on these empirical investigations, a simulation model is to be developed that enables the simulation of the experimental data.

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

The central research objective in this project is the examination and the testing how additive manufacturing (AM) processes are useable for the production of encoderless controlled permanent magnetic synchronous DC motors (PMSM). Therefore, experimental investigations based on test specimens were carried out and the rotor design was changed to a production optimized design.
The manufactured rotor showed a lower weight and a better acceleration than a conventional manufactured rotor. Furthermore, the project showed the demand of further investigations in material science and the possibility of flux optimization with help of AM.

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FUNDED BY FVA Forschungsvereinigung Antriebstechnik e.V.

Lightweight construction of hydraulic clamping devices processed by SLM

The central research objective of this project is the qualification of materials and methods for the additive production of soft magnetic components for use in electrical machines. For this purpose, a suitable soft magnetic material is developed and its suitability for additive processability is tested. The material will be compared with the help of a redesigned demonstrator with the results of the "Feasibility study 3D-printing electric motors" (FVA 731I) as well as conventionally manufactured rotors.
As a method for additive manufacturing, the selective laser melting is selected, since this has a high degree of maturity in comparison with other additive manufacturing methods and appears to be very suitable for processing soft magnetic material.

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FVA
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Concept and Case Studies 2017 (CaCS 2017)

"Concept and Case Studies 2017" addresses the two issues of "thermal management" and "structural optimization and light weight design", as well as the development of suitable forms of catalogue presentation.
Therefore, active principles or design aids are visualized appended by illustrative demonstrators and collected in a design catalogue. In this way, the designers are to be given the opportunity to use a uniformly designed reference work during product development in order to achieve an efficient use of additive manufacturing.
In principle, this concept is designed for several years so that the latest developments in technology can be taken into account and the questions relevant to the industrial partners can be investigated.

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KUNSTSTOFFTECHNIK PADERBORN (KTP)

> 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

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

INTRODUCTION

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

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

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

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

In the field of additive manufacturing, the research of the KTP focuses on the continuous development of processes with regard to material development, mechanical and geometrical properties, surface quality and process optimization. The research takes place in the fields of Fused Deposition (FDM) or Fused Layer Modeling (FDM) and ARBURG Plastic Freeforming (APF).

ADDITIONAL EQUIPMENT OF THE CHAIR

Simulation Programs

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

Equipment

- Zwick Roell: Pendulum impact tester (HIT5.5P);
- Zwick Roell: Universal Testing Machine ProLine Z010 (10 kN, climatic chamber with elastic modulus);
- Zwick Roell: Universal Testing Machine 1446 (10 kN);
- Zwick Roell: Universal Testing Machine 1474 (50 kN);
- *....further equipment see page 105*

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

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CURRENT RESEARCH PROJECTS

Processing of alternative FDM materials

For professional FDM systems only a small number of various starting materials can be received. These materials are provided by the machine manufacturers and the material properties are often insufficiently known. Additionally, not many high performance polymers are available for the AM process and the available high performance materials are very expensive.
The aim of the project is to investigate the process qualification for different materials. For this purpose, as a first step micro granules have to be processed to produce FDM-processible monofilaments. If the production of FDM monofilaments is practicable, the selected materials are processed on an open source FDM system and afterwards the processability should be improved. Characteristic values have to be determined for the different materials.

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FUNDED BY DMRC DIRECT MANUFACTURING RESEARCH CENTER

ZIM - Rupture Discs: Development and Optimization of AM Components for HGU

This project is about the ability how to use AM components for forming processes. Innovative rupture discs should be produced with a high-speed forming process called 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 in an innovative and unique tool system. The result is an efficient manufacturing process in which process steps can be saved.

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

FDM-structures for the partial reinforcement of hybrid structures

The mechanical properties of thin-walled plastic components are limited. One approach of improving the stiffness and strength is to apply individual adapted FDM-structures onto the thin-walled components. To achieve an optimal reinforcing effect, the properties of the FDM-structure must be optimized first. This project aims to determine design and process guidelines for FDM-structures, which are aligned for specific load cases and shall be used for a partial reinforcement of lightweight parts. To realize the maximum increase of the mechanical properties the inner structure is adjusted to the specific load case by using different parameters for the layer generation. In addition, the design of the FDM-reinforcement-structure shall be adapted. The aim is a topology-optimized construction (FEM-analysis).

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Development and modeling of design and manufacturing guidelines for the plastic freeforming

The aim of the project is the development and modeling of design and manufacturing guidelines for the plastic freeforming process with regard to the mechanical properties, warpage, surface quality and tolerances. The provided guidelines should demonstrate the efficiency of the plastic freeforming process. Moreover, the mechanical properties (tensile, compressive and bending strength) should be determined taking into account the porous construction of a plastic freeforming-made structure. Besides the variation of the manufacturing parameters in particular the influence of the material viscosity on the porosity should be examined. In addition, the process-specific material degradation should be analyzed. The aim of this purpose is to develop strategies, which minimize the material degradation.

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Material development of non-reinforced and fiber-reinforced polymers for extrusion deposition 3D printing

The aim of this project is to investigate the requirements for materials and semi-finished products which are processed in extrusion deposition 3D printing processes. By gaining a better understanding of the process, a knowledge base should be created, to increase the variety of materials that are available for the extrusion deposition 3D printing processes. This project is conducted in cooperation with the company ALBIS PLASTIC GmbH and under the NRW Fortschrittskolleg “Lightweight – Efficient – Mobile” (FK LEM). As one of the six Forschrittkollegs established in 2014, the FK LEM is sponsored by the Ministry of Innovation, Science and Research of the State of North Rhine-Westphalia.

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

FINISHED RESEARCH PROJECTS 2015-2017

Long-term Properties of a High Temperature FDM Material

Information about the mechanical properties are essential for designers in order to design products for application. Particularly for a dynamical application, like in the automotive industry or aircraft, the fatigue and creep behavior of the parts has to be known.

The aim of this project is to characterize the fatigue behavior for FDM parts built with Ultem 9085 and Ultem 1010 by using the FDM standard parameters. The long- and short-term properties of Ultem 9085 will be identified for different build orientations at different temperatures. For that purpose, the dynamic properties are tested at low temperatures up to -50 °C and higher temperatures up to around 100 °C. In addition, short-term deforming tests are done at higher temperatures up to 100 °C.

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Fatigue Behavior of FDM and LS Parts

In practice, the knowledge of the fatigue prop- erties, in addition to the static material prop- erties, is crucial for a reliable com- ponent design. Many components are not only stati- cally load- ed, but also dynamically loaded in the area of application, such as a fastener on an airplane. Therefore, the fatigue behavior of Fused Deposition Modeling (FDM) parts manu- factured with Ul- tem 1010 and Ultem 9085 as well as Laser Sintering (LS) parts manufac- tured with Polyamide (PA) 12 are analyzed in this proj- ect. Furthermore, chemical surface treatment can be used for surface smoothing of additive manufactured polymer parts. The in uence of the chemical surface treatment on the mechanical properties will be analyzed in static and dynamic tests.

RESEARCH LEADER Prof. Dr.-Ing. Volker Schöppner

ASSISTENT Matthias Fischer, M.Sc.

ADDITIONAL EQUIPMENT OF THE CHAIR

Equipment

- Instron: Elektrodynamic Testing Machine ElectroPuls E10000 (7 kN);
- Reichert Jung: Thin Cutting Device (Polycut);
- Keyence: Digital Microscope (VHX-600);
- Keyence: Confocal Laser Microscope (VK-9710);
- Streurs: Grinding and Polishing Device (Tegral/Force-5);
- GE: Computer Tomography CT (Phoenix nanotom s);
- Mettler Toledo: Thermoanalytical Testing Device TGA/DSC (1 Star-System + TMA/SDTA 841)

AUTOMOTIVE LIGHTWEIGHT CONSTRUCTION (LiA)

www.Leichtbau-im-Automobil.de

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

- ensile testing machines (dynamic, static, high/low temperature)
- Drop weight tester 150kg-500kg
- Clamping plate for multiaxial loadings
- Component crash-test facility (bending, compression, high-speed testing)
- Cupping test (Nakajima, Bulge)
- 3D Optical measurement for elongation- and deformation analysis (Aramis GOM)

ADDITIONAL EQUIPMENT OF THE CHAIR

Hardware

- 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 machines

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CURRENT RESEARCH PROJECTS

OptiAMix - Multi-target optimized Product Development for Additive Manufacturing

In January 2017 the research project “OptiAMix” started at the Paderborn University, funded with 2.54 Mio. Euro by the Federal Ministry of Education and Research (BMBF) by a total volume of 4.4 Mio. Euro.
The aim of this project is the multi-objective and continuous, automated component development for the additive manufacturing process in the whole product development process. In order to achieve a multi-objective optimization with regard to diverging factors, such as low costs or load-balanced design, a new software tool for production-oriented, post-processing-oriented, load-balanced and cost-effective design of components will be developed and combined with existing tools. Thus, increasing product complexity can be mastered and a high level of data security will be ensured.

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FUNDED BY Bundesministerium für Bildung und Forschung

Fatigue strength properties of SLM components

The impact of process-induced defects, e.g. pores and residual stresses, is particularly strong in the case of cyclic loading. Regarding the porosity, the question arises to what extent these defects can be closed by a suitable post treatment. A promising method for this question could be the “hot isostatic pressing” process. It is conceivable that argon within the pores counteracts a downsizing. Regarding the residual stresses, one possible approach is to keep the temperature in the building chamber as close as possible to the melting temperature of the material. Of course this approach is restricted, so that a subsequent heat treatment is often applied. By an appropriate heat treatment effects are observed with respect to microstructure and residual stresses. These mechanisms and their effects on the mechanical properties of SLM components are described and discussed in the present study.

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

CHAIR OF MATERIAL SCIENCE (LWK)

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 Material 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.

ADDITIONAL EQUIPMENT OF THE CHAIR

- 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)
- Miniature Load Frame
- MiniCell System (Ibendorf)
- Optical / Stereo Microscopes (Axiophot, Zeiss & Olympus)
- Pendulum Impact Tester (PW 30-E, Otto Wolpert-Werke)
- Potentiostat (MLAb 100, Bank Electronik)
- Precision Cutting Machines

ADDITIONAL EQUIPMENT OF THE CHAIR

- 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))

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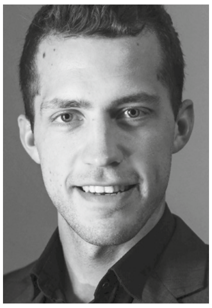

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CURRENT RESEARCH PROJECTS

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

In order to achieve the efficiency of conventionally produced components, the additively manufactured parts must at least meet the same requirements. Thus, the surface is functionalized to achieve a sufficient fatigue strength of the component-surface-system. Contrary to former research projects regarding a surface modification, neither the surface modification process nor the layer system is in the focus. Therefore, new fundamental studies are essential to determine the challenges of additive manufacturing, especially for metal powders, to enable a subsequent surface modification. The impact on the surface modification by residual stress and surface roughness, as known restrictions of selective laser melting (SLM®), is investigated and the dynamic properties of the overall system are observed.

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FUNDED BY Deutsche Forschungsgemeinschaft

Additive manufacturing of medium carbon steels and a CoCr-alloy

Medium carbon steels obtain a limited hot hardness, which is important for moulding or hot forming operations. Therefore, W360, a tool steel for applications with high toughness and hot hardness, is processed and characterized. Furthermore, the quenched and tempered steel 1.6773, which exhibits high toughness accompanied by high strength, is processed and analysed. Both steels possess medium carbon contents, which has not successfully been processed at larger diameters (>50 mm). Evolving residual stresses lead to cracks during fabrication. A promising approach is a modification of the scan-strategy combined with varying build platform temperatures.
Finally, the CoCr-alloy Stellite 6 is processed and analysed. This alloy possesses superior tribological and corrosion properties in aggressive conditions.

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FUNDED BY DMRC DIRECT MANUFACTURING RESEARCH CENTER

FINISHED RESEARCH PROJECTS 2015-2017

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

Nickel based superalloys like Inconel 718 (IN718) are widely used in high temperature applications. IN718 is a precipitation-hardened alloy that provides a good corrosion and oxidation resistance at high temperatures. Selective laser melting enables the production of dense metal parts direct from the sliced CAD files without any tooling operation. However, pores cannot be avoided even with adapted process parameters. In order to reduce the porosity, hot isostatic pressing is of interest. A promising approach to further improve the material properties is functional encapsulation using cathodic arc deposition. Therefore, the influence of both processes on the microstructural and mechanical properties at different temperatures under quasi-static as well as under cyclic load are investigated.

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Soft magnetic alloys for additive manufacturing of electric motors

In this study, two soft-magnetic materials, a FeSi alloy with a Si content of 2.9 wt% and a FeCo alloy having a Co content of 50 wt%, were selected for processing with selective laser melting (SLM). In the electrical industry, both alloys are widely used as sheet material due to their superior (electro-)mechanical and magnetic properties, especially the increased specific resistance, in particular regarding the FeSi alloys. The conventional production methods of electrical steel sheets have been extensively researched and optimized in terms of cost-effectiveness. Therefore, new production techniques have to be taken into account for new lightweight designs and to increase the efficiency of motor components, e.g., rotors.

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FUNDED BY FVA Forschungsvereinigung Antriebstechnik e.V.

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

Additive layer manufacturing processes like selective laser melting (SLM) are well suited for the fabrication of complex cellular structures for lightweight applications. This is due to their high geometrical freedom and flexibility in comparison to conventional manufacturing processes. In this context, design adaptations concerning the loading conditions for additional weight reduction play a key role in today's research. In order to exploit these potentials, it is mandatory to understand the characteristics and mechanical behaviour of such lattice structures under static and dynamic load. This research addressed the deformation behaviour of two different lattice structures produced by SLM from Ti6Al4V and the stainless steel 316L.

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

One of the main advantages of selective laser melting is the possibility to manufacture complex geometries and highly customized parts. In this project, this approach was applied to produce moulds which are used for the production of polymer parts. The main materials challenge in this case is the achievement of sufficient corrosion resistance of the alloy. For standard Fe-alloys, literature provides information of passivity and breakdown of passivity. However, such studies do not include laser molten Fe-alloys. For alloys processed by powder based additive manufacturing techniques no information regarding the influence of microstructure, distribution of alloying and intermetallic phases on the corrosion process is given. Thus it was investigated in which way such materials interact with the electrolytes.

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High Temperature Processing of Metallic SLM Powders

The aim of this project is to reduce the high residual stresses and the shrinking of the material caused by the high cooling rate during the building process. The high cooling rate leads to crack formation during the building process. In this project, a heated building platform reduces the temperature gradient, which leads to different microstructural changes that allow these materials to become processable using additive manufacturing.

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FUNDED BY DMRC DIRECT MANUFACTURING RESEARCH CENTER

PARTICLE TECHNOLOGY GROUP (PVT)

> In Laser Sintering a detailed understanding of particle properties and particulate interface characteristics is decisive for processability as well as final part properties.
>
> Prof. Dr.-Ing. Hans-Joachim Schmid

INTRODUCTION

Particle technology is a specialization in Process Engineering. We investigate the properties of particulate systems, the production, conditioning and manipulation of 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'. Particularly, if particles become smaller and smaller particle-particle interactions become dominant for the behavior of such systems.

The Particle Technology Group is involved in both 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 cooperation's with companies on very specific projects, to develop solutions in the field of particle technology. The Particle Technology Chair performs research and offers expertise in the following fields:

- Particle synthesis
- Aerosol particle formation
- Characterization of particles and dispersed systems
- Selected 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

Dispersion

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

Interfacial properties

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

Material properties

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

Particle size analysis

- Laser Diffraction Spectrometer - Malvern Mastersizer 2000 and Sympatec Helos Vario F

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
- Sieve analysis
- Sedimentation Balance
- Scanning Mobility Particle Sizer (SMPS) - TSI
- Goniometer (Combined Static-Dynamic Light Scattering) – ALV-GmbH – ALV/CGS3

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

Crushing
- Cutting Mill - Retsch SM2000
- Stone Mill - Fritsch Pulverisette
- Stirring Ball Mill - Netzsch LabStar

Software
- Labview
- Origin
- Pasival
- Itasca PFC 3D

Other
- Laboratory Extruder - Dr. Collin Teach Line E 20 T
- Particle Image Velocimetry (PIV)One-Shot 3D Measuring Macroscope - VR-3100, Keyence
- Dust-Free Work Bench - Weiss GWE WIBObarrier Vertical
- Vacuum Drying Oven - Heraeus vaccum oven

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CURRENT RESEARCH PROJECTS

Efficient and Interconnected Product and Production Development for Aircraft Passenger Cabins – VERONIKA Sub-project: Additive Lightweight Structures for the Aircraft Cabins

The DMRC work package is part of the VERONIKA project, which aims 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. A study on AM processes and material for aircraft industries was created. Based on a case study several parts or assemblies have been selected and will be optimized for lightweight, function and assembly integration and change in material. Finally, demonstrator parts are build and verified based on performance requirements as well as cost, time and quality.

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FUNDED BY Bundesministerium für Wirtschaft und Energie

PA613: LS Polyamide for High Temperature Applications

The availability of high performance laser sinter materials is still limited to mainly polyamide 11 and polyamide 12 powder. However, these materials do not match the requirements of some advanced applications. For example in the electronics or automotive industry, higher material strengths and temperature resistance are required. Finding robust process parameters and specify its powder and SLS manufactured part properties for – PA613, delivered by Evonik – are the objections of this project. Since the material can be processed on regular “low temperature” LS systems like EOS P39x machines, PA613 material promises a great increase of application fields using already industrially established machine types. The overall aim is to find optimal processing parameters, possible limits of manufacturing as well as advanced part properties.

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FUNDED BY DMRC DIRECT MANUFACTURING RESEARCH CENTER

QuLS: Qualification of Laser Sintering Serial Production

The superior motivation of the project is to enhance laser sintering (LS) more and more for serial production processes. In serial production the AM technologies are still rarely used. One reasons are given by a lack of quality standards, as well as no methodological approach to assess parts for serial production. The overall aim of this project is to develop a guideline for the qualification procedure of serial part production by laser sintering and a catalog of measures along the process chain to achieve high quality and reproducibility properties of LS parts. This guideline shall be tested and evaluated within the scope of an inter laboratory test.

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FUNDED BY
DMRC
DIRECT MANUFACTURING RESEARCH CENTER

Additive Manufacturing of polymer-based parts for drive components

Together with the Research Association for Drive Technology - Forschungsvereinigung Antriebstechnik e.V. (FVA) - the DMRC will investigate new potentials of additive manufacturing in drive technology. Therefore, polymer AM technologies and a variation of materials shall be considered and assessed. A literature review, in form of a study on polymer AM technologies and polymer materials from an economic and scientific point of view, is the first part of the objective for this project. Additionally the performance limits of additive manufactured polymer-based parts shall be revealed by investigations of e.g. mechanical und tribological properties.

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FUNDED BY
FVA
Forschungsvereinigung Antriebstechnik e.V.

FINISHED RESEARCH PROJECTS 2015-2017

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

Insufficient surface quality, e.g. stair case effect, etc., is one of the most pregnant issues of AM parts. This project analyses the effects and propose countermeasures for polymer laser sintered parts. The surface quality in dependence to variations of manufacturing process parameters are investigated to identify the most relevant parameters. Furthermore, subjective haptic impressions are considered and correlated to objective values. The build orientation as a main influencing factor is considered with a newly built tool to predefine the optimal orientation for good surface quality of functional areas. As well as a variety of post-processing methods are examined and assessed on their potential.

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FUNDED BY DMRC DIRECT MANUFACTURING RESEARCH CENTER

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

Materials for laser sintering process are still rare and in focus of current research. Standard material Polyamide 12 is well known in terms of material characteristics, laser sintering process and resulting part properties. Furthermore, it is applicable in a broad amount of technical cases. However, Polyamide 12 is only one of numerous technical polymers and the here investigated TPE-A material supplements the material database of laser sintering. TPE-A is a thermoplastic elastomer, having elastic and simultaneously thermoplastic properties. This way it is possible to use TPE-A for the laser sintering process, realizing new applications like for seals, bellows and shoe soles. Determining part and material properties of EOS's PrimePart ST, a PEBA (polyamide-based TPE) is the objective of this project.

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FUNDED BY Bundesministerium für Wirtschaft und Energie

D-TAM: Dimensional tolerances for additive manufacturing

Within this project Dimensional tolerances has been systematically determined that can be stated if additive manufacturing is used under normal workshop conditions. Normal workshop conditions describe the application of often used and established standard parameters, materials and machine settings.

2. Objective: Relevant process parameters and manufacturing influences are investigated in order to define measures that minimized dimensional deviations.

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FUNDED BY

DMRC
DIRECT MANUFACTURING RESEARCH CENTER

New Member

DATABASE AND INFORMATION SYSTEMS (DBIS)

> To ensure that tomorrow's innovative software systems meet user requirements, we research model-based development and quality assurance methods that are precise and practical.
>
> Prof. Dr. Gregor Engels

INTRODUCTION

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

The spectrum of our research ranges from the formal basis of visual and domain-specific modelling languages to analytical approaches for quality assurance of models and software and their practical application in current technology areas such as web services, software product lines, socio-technical systems, and service-oriented architectures. Based on established industry standards such as UML, SysML, and XML, we develop modelling techniques, concepts and methods for future software generations. By analysing models with formal techniques, we can detect, visualize and correct errors early on.

Our development tools thus provide an active contribution for quality improvement in software development. Following a holistic approach of quality software engineering, we link model-based and generative software development with requirements engineering and management, domain modelling, human-centred design methods, software architecture management and evolution, adaptive systems technology, data analytics and quality models. Within the collaboration of the DMRC, we are expanding the cooperation between mechanical engineering and informatics. By applying the methods for analysis and modelling of problems, the processes in additive manufacturing can be further optimized.

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Publications

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BOOKS AND JOURNALS

Herstellbarkeit und mechanische Charakterisierung von lasergesinterten Gitterstrukturen

AUTHOR D. Menge, S. Josupeit, H.J. Schmid

PUBLISHED IN 2017, Additive Fertigung von Bauteilen und Strukturen, Springer Verlag, 105-120

Entwicklung von Fahrradtretkurbelsystemen mittels additiver Fertigung

AUTHOR J.-P. Brüggemann, L. Risse, A. Riemer, W. Reschetnik, G. Kullmer, H.A. Richard

PUBLISHED IN 2017, Additive Fertigung von Bauteilen und Strukturen

Universelle Mikrobearbeitungsplaffform und Basistechnologien für das Fertigen und Markieren mikrophysiologischer Systeme

AUTHOR K. Günther, E. Moritzer, A. Hirsch, S. Teutoburg-Weiss, A. F. Lasagni, U. Klotzbach, F. Sonntag

PUBLISHED IN 2017, 6. Dresdner Medizintechnik-Symposium, Biomedizinische Technik - interdisziplinär, integrativ und innovativ, Dresden, 65-70

Beurteilung der Schweißnahtfestigkeiten verschiedener Kunststoffe im FDM-Prozess

AUTHOR V. Schöppner, C. Schumacher, J. Guntermann

PUBLISHED IN 2017, Jahresmagazin Kunststofftechnik, 108-114

Holistic approach for industrializing AM technology - from part selection to test and verification

AUTHOR T. Reiher, C. Lindemann, U. Jahnke, G. Deppe, R. Koch

PUBLISHED IN 2017, Progress in Additive Manufacturing, Heidelberg, 43-55

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AUTHOR G. Deppe, C. Lindemann

PUBLISHED IN 2017, CECIMO Magazine, Brussels

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AUTHOR A. Riemer, H.A. Richard

PUBLISHED IN 2016, Procedia Structural Integrity: Catania, 1229-1236

Fatigue crack growth behavior and mechanical properties of additively processed EN AW-7075 aluminium alloy

AUTHOR W. Reschetnik, J.-P. Brüggemann, M.E. Aydinöz, O. Grydin, K.-P. Hoyer, G. Kullmer, H.A. Richard

PUBLISHED IN 2016, Procedia Structural Integrity, 3040-3048

Modelling of temperatures and heat flow within laser sintered part cakes

AUTHOR S. Josupeit, L. Ordia, H.J. Schmid

PUBLISHED IN 2016, Additive Manufacturing

Neue Prototypen-Werkzeugtechnologie für Bipolarplatten und Batteriekomponenten

AUTHOR T. Hickmann, D. Ahlers, N. Fulland

PUBLISHED IN 2016, Der Stahlformenbauer: Velbert

On the microstuctural and mechanical properties of post-treated additively manufactured Inconel 718 superalloy under quasi-static and cylic loading

AUTHOR M.E. Aydinöz, F. Brenne, M. Schaper, C. Schaake, W. Tillmann, J. Nellesen, T. Niendorf

PUBLISHED IN 2016, Material Science and Engineering A , 246-258

Optimized build orientation of additive manufactured parts for improved surface quality and build time

AUTHOR P. Delfs, M. Tows, H.J. Schmid

PUBLISHED IN 2016, Additive Manufacturing

Process Gas Infiltration in Inconel 718 Samples during SLM Processing

AUTHOR C. Schaak, W. Tillmann, M. Schaper, M.E. Aydinöz

PUBLISHED IN 2016, Rte Journal - Forum für Rapid Technologie

Scenario Based Outlook of Additive Manufacturing Applications for the Aerospace Market

AUTHOR C. Lindemann, G. Deppe, R. Koch

PUBLISHED IN 2016, Digital Manufacturing - Prospects and Challenges: Weimar

Einfluss von Werkstoff, Prozessführung und Wärmebehandlung auf das bruchmechanische Verhalten von Laserstrahl-schmelzbauteilen

AUTHOR A. Riemer

PUBLISHED IN 2015, Shaker Verlag: Paderborn

Prozessqualifizierung zur verlässlichen Herstellung von Produkten im Polymer Lasersinterverfahren

AUTHOR S. Rüsenberg

PUBLISHED IN 2015, Shaker Verlag: Paderborn

Systematische Erarbeitung von Konstruktionsregeln für die additiven Fertigungsverfahren Lasersintern, Laserschmelzen und Fused Deposition Modeling

AUTHOR G. Adam

PUBLISHED IN 2015, Shaker Verlag: Paderborn

Temperature History within Laser Sintered Part Cakes and it's Influence on Process Quality

AUTHOR S. Josupeit, H.J. Schmid

PUBLISHED IN 2016, Rapid Prototyping Journal, p. 788-793

Duplex stainless steel fabricated by selective laser melting - Microstructural and mechanical properties

AUTHOR F. Hengsbach, P. Koppa, K. Duschik, M.J. Holzweissig, M. Burns, J. Nellesen, W. Tillmann, T. Tröster, K.-P. Hoyer; M. Schaper.

PUBLISHED IN 2017, Materials & Design 133, p. 136-142

Numerische und mechanische Untersuchung additiv gefertigter TiAl6V4 Gitterstrukturen

AUTHOR Taube, A.; Reschetnik, W.; Pauli, L.; Hoyer, K.-P.; Kullmer, G.; Schaper, M.

PUBLISHED IN 2017, Additive Fertigung von Bauteilen und Strukturen

CONFERENCE PROCEEDINGS

AREAL SURFACE CHARACTERIZATION OF LASER SINTERED PARTS FOR VARIOUS PROCESS PARAMETERS

AUTHOR P. Delfs, H.J. Schmid

PUBLISHED IN 2017, 28th Annual International Solid Freeform Fabrication Symposium, Austin, 2624-2631

Betriebssichere Auslegung einer lasergeschmolzenen Fünfstern-Tretkurbel

AUTHOR D. Menge, S. Josupeit, H.J. Schmid

PUBLISHED IN 2017, Rapid Tech - International Trade Show & Conference for Additive Manufacturing, Erfurt, 94-107

Bruchmechanische Charakterisierung von laserstrahlgeschmolzenen Werkstoffen

AUTHOR W. Reschetnik, J.-P. Brüggemann, Kullmer, H.A. Richard

PUBLISHED IN 2017, DVM Tagung - Additiv gefertigte Bauteile und Strukturen, Berlin, 147-156

Computer integration for geometry generation for product optimization with Additive Manufacturing

AUTHOR T. Reiher; S. Vogelsang; R. Koch:

PUBLISHED IN 2017, 28th Annual International Solid Freeform Fabrication Symposium, Austin

Considering Machine- and Process-Specific Influences to Create Custom-Built Specimens for the Fused Deposition Modeling Process

AUTHOR V. Schöppner, C. Schumacher, J. Guntermann

PUBLISHED IN 2017, 28th Annual International Solid Freeform Fabrication Symposium, Austin

Crack length measurement of additive manufactured plastics based on the current potential drop method.

AUTHOR B. Bauer, W. Reschetnik, G. Kullmer, H.A. Richard

PUBLISHED IN 2017, Symposium on Fatigue and Fracture of Additive Manufactured Materials and Components, Atlanta

Entwicklung einer additiv gefertigten Fußorthese

AUTHOR J.-P. Brüggemann, L. Risse, B. Schramm, H.A. Richard

PUBLISHED IN 2017, Rapid Tech - International Trade Show & Conference for Additive Manufacturing, Erfurt, 26-37

Entwicklung und additive Herstellung einer Leichtbau-Rotorwelle für eine permanentmagneterregte Synchronmaschine

AUTHOR	S. Lammers, F. Quattrone, R. Mrozek, D. Zimmer, H. Schmid, B. Ponick, M.J. Hoffmann
PUBLISHED IN	2017, Proceedings of Rapid Tech 2017, Erfurt

Geometrical Accuracy of Holes and Cylinders Manufactured with Fused Deposition Modeling

AUTHOR	F. Knoop, V. Schoeppner
PUBLISHED IN	2017, 28th Annual International Solid Freeform Fabrication Symposium, Austin, 2757-2776

Konzepte zur Risslängenmessung an additive gefertigten Kunststoffen

AUTHOR	B. Bauer, W. Reschetnik, G. Kullmer, H.A. Richard
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Maßtoleranzen für die additive Fertigung: Experimentelle Untersuchungen für das Lasersintern

AUTHOR	T. Lieneke, G.A.O. Adam, S. Josupeit, P. Delfs, D. Zimmer
PUBLISHED IN	2017, Proceedings of the Rapid Tech 2017, Erfurt

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AUTHOR	B. Bauer, W. Reschetnik, G. Kullmer, H.A. Richard
PUBLISHED IN	2017, 14th International Conference on Fracture, Rhodos

Optimierung des Operationsablaufs durch präoperative CAD-gestützte Planung und additiven Fertigung

AUTHOR	L. Risse, B. Schramm, G. Kullmer, H.A. Richard
PUBLISHED IN	2017, DVM Tagung - Additiv gefertigte Bauteile und Strukturen, Berlin, 67-76

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Quality Improvement of FDM Parts by Parameter Optimization

AUTHOR	F. Knoop, A. Kloke, V. Schoeppner
PUBLISHED IN	2017, AIP Conference Proceedings, Vol. 1914, Iss. 1

Rational Decision-Making for the Beneficial Application of Additive Manufacturing

AUTHOR G. Deppe, R. Koch

PUBLISHED IN 2017, 28th Annual International Solid Freeform Fabrication Symposium, Austin

Reproduzierbarkeit der Maßhaltigkeit im Fused Deposition Modeling

AUTHOR F. Knoop, T. Lieneke, V. Schoeppner

PUBLISHED IN 2017, Rapid Tech 2017, Erfurt

Risslängenmessung in additiv gefertigten Kunststoffproben auf Basis von Steifigkeitsänderungen infolge Ermüdungswachstum.

AUTHOR B. Bauer, W. Reschetnik, G. Kullmer, H.A. Richard

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Strukturoptimierung von Kurzschaft-Hüftendoprothesen durch den Einsatz der additiven Fertigung

AUTHOR L. Risse, J.-P. Brüggemann, B. Schramm, G. Kullmer, H.A. Richard

PUBLISHED IN 2017, VM Tagung - Zuverlässigkeit von Implataten und Biostrukturen, Berlin

Universelle Mikrobearbeitungsplaffform und Basistechnologien für das Fertigen und Markieren mikrophysiologischer Systeme

AUTHOR K. Günther, E. Moritzer, A. Hirsch, S. Teutoburg-Weiss, A. F. Lasagni, U. Klotzbach, F. Sonntag

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Vergleich zweier Optimierungsstrategien am Beispiel additiv gefertigter Rennradvorbauten

AUTHOR J.-P. Brüggemann, L. Risse, H.A. Richard, G.Kullmer

PUBLISHED IN 2017, DVM Tagung - Additiv gefertigte Bauteile und Strukturen, Berlin, 49-66

Additive Fertigung in der Medizintechnik - Überlick und Beispiele -

AUTHOR B. Schramm, J.-P. Brüggemann, A. Riemer, H.A. Richard

PUBLISHED IN 2016, DVM Conference - Additively manufactured components and structures: Berlin, 21-30

Chemical Surface Treatment of Ultem 9085 Parts

AUTHOR M. Fischer, O. Seewald, V. Schoeppner

PUBLISHED IN 2016, Rapid Tech - International Trade Show & Conference for Additive Manufacturing: Erfurt, 121-132

Combining material efficiency and part reliability by product optimization applying additive manufacturing

AUTHOR T. Reiher, G. Deppe, R. Koch

PUBLISHED IN 2016, International Conference Production Engineering and Management 2016: Lemgo, 27-38

Data Management for additive manufacturing: survey on requirements and current state

AUTHOR I. Gräßler, P. Taplick, J. Pottebaum, P. Scholle, T. Reiher

PUBLISHED IN 2016, 14th International DESIGN Conference 2016: Dubrovnik,

Dimensional accuracy of polymer laser sintered parts: Influences and measures

AUTHOR S. Josupeit, P. Delfs, T. Lieneke, G. Adam, H.J. Schmid

PUBLISHED IN 2016, Rapid Tech - International Trade Show & Conference for Additive Manufacturing: Erfurt, 107-120

Dimensional tolerances for additive manufacturing: Experimental investigation for Fused Deposition Modeling

AUTHOR T. Lieneke, V. Denzer, G.A.O. Adam, D. Zimmer

PUBLISHED IN 2016, CAT 2016: Gothenburg,

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AUTHOR T. Lieneke, S. de Groot, G. Adam, D. Zimmer

PUBLISHED IN 2016, ASPE 2016 Summer Topical Meeting: Raleigh, S.9-15

Extended Analysis of the Surface Topography of Laser Sintered Polymer Parts

AUTHOR P. Delfs, H.J. Schmid

PUBLISHED IN 2016, Fraunhofer Direct Digital Manufacturing Conference: Berlin,

Festigkeits- und leichtbauoptimierte Konstruktion und Auslegung eines additiv gefertigten Fahrradvorbaus

AUTHOR J.-P. Brüggemann, W. Reschetnik, H.A. Richard, G. Kullmer, B. Schramm

PUBLISHED IN 2016, Rapid Tech - International Trade Show & Conference for Additive Manufacturing: Erfurt, 290-300

Herstellbarkeit und mechanische Charakterisierung von lasergesinterten Gitterstrukturen

AUTHOR S. Josupeit, P. Delfs, D. Menge, H.-J. Schmid

PUBLISHED IN 2016, 1. DVM-Tagung “Additiv gefertigte Bauteile und Strukturen: Berlin, 55-61

IN 718 processed by selective laser melting: Effect of precipitation hardening and hot isostatic pressing on the low-cycle fatigue behavior at 650°C

AUTHOR M.E. Aydinöz, C. Schaak, F. Hengsbach, K.-P. Hoyer, T. Niendorf, W. Tillmann, M. Schaper

PUBLISHED IN 2016, DVM Conference - Additively manufactured components and structures: Berlin, 141-150

Lebensdauerbeeinflussung durch Additive Fertigung

AUTHOR W. Reschetnik, J.-P. Brüggemann, M.E. Aydinöz, G. Kullmer, H.A. Richard, M. Schaper

PUBLISHED IN 2016, DVM Tagung - Additiv gefertigte Bauteile und Strukturen: Berlin, 131-140

Manufacturability and Mechanical Characterization of Laser Sintered Lattice Structures

AUTHOR S. Josupeit, P. Delfs, D. Menge, H.J. Schmid

PUBLISHED IN 2016, 27th Annual International Solid Freeform Fabrication Symposium: Austin, 2077-2086

Materialkennwerte lasergeschmolzener Werkstoffe

AUTHOR A. Riemer, L. Leuders, G. Kullmer, H.A. Richard

PUBLISHED IN 2016, DVM Tagung - Additiv gefertigte Bauteile und Strukturen: Berlin, 161-174

Optimierung von Fahrradtretkurbeln mittels additiver Fertigung

AUTHOR J.-P. Brüggemann, A. Riemer, W. Reschetnik, M.E. Aydinöz, G. Kullmer, H.A. Richard, M. Schaper

PUBLISHED IN 2016, DVM Tagung - Additiv gefertigte Bauteile und Strukturen: Berlin, 101-112

Product optimization with and for Additive Manufacturing

AUTHOR T. Reiher, R. Koch

PUBLISHED IN 2016, 27th Annual International Solid Freeform Fabrication Symposium: Austin,

Reproducibility of the Dimensional Accuracy - Investigations for FDM

AUTHOR F. Knoop, T. Lieneke, V. Schoeppner

PUBLISHED IN 2016, ASPE Spring Topical Meeting: Raleigh, S.3-8

Supporting the Decision Process for applying Additive Manufacturing in the MRO Aerospace Business by MADM

AUTHOR	G.Deppe, R. Koch
PUBLISHED IN	2016, 27th Annual International Solid Freeform Fabrication Symposium Proceedings: Austin,

Thermal properties of polyamide 12 powder for application in laser sintering

AUTHOR	S. Josupeit, H.J. Schmid
PUBLISHED IN	2016, International Congress on Particle Technology (PARTEC): Nuremberg,

Unterstützung des AM Entscheidungsprozesses in der Luftfahrtersatzteilversorgung

AUTHOR	G. Deppe, R. Koch
PUBLISHED IN	2016, Rapid Tech 2016: Erfurt,

Additiv gefertigte Strukturen unter zyklischer Belastung - Einfluss von Prozessparametern und Nachbehandlungen auf die Eigenschaften

AUTHOR	J. Günther, F. Brenne, M. E. Aydinöz, S. Leuders, A. Riemer, T. Niendorf
PUBLISHED IN	2015, Werkstoffwoche

Analysis and Optimization of the Dimensional Accuracy for FDM Parts manufactured with ABS-M30

AUTHOR	F. Knoop, V. Schoeppner
PUBLISHED IN	2015, ASPE Spring Topical Meeting: Raleigh, 26-31

Developement of an economic decision support for the application of Additive Manufacturing in aerospace

AUTHOR	G. Deppe, C. Lindemann, R. Koch
PUBLISHED IN	2015, 26th Annual International Solid Freeform Fabrication Symposium: Austin, 1560-1563

Einsatz additiver Fertigung zur Optimierung des Ermüdungsverhaltens von gekerbten Strukturen

AUTHOR	W. Reschetnik, A. Riemer, H.A. Richard
PUBLISHED IN	2015, DVM-Arbeitskreis Bruchvorgänge: Freiberg, 63-72

Entwicklung einer Methode zur systematischen Erarbeitung von Maßtoleranzen für additive Fertigungsverfahren

AUTHOR	T. Lieneke, G.A.O. Adam, S. Leuders, F. Knoop, S. Josupeit, P. Delfs, N. Funke, D. Zimmer
PUBLISHED IN	2015, Proceedings of the Rapid Tech 2015: Erfurt

Exploring the cost and lifetime benefits of a topology optimized aerospace part applying additive manufacturing

AUTHOR G. Deppe, T. Reiher, R. Koch

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