Direct Manufacturing Research Center

Annual Report 2015

DMRC
DIRECT MANUFACTURING RESEARCH CENTER

Direct Manufacturing Research Center

Annual Report 2015

Imprint

Scientific Director
Prof. Dr.-Ing. Hans-Joachim Schmid
Particle Technology Group
Faculty of Mechanical Engineering
University of Paderborn, Germany
Phone: +49/5251/602404
Fax: +49/5251/603207
E-Mail: hans-joachim.schmid@upb.de
Web: http://www.mb.upb.de/pvt/

Business Director
Dr.-Ing. Eric Klemp
University of Paderborn, Germany
Direct Manufacturing Research Center (DMRC)
Phone +49/5251/605415
Fax: +49/5251/605409
E-Mail: eric.klemp@dmrc.de

By Order of
University of Paderborn, Germany
Direct Manufacturing Research Center (DMRC)
Mersinweg 3
33098 Paderborn
Web: http://www.dmrc.de

Layout
PADA Werbeagentur
pada-werbeagentur@t-online.de

Photos

Photos Equipment
Marc Kröger
Filmemacher und Fotograf
www.marckroeger.de

Other Photos: Universität Paderborn

We gratefully thank our Partners:

BAKER HUGHES

bp blue production

BOEING

EISENHUTH

eos

EVONIK INDUSTRIES

H&H INNOVATION
H&H SMART PRODUCTS

JOHN DEERE

KRAUSE DiMaTec

LIEBHERR

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

Parker

PHŒNIX CONTACT

rembe

SIEMENS

SLM Solutions GmbH

stratasys

SAC FS Stükerjürgen

The **LEGO** Group

UNIVERSITÄT PADERBORN
Die Universität der Informationsgesellschaft

Table of Contents

Table of Contents

1 Preface


Prof. Dr.-Ing. Hans-Joachim Schmid


Dr.-Ing. Eric Klemp

Dear Reader!

we are proud to present the fourth sequel of our annual Direct Manufacturing Research Center (DMRC) report. The DMRC has been running for seven years – ever since we made tremendous progress in our goal to advance Additive Manufacturing (AM) to Direct Manufacturing (DM). Also, we take great pride in our worldwide visibility.

This report will provide a comprehensive overview of the DMRC, the current research projects in our consortium and our participation in publicly funded projects. It is a concise summary of our scientific output and the topics we addressed in 2015. Our activities are supposed to generate benfit for our partners in industry, the University of Paderborn and the AM community. We endeavor to find the potentials of AM and provide them to our stakeholders in industry and academia.

In the pursuit of our goal, we never get tired of emphasizing the importance of interdisciplinarity, that is the joint research of various Engineering chairs at the University of Paderborn. Additionally, the DMRC takes advantage of the knowhow of our industrial partners. The DMRC's integration within the university and industry makes it possible for students of Engineering Sciences to be trained in a state of the art environment in industry-relevant projects. In doing so, we cover the entire AM-value chain allowing for a holistic approach in finding technical solutions. Meanwhile we have gathered 18 industrial partners to participate in the research of DMRC – overall we have conducted well above 40 projects. Meanwhile we host nearly 30 researchers from 9 different chairs of University together with 12 professors.

This year we welcomed new partners like John Deere, Krause DiMaTec, Rembe and Parker. It makes us very happy to see the DMRC prosper and receiving the feedback of being on the right way: Obviously, we are attractive to be joined in our activities and research!

Besides, we are well aware of our obligation in educating the next generations of engineers: During the summer-semester of 2015 more than 100 students attended our lecture Additive Manufacturing. This lecture conveys deeper knowledge of AM related topics – in doing so we remain faithful in the principle of interdisciplinarity. Students may choose 3 from 7 AM related topics like Material Science, Plastics Engineering, Design and e.g. Particle Process Engineering. We are convinced; the students receive a high-quality education by this model. In addition we had more than 100 students writing seminar papers or final studies about AM. Last but not least, the aim of the researchers at DMRC is to earn their PhDs. This year, five researchers ended their doctoral studies: Guido Adam, Agnes Kloke (Bagsik), Andre Riemer, Stefan Rüsenberg and Marina Wall.

Besides internal and interdisciplinary industrial driven projects, we more and more extend our funding base: For instance, we began to launch international projects with the European Commission (RP7 and Horizon 2020) and the European Space Agency (ESA). Also, we increase our activities in German projects funded by BMBF, BMWi, DFG, DBU and ZIM. We consider this both, a chance to obtain additional funding, but also to provide knowhow to the public and improving the technology. Other than that, we are involved in regional projects within the "Spitzencluster It's OWL".

In 2015 we participated in the most important events, like RapidTech or the Inside 3D printing and we will be visible with our partners at Formnext in Frankfurt. We are proud be repeatedly asked to display our scientific results in international conferences as e.g. at SFF in Austin and to have publications in journals – see publication list at the end of this report. We are also involved in organisations like ASTM, DIN, VDI, VDMA and NMWP.

We are totally convinced, the DMRC will maintain its leading role in the AM community and we will do our very best to improve the AM process towards reliable and smart parts, provide solutions along the value chain and to improve ourself as an institute along the way.

So we are looking very forward to our 8th year and would be very happy to have you cooperating with us, in the one or the other way. There are many opportunities, you are gratefully invited to join us on our way.

Kind regards

Dr.-Ing. Eric Klemp

Prof. Dr-Ing. Hans Joachim Schmid

2 Direct Manufacturing Research Center

The model of the DMRC

The DMRC is a multi-stakeholder organization. Its organizational and contentual setup can be derived from the picture on the next page. The DMRC is founded on five contentual pillars, Laser Sintering, Laser Melting, Fused Deposition Modeling, Design and Business. Its obvious: We pay attention to the entire process from thinking ahead products of tomorrow to laying the foundations for their manufacturing. In doing so we work closely to the technology and to business. From a research perspective, we support the contentual pillars by nine chairs. Each chair conducts research projects within one or more of these pillars – the dots in the illustration show the main activities of each chair.

We draw our funding from both, public and industrial sources. Companies supporting us, called partners, can initiate (research) projects. For our partners, three different partnership models are available – essentially differing in the annual payment and voting power. As our projects are publicly and privatly funded, we maintain a balance of interests in the diverse field of Additive Manufacturing. It is also worth pointing out the importance of the DMRC as a communication platform for all of our stakeholders. Thereby, we quickly leverage contacts and initiate projects. Eventually our success boils down to a simple recipe: Talented staff, engagement of professors, superb equipment and powerful partners. In our annual report we present the projects being performed under the funding conditions.

Motivation

We note a significant progress in the field of Additive Manufacturing: the technology is gradually permeating various markets and triggers major upheavals reshaping supply chains and business models today and in the future. Many industries seek opportunities to capitalize on the benefits Additive Manufacturing provides. Also traditionally hesitant industries shift their attention towards AM. This already dynamic development is fueled further by globally dispersed research initiatives funded by different governments – they spark new impulses in the research landscape. Established and newly founded research centers are continuously striving to close gaps in the research landscape and to transfer their output to tangible outcomes for the industry. However, we believe that we as a global research community still have a long way to go to tap the full potential of Additive Manufacturing.

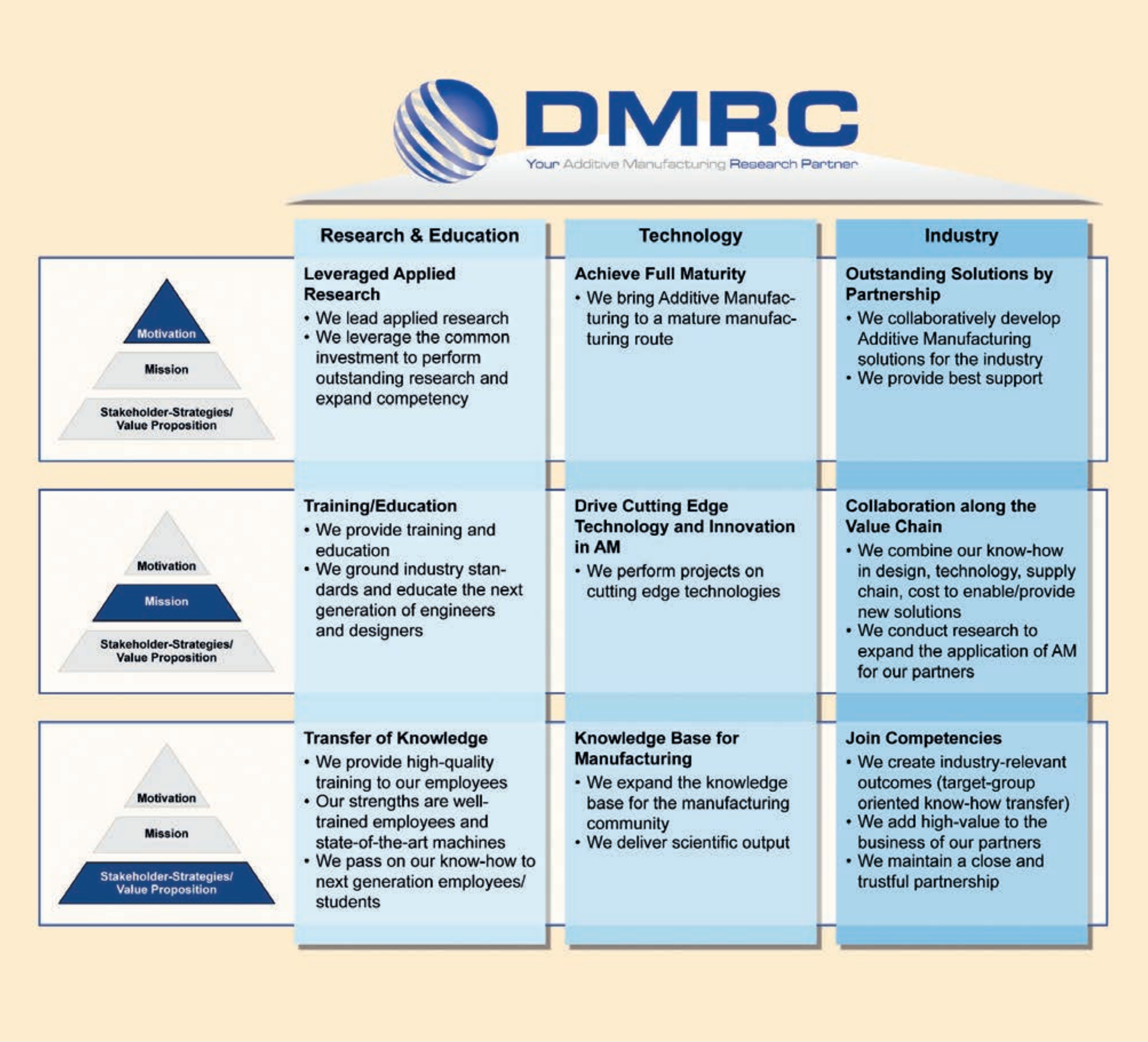
The DMRC wants to lead applied research in Additive Manufacturing and actively brings Additive Manufacturing to a mature manufacturing route. Consequently, we strive to provide outstanding solutions by partnerships along the whole value chain of Additive Manufacturing. We want to leverage the investment of all parties by performing research projects with the utmost benefit for potential users and continuously expand our competences.

Direct Manufacturing Research Center

	Sintering	Melting	FDM	Design	Business
c.l.k.	●	●		●	●
FAM		●			
HEINZ NIXDORF INSTITUT UNIVERSITÄT PADERBORN					●
University of Paderborn Design and Drive Technology KAt	●	●	●	●	
KTP			●		
LiA		●		●	
LWK		●			
PVT	●				
TMC		●			

Mission

We strive to be one of the leading institutes in Additive Manufacturing. To achieve this, we have to drive cutting edge technology and innovation in Additive Manufacturing. Therefore, we want to collaborate along the entire value chain, combining our know-how in design, technology, supply chain, costs etc. to enable and provide new solutions along the whole value chain. We combine basic and applied research to produce novel insights and to open doors for new possibilities enriching our partners' business. We are strongly committed to academic and industrial education with the goal to train the engineers of the future.



Research & Education	Technology	Industry
Leveraged Applied Research • We lead applied research • We leverage the common investment to perform outstanding research and expand competency	**Achieve Full Maturity** • We bring Additive Manufacturing to a mature manufacturing route	**Outstanding Solutions by Partnership** • We collaboratively develop Additive Manufacturing solutions for the industry • We provide best support
Training/Education • We provide training and education • We ground industry standards and educate the next generation of engineers and designers	**Drive Cutting Edge Technology and Innovation in AM** • We perform projects on cutting edge technologies	**Collaboration along the Value Chain** • We combine our know-how in design, technology, supply chain, cost to enable/provide new solutions • We conduct research to expand the application of AM for our partners
Transfer of Knowledge • We provide high-quality training to our employees • Our strengths are well-trained employees and state-of-the-art machines • We pass on our know-how to next generation employees/ students	**Knowledge Base for Manufacturing** • We expand the knowledge base for the manufacturing community • We deliver scientific output	**Join Competencies** • We create industry-relevant outcomes (target-group oriented know-how transfer) • We add high-value to the business of our partners • We maintain a close and trustful partnership

Stakeholder Value Proposition

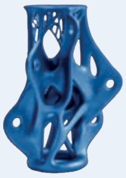
We are part of an interdisciplinary network. Various stakeholders expect us to create value according their respective needs and requirements; we want to harmonize the value creation in our strategic acting.
With regard to the technology itself, we create a knowledge base for manufacturing. Thereby, we serve the Additive Manufacturing community in general. For our partners, we transform our research output into tangible, industry-relevant outcomes. We generate impulses for interdisciplinary innovation and thus add value to the partners' business in a close and trustful partnership. Furthermore, we provide well-trained graduates for the industry.

The main benefits of Additive Manufacturing

The DMRC would not be where it is right now, if we did not believe in the power of Additive Manufacturing. For starters, we have collected the main benefits of the technology and outlined them briefly.

Description

Complex (Bionic) Structures



The main advantage of AM is its ability to produce parts with complex structures. As compared to subtractive manufacturing methods such as lathing, milling or forging, AM can produce parts with undercuts and holes. Conventional downstream manufacturing steps are often rendered needless. To harness the potential of complex structures, design engineers more and more draw on numerical optimization methods such as topology optimization to minimize material in parts. The results of these optimizations oftentimes resemble principles known from biology, hence the name bionic structures.

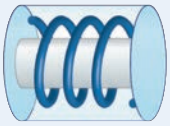
Functional Integration

With AM it is possible to pursue functional Integration during the manufacturing process. Functional Integration means building in one part, what formerly had to be built as separate parts. Thereby, downstream assembly steps can be eliminated if not significantly reduced. As of 2015 it is possible to integrate springs, joints, hinges and even pneumatic actors into one part. Potentials can naturally be sought in complex manufacturing lines with many assembly steps.

Lightweight Design

Lightweight Design is one of the core advantages of AM parts. Due to its capability to produce undercuts and holes, material can be cut where unnecessary. The technology has already proved to be a viable production technology in the aerospace industry. With regard to functional performance and strength, AM parts are on par with their substractive counterparts. While they are usually more expensive to manufacture, they yield high potential to reduce costs during operation (total cost of ownership). Potentials can naturally be sought in moving parts with many load cycles.

Conformal Cooling

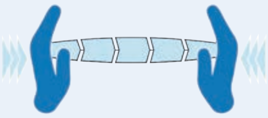


Conformal Cooling describes integrating cooling channels into areas which had formerly been inaccessible for e.g. drills. Thereby, heat can be transferred faster. Especially tools benefit from this advantage for they can be used in shorter cycles. For instance, injection moulds made by AM allow for a higher quality of the polymer part and also increase productivity.

Decentral Manufacturing

Decentral Manufacturing describes distributing the production to local production facilities as compared to centralized production facilities. Each small production facility is supplied with the material necessary to produce the required parts, as compared to distributing final parts. The material can be supplied in larger batches reducing emissions and local manufacturing units can specialize on e.g. regional product variants. Once large production capacities are required, an intelligent platform distributes build jobs according to a multiobjective optimization.

Reduce Time to Market



The mega-challenge „shorting product life cycles“ necessitates shorter development cycles. AM has proven to be a viable option in order to shorten development cycles. 1) As a Rapid Prototyping technology, it allows for faster design feedbacks and functional testing and 2) as a Direct Manufacturing technology it renders the production of tools unnecessary, therefore enabling a production directly from CAD file.

On the last pages we have outlined how the DMRC is structured, its strategic goals and what the main advantages of Additive Manufacturing are. In the following, we are going to briefly present some of the projects we have been running in 2015. If you are having specific questions, do not hesitate to contact the researchers directly.

3 Current Projects

Direct Manufacturing Design Rules 2.0

Guido Adam

As additive manufacturing processes create parts layer by layer without using formative tools, they have a great potential to provide new design freedoms to their users. To publish these freedoms and to support a suitable design for manufacturing, comprehensive design rules for additive manufacturing are required. Within the "Direct Manufacturing Design Rules" project (DMDR) design rules for additive manufacturing processes were developed. At the end of the DMDR project, the developed design rules applied only for the considered boundary conditions. Thus, the "Direct Manufacturing Design Rules 2.0" project has the aim to extend the range of validity for the developed design rules.

Design Rules given by the DMDR project

In order to develop design rules, standard elements were defined first. These are geometrical elements, which often reoccur by designing technical products. Based on these elements a process independent method for the development of design rules was set up. Using this method, design rules were developed for the laser sintering, laser melting and fused deposition modeling processes. Therefore the machines Eosint P395 (laser sintering), SLM 250HL (laser melting) and Fortus 400mc (fused deposition modeling) were used. For each machine one common parameter setting was considered with one material. So, for the laser sintering process the material PA2200, for the laser melting process stainless steel 316L and for the fused deposition modeling process Ultem were used.

How the material, the according parameter settings and the machine itself do influence the geometrical quality of the considered elements is unknown. Because of this, the developed design rules are only applicable for the described boundary conditions, which were considered within the DMDR project (Figure 1).

Objectives

In general, design rules for additive manufacturing technologies, which can

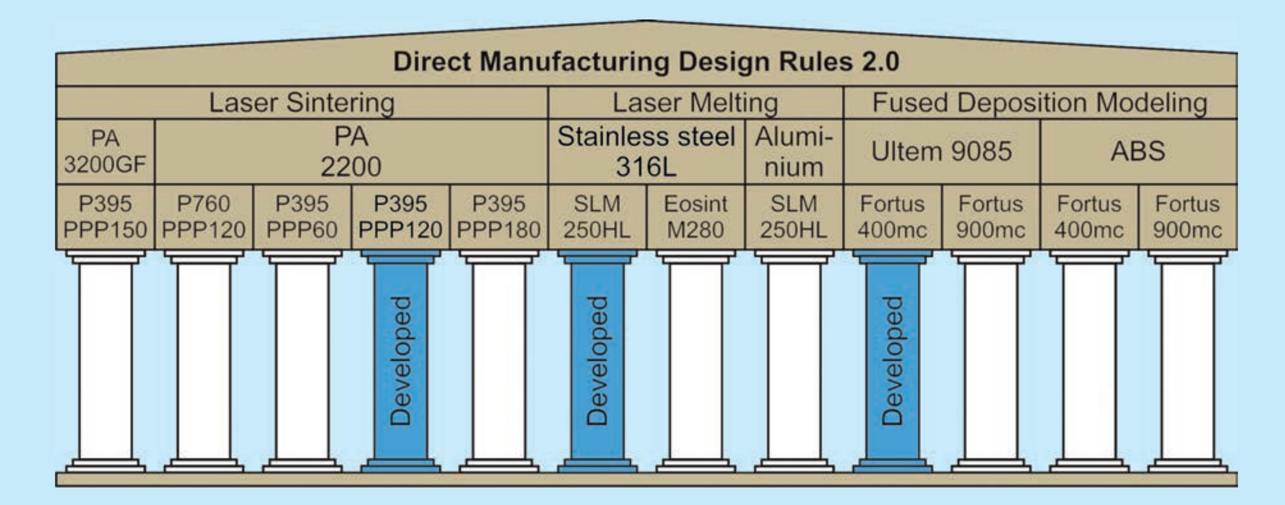


Figure 1: Range of validity for the developed design rules before (blue pillars) and after (white pillars) the DMDR 2.0 project.

be used for training and teaching, need to be applicable for different boundary conditions. Thus, the research project “Direct Manufacturing Design Rules 2.0” (DMDR 2.0) has the objective to extend the range of validity for the developed design rules.

Using the method given by the DMDR project, it shall be proven if the developed design rules apply for different boundary conditions, too. Different materials, manufacturing machines and parameter settings will be considered (Figure 1). As a result, the validity range will be extended and (in case of success) the transferability of the design rules to different boundary conditions is possible.

Adaption of the design rule catalogue

A main result will be the adaption of the design rule catalogue. The catalogue was developed within the DMDR project and will be adapted with the results of the DMDR 2.0 project. Therefore the results of both the DMDR project and the DMDR 2.0 project will be analyzed and compared. It will be analyzed if the design rules given by the DMDR project fit for all considered boundary conditions. The results will be interpreted and if necessary, the design rule catalogue will be extended with additional design rules.

Latest results

During this year, the extension of the design rules was investigated for laser melting. Therefore, the material was varied from the reference material 316L to aluminum (AlSi7Mg) and tool steel (15-5PH). Also, within spot-checks, the EOSINT M280 machine has been considered. Thereby, all measurement curves show very similar characteristics (Figure 2). For example, large deviations occur for small nominal thicknesses.

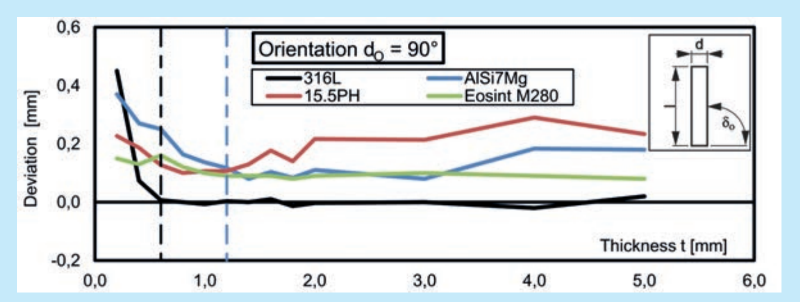
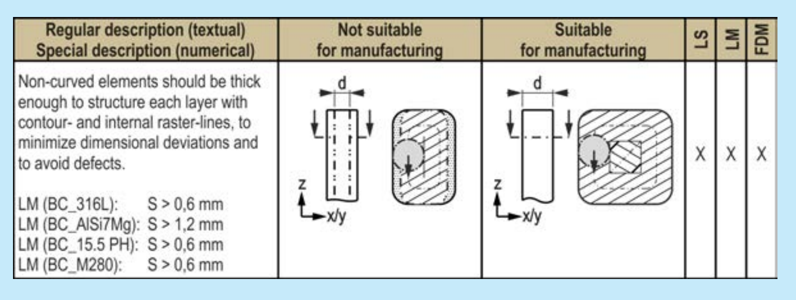


Figure 2: Measurement values for thicknesses of walls for different boundary conditions in laser melting.

The analysis of the results clearly indicates that in most cases the regular descriptions of the prior developed design rules are applicable for different boundary conditions in laser melting. However, varied boundary conditions lead to different numerical values for which the general descriptions become valid. These numerical values are stated within the specific descriptions of the design rules (Figure 3). Both the regular and specific descriptions provide the information that is required to design parts that shall be manufactured with certain boundary conditions.



Regular description (textual) Special description (numerical)	Not suitable for manufacturing	Suitable for manufacturing	LS	LM	FDM
Non-curved elements should be thick enough to structure each layer with contour- and internal raster-lines, to minimize dimensional deviations and to avoid defects. LM (BC_316L): S > 0,6 mm LM (BC_AlSi7Mg): S > 1,2 mm LM (BC_15.5 PH): S > 0,6 mm LM (BC_M280): S > 0,6 mm			X	X	X

Figure 3: Design rule for different boundary conditions for laser melting.

Fatigue Behavior of FDM and LS Parts

Matthias Fischer

In practice, the knowledge of the fatigue properties, in addition to the static material properties, is crucial for a reliable component design. Many components are not only statically loaded, but also dynamically loaded in the area of application, such as a fastener on an airplane. In addition to the actual load carried during turbulence or takeoffs and landings, this component is subjected to a certain oscillation, which leads to peak loads. By determining SN-curves, reliable statements about the relationship between the number of load cycles and the discontinued load can be determined, so that the risk of an unexpected failure of the components is drastically minimized. If plastic components are permanently loaded, e.g., such as it may be in the case of a fastener, a creep of the material will occurs. Creep designates the plastic deformation under a sustained load. This can eventually lead to the failure of the component.

In this project, dynamic strength values in the form of SN-curves are initially determined for Laser Sintering (LS), components made out of the material Polyamide 12 (Type PA 2200), as well as Fused Deposition Modeling (FDM), components made from the materials Ultem 1010 and Ultem 9085. For the LS parts an EOS P 396 and for FDM parts a Stratasys Fortus 400 mc machine is used. The dynamic testing of plastics is connected to some specific features, due to the plastic-specific material behavior. For metallic materials, higher test speeds of 100 Hz, for example, are used to achieve a high number of load cycles in a short time on the test bench. Due to internal friction of the molecules, thermoplastic polymers have the ability to reach the softening temperature because of the simultaneous poor thermal conduction properties and low temperature resistance at high test frequencies. This leads to an early failure of the test specimens. Thus, dynamic testing of plastic components with significantly reduced testing frequency, in comparison to metallic materials, should be carried out, resulting in a significant increase of the test

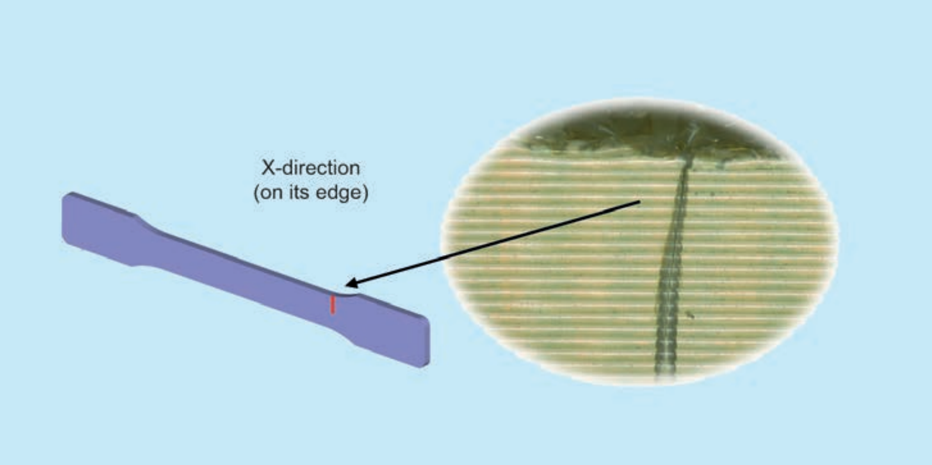


Figure 1: Cracks in Ultem 9085 specimens due to dynamic loads.

duration. The SN-curves are prepared for swelling loads with a constant minimum stress. Here it is possible to use standard tensile bars.

Besides the detection of SN-curves the fracture behavior of Ultem 1010 and Ultem 9085 specimens will be analyzed. Therefore, microscopy pictures will be taken. The aim of this analysis is a specific variation of process parameters with regard to improve the fatigue behavior. This improvement will be performed for both Ultem materials and in X, Y and Z orientation. Afterwards, additional SN-curves for parts with optimized process parameters will be carried out.

In addition to the dynamic characteristics, the FDM materials are also analyzed on the basis of long-term creep tests, in which the failure time is determined for different load levels. The creep tests will be performed at room temperature in standard atmosphere.

The use of components as the final product generally places a great demand on the appearance. For this purpose, previous projects at the DMRC have analyzed chemical possibilities for surface treatments for the materials listed above. Chemical methods have the advantage of an effective leveling of the most rough and wavy surfaces from additively manufactured products. Another focus of this project is to analyze the influence of the chemicals on the dynamic strength values and creep properties. For Ultem 9085, chemical treatment shows no influence on mechanical properties, given that the treatment time is not too long. The influence on fatigue behavior has been unknown so far. Due to a smoother surface, the chemical treatment may have positive influences on fatigue. As of today, long term influence on mechanical properties is also unknown for the used chemicals. Therefore, long term tests will be performed, while specimens will be treated and stored for a minimum of one year before static and dynamic testing.

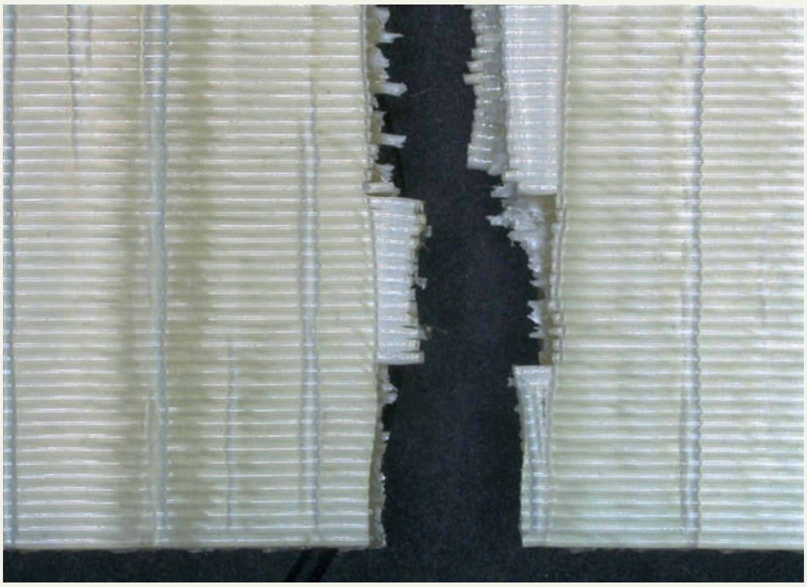


Figure 2: Fracture of an Ultem 9085 specimen as a result of creep.

All in all, this project delivers valuable information regarding fatigue and creep data of different additively manufactured polymers. For FDM Ultem 1010 and Ultem 9085, improvement of fatigue properties by process parameter optimization will be carried out.

DynAMiCS: Development of an Additive Manufacturing Potential Check System

Martin Kage

From the very first invention to broad-scale application, technologies usually undergo a diffusion process. The antecessors of modern AM machines date back to the 80s. However scholars are still waiting for the announced industrial revolution. As of today, the DMRC has been working on propelling the technology from Rapid Prototyping to Direct Manufacturing for more than six years. The DMRC's competences enable it to act as a technology mediator: It can draw accurate estimations of whether AM makes sense in a case or not. Therefore, the aim of this project is a scalable, workshop-based check system. In the course of the project, we employ methods of strategic planning and adapt them in the context of AM. For their validation we continuously conduct validation workshops in producing companies.

Before even thinking about the additive construction of parts, companies will have to check the suitability of AM in a business case. Depending on a company's prior degree of exposure with AM, it is going to be interested in answering different questions (see figure 1 – corresponding work packages of the project).

In the project, we want to develop a systematic framework that will help our partners and other companies in answering the above questions and deduce the desired result. As outlined in figure 1, the project is structured into three major parts: Potential Identification, Product Discovery and Business Planning.

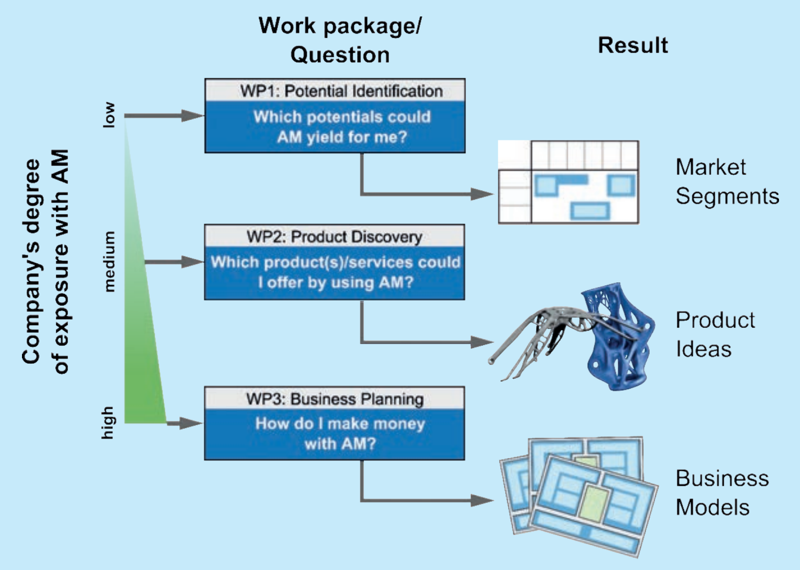
Potential Identification

In the first phase of the project, a framework for companies with little to no knowledge of AM will be developed. Their goal is obtaining a first impression of the benefits AM could provide for their business. To identify potentials, applications fields (in terms of market segment and product category combinations) are determined and assessed with regard to their respective AM potential. The criteria used to tell apart attractive from non-attractive application fields are determined in workshops with our partners and then validated. As a consequence, the DMRC is going to be equipped with a tool to answer the question "Which potentials could AM yield for me" (figure 1).

Product Discovery

In the second phase of the project, a framework for product discovery will be developed. Once a company knows it would like to apply AM (for either production or service provision), it will be confronted with the challenge "Which

Figure 1: Proceeding in DynAMiCS.



products and services could I offer by using AM". The main task is not merely to find creative product ideas, but rather selecting the right ones. On the one hand, product ideas have to be judged from a technical standpoint. In doing so, the DMRC can draw on the technical know-how of its engineering staff. On the other hand, product ideas have to be auspicious with regard to a company's business of the future. The project will yield a framework to generate and select promising, feasible product ideas.

Business Planning

As a matter of fact, there is more to additive manufacturing than the plain production of parts – it changes value chains, manufacturing complexity, competitive relationships and will drastically alter a company's competence base. Therefore, in a third step, a guideline for the generation of AM-business models will be developed. To yield the full potential of AM, companies will have to revert to specific AM business models. A business model is an abstract representation of a company's way to make money. Recently, the concept of business models has gained ample attention among scholars. We aspire to extend the current understanding of business models and enable the DMRC to develop specific AM business models.

The way to our strategy

Eventually, DynAMiCS is a step towards our strategy – being an Industrial Research Base. As one of the many steps towards our vision, we transform our competences to service offers and place them on the market. Figure 2 shows the covers of the three service offers which have been developed in DynAMiCS.

Figure 2: Service Offers of the DMRC in the three addressed competence fields

Additive Manufactured Function Integrated Damping Structures

Thomas Künneke

Mechanical vibrations occur in almost all industrial applications. These are periodically returning movements of technical systems or components. 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. To mitigate these effects, the damping of mechanical vibrations is necessary. At the moment this is done by additional damping elements which are adapted to the vibrating components. A disadvantage of these elements proves to be the additional mass and the increase in installation space. Furthermore, a separate assembly step is required. This leads to higher manufacturing and assembly costs and increased weight. To minimize the manufacturing and assembly costs of technical systems, to adjust the damping functions to the corresponding mechanical vibrations and to reduce the weight, an integration of the damping function into existing structures of engineering systems is desirable.

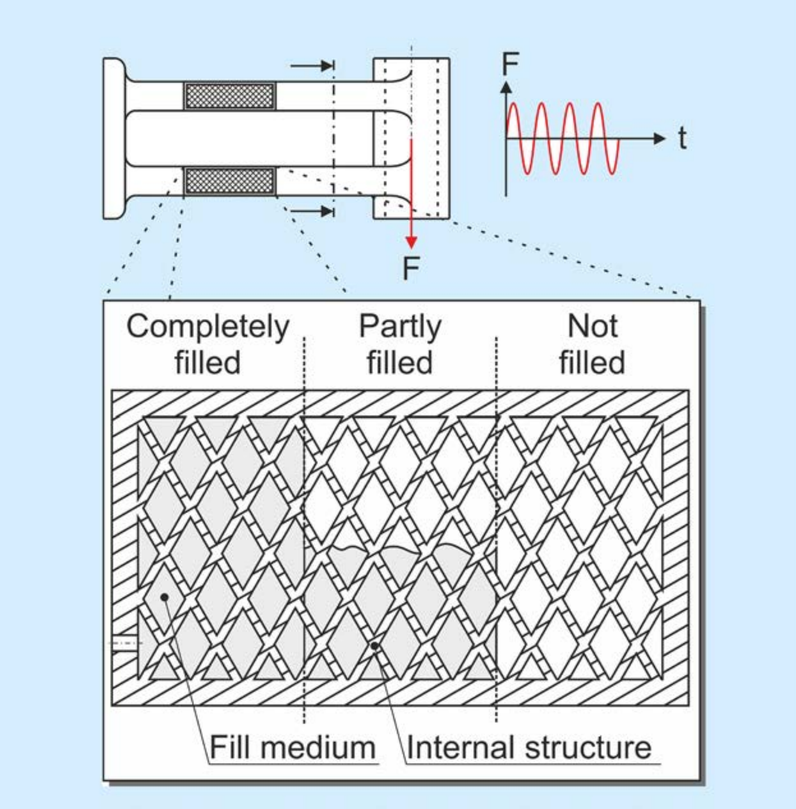


Figure 1: Integration of damping functions into existing structures.

Use of Additive Manufacturing

The integration of the damping function into existing structures of technical systems can be easily made possible via the use of Additive Manufacturing processes (shown in figure 1). Since Additive Manufacturing processes create parts and assemblies layer by layer from metal and plastic materials, they provide design freedoms that cannot be gained with conventional manufacturing processes. For example, it is possible to manufacture parts with complex inner structures. Utilizing this design freedom, it is possible to design and manufacture parts that already imply an integrated damping function. Especially for the Laser Sintering or Laser Melting processes the function integration is highly encouraged. Both processes use powder shaped initial materials made of plastic or metal, which are solidified using a laser during the manufacturing process. Powder that is not solidified by the laser surrounds the part during the manufacturing and is usually removed subsequently. Yet, this powder can also be used to support the damping function. For this purpose, the powder can remain sealed within the inner structures of the part to support the damping function and transform the kinetic energy of the vibration by means of impacts and inner friction into deformation and thermal energy.

Objective

The goal of the Additive Manufactured Function Integrated Damping Structures (AMFIDS) project is to research how Additive Manufacturing processes can be used to integrate damping functions into existing structures of technical systems. In addition, it has to be analysed how the damping effect can be specifically adjusted to different occurring vibrations, in order to achieve an optimal damping value. Based on the empirically developed results a simulation model will be conceived, that can simulate the damping function for different vibrations and for different part structures. The conceived simulation model should support the design of parts with integrated damping functions for different occurring vibrations.

Proceeding

In order to fulfil the objectives of the AMFIDS project, the required test technology has been developed and manufactured first. The test technology is able to create free and forced vibration under bending or torsional load. Furthermore, test specimens with different integrated damping functions will be developed. Subsequently to the development of the test technology and the test specimens, experimental tests will be conducted. For this purpose, the test specimens will be manufactured using the Laser Melting (metal), the Laser Sintering (plastic) and the Fused Deposition Modeling (plastic) processes. First experimental tests of specimens manufactured by Laser Sintering under bending vibrations show the great potential of Additive Manufactured particle dampers (see figure 2). The goal of further examinations is to determine optimal variations for the influencing factors, so that vibrations can be specifically minimized, changed or eliminated. By comparing the results to the results of a reference test specimen, which does not have an integrated damping effect, the degree of minimization, change or elimination of the vibration will be determined. On the basis of the experimental examinations' results a simulation model will be conceived. Finally, the results will be validated using a technical sample part. For this purpose a damping function is integrated into a vibrating part and simulated. By means of an application test, it will be shown that the damping effect was specifically included.

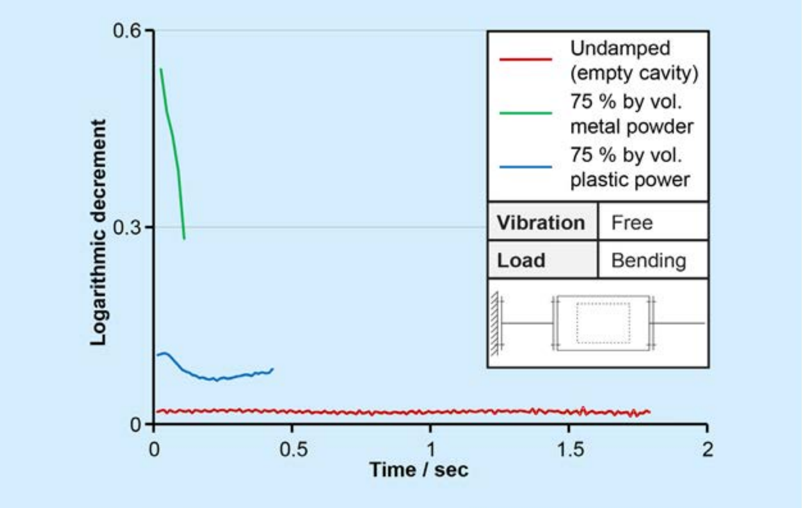


Figure 2: Logarithmic decrement for different dampers.

Dimensional Tolerances for Additive Manufacturing (DT-AM)

Tobias Lieneke

Technical parts are designed computer-aided at its nominal shape, which corresponds to the theoretical ideal shape. However, manufacturing always leads to geometrical deviations from the nominal shape. This could result, for instance, in geometric deviations of size, form, location and surface. Thereby, the functionality of technical parts in terms of its assembling ability is significantly influenced by the interaction of various geometric deviations. For this reason, it is essential that the geometric shapes meet their requirements. Thus, limits need to be given for the geometrical deviations, which is typically done by tolerances. For Additive Manufacturing, it is currently unknown how large such tolerances can and have to be. Reliable and comprehensive information about tolerances for additive manufacturing are neither known in literature nor in standards.

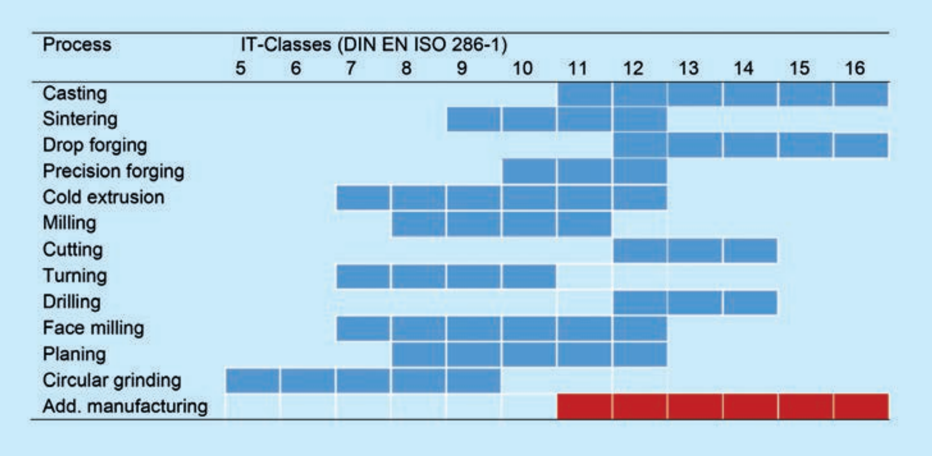
Objectives

The project "Dimensional Tolerances for Additive Manufacturing" has two different objectives.

- 1. Objective: Dimensional tolerances will be 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.

Approach

WP1 & 2: Within the first step of the project, two methods were developed. The first method describes a proceeding for the examination of dimensional deviations that can be used to derive realistic tolerances. The second method describes a proceeding for the reduction of dimensional deviations due to the identification and optimization of process parameters and manufacturing influences.



Process	IT-Classes (DIN EN ISO 286-1)											
	5	6	7	8	9	10	11	12	13	14	15	16
Casting							🟦	🟦	🟦	🟦	🟦	🟦
Sintering					🟦	🟦	🟦	🟦				
Drop forging								🟦	🟦	🟦	🟦	🟦
Precision forging						🟦	🟦	🟦				
Cold extrusion			🟦	🟦	🟦	🟦	🟦	🟦				
Milling				🟦	🟦	🟦	🟦					
Cutting								🟦	🟦	🟦		
Turning			🟦	🟦	🟦	🟦						
Drilling								🟦	🟦	🟦		
Face milling			🟦	🟦	🟦	🟦	🟦	🟦				
Planing				🟦	🟦	🟦	🟦	🟦				
Circular grinding	🟦	🟦	🟦	🟦	🟦							
Add. manufacturing							🟥	🟥	🟥	🟥	🟥	🟥

Table 1: Overview of achievable IT-classes for various manufacturing processes

WP3 & 4: Within the second step, experimental tests are performed to investigate occurring dimensional deviations. Parallel, optimized settings for process parameters and manufacturing influences are identified in order to reduce dimensional deviations.

WP5 & 6: Within the third step, dimensional tolerances will be derived from the measured dimensional deviations. Furthermore, measures will be derived that can be used to reduce dimensional deviations.

WP7: In the end, the results will be analyzed and interpreted.

Latest results

The development of the method was carried out in two parts:

- In the first part, a method was developed that enables a systematic development of dimensional tolerances for a normal workshop application of Additive Manufacturing (WP1).
- The second part aims to minimize dimensional deviations by optimizing the process parameters and manufacturing influences (WP2).

For both methods, factors that influenced the geometrical accuracy of additively manufactured components were identified. Two main groups of the selected factors are geometrical (WP1) and process specific parameters (WP2). The geometric factors describe the components shape and the spatial position of the component within the build chamber. Additionally, process parameters have a high potential to improve the geometric accuracy. In order to identify the influence of these factors in detail, experimental investigations are necessary. For this purpose, characteristic limitations and steps have been determined for each factor.

In order to establish tolerances for Additive Manufacturing processes, the occurring deviations must be examined (WP3). The results of the experimental tests were classified in the ISO tolerance system according to DIN EN ISO 286-1 in order to compare the achievable tolerances with established manufacturing processes (Table 1). Under the examined boundary conditions, the considered Additive Manufacturing processes achieve IT classes between 11 and 16 and are similar with respect to their achievable tolerances with casting, drop forging, drilling, and cutting.

For the minimization of dimensional deviations, process parameters and manufacturing influences were investigated experimentally (WP4). The first experimental studies of process factors demonstrated that dimensional deviations could be reduced by an optimal selection of parameter settings.

Prospects

Currently, further experimental tests are being executed. For the derivation of realistic tolerances (WP5), a successive change of the geometrical factors is essential. For instance, different dimension groups, geometries or a higher structure complexity need to be considered. Investigations of process factors and manufacturing influences with regard to the geometrical accuracy are executed. Further experimental studies on the influence of process factors are required as well. In this context, approaches to minimize dimensional deviations should be continuously developed (WP6).

Fatigue Life Manipulation


Wadim Reschetnik

In this project opportunities to optimize the fatigue behavior of additive manufactured structures are being investigated. Specific heat treatments, different notch geometries in the crack path, as well as the change between the crack initiation and crack growth phase, figure 1, are possible optimization measures. Because various stresses reduce the service lifetime of technical structures under fatigue loading, the main goal of this project is to extend the total lifetime by using sophisticated configurations of notch form, notch position and notch orientation. By varying these notch parameters, basic knowledge about crack growth behavior in SLM processed components is being obtained.

By using crack growth retardation methods, substantially higher fatigue life can be achieved. Figure 1 shows the effect of notches on the lifetime during crack initiation and crack growth period. The reason for the difference in lifetime can be found in the crack growth behavior during initiation. The holes positioned in the crack path lead to a new crack initiation at each notch. The significantly higher number of load cycles within the crack initiation period (compared to the number of cycles during crack propagation) will be used to manipulate the total life time.

Theoretical and numerical studies

The first task of this project is the development of the theoretical basis for the crack initiation and fatigue crack growth. Using these fundamentals, numerical simulation studies of notched and unnotched components and structures are carried out to specify the crack growth direction or crack paths and the total lifetime. On the basis of simulation results test specimens are developed for studying crack initiation, crack deflection, crack retardation and crack arrest. Afterwards the developed specimens can be generated by Additive Manufacturing.
To complete this task the simulation tool FRANC/FAM is used wherein the

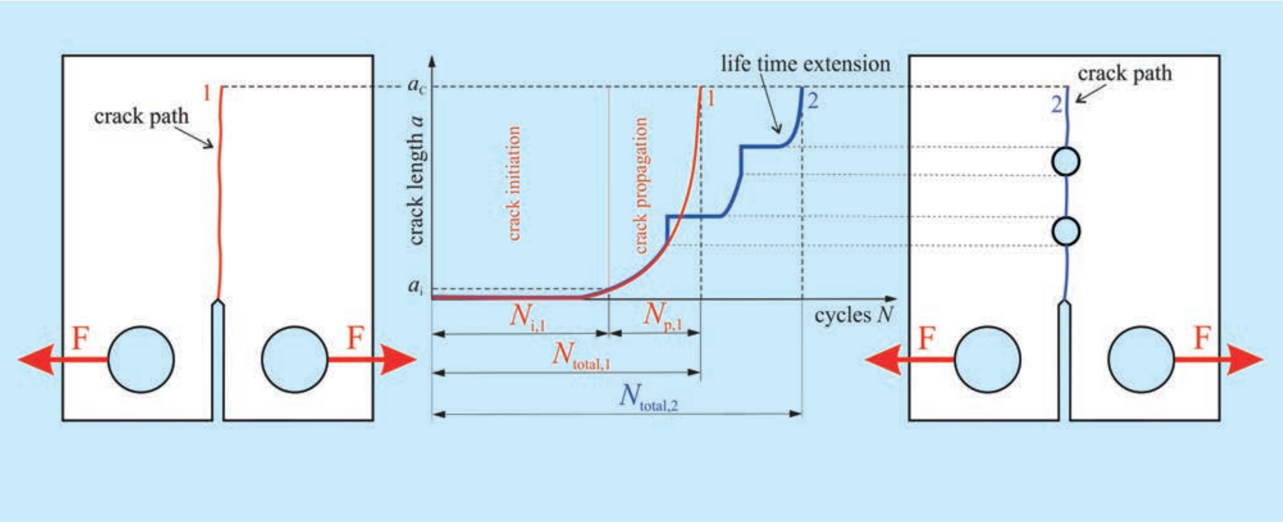


Figure 1 Manipulation of life time caused by notches - schematic illustration.

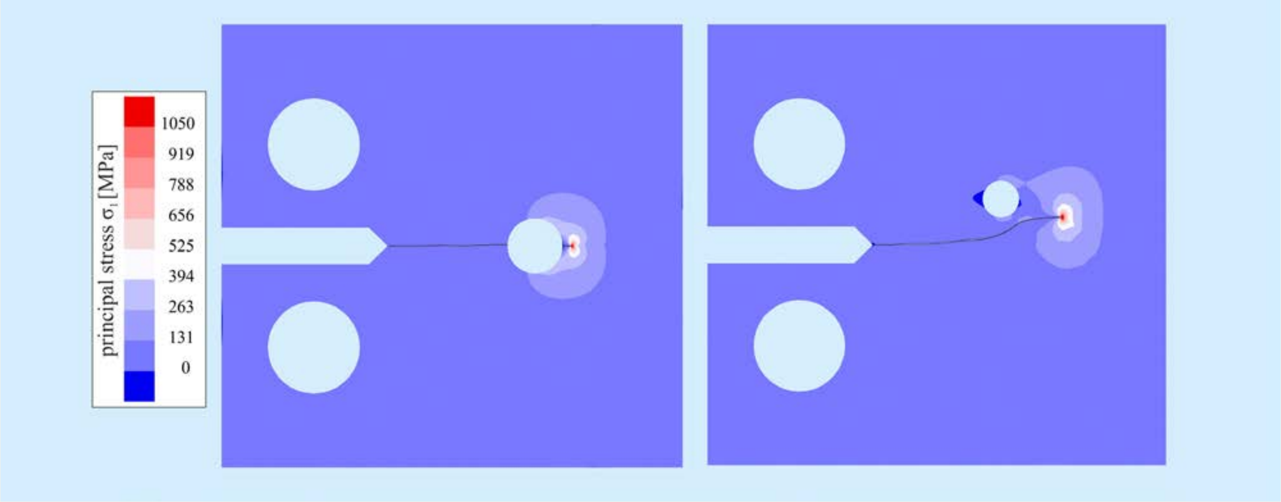


Figure 2 Simulation results of crack path in notched structures with FRANC/FAM.

program code was redesigned. Figure 2 shows two simulation results of the fatigue behaviour in notched structures. On the left side the principal stress in a symmetric notched compact tension specimen is shown. Here, the crack path passes under a Mode I loading condition in the plane of symmetry. The simulation is divided at this point into two basic steps: crack growth up to the notch and crack initiation and growth from the notch. On the right side in Figure 2 an asymmetrical, notched structure with deflected crack due to the notch is shown. Despite identical boundary conditions it becomes clear that the notch has a significant influence on the crack propagation.

Experimental investigations

For the experiments modified compact tension specimens are utilized. At first, studies on specimens containing one notch in the form of a hole are carried out. It is expected that due to changes in stress distribution caused by the notch the crack growth behavior is influenced. By varying the notch size and notch position basic knowledge about crack behavior in additively manufactured, notched components will be obtained. In further experimental research the number of notches, the notch geometries, notch position and notch orientation will be changed to manipulate the fatigue lifetime. The results are compared to the fracture mechanical data for solid material. These investigations will be conducted on different materials.

Conclusions for the additive manufacturing process

This project should figure out the influence of additively manufactured notches on the fatigue behavior. The impact of the microstructure, the material and the material condition are examined. The findings of the experimental investigations are used to describe the relationship between the additive manufacturing process, the microstructure and the crack growth performance in high-graded notched structures.

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

Markus Wiesener

In order to decrease production time in the injection molding of polymer parts, it is of utmost interest to have fast cooling of the injection molding tool. Therefore cooling channels are implemented into the molding tools, which are in contact with an electrolyte consisting of biocides, inhibitors and chlorides at varying temperatures. Those injection molding tools with cooling channels are producible only by selective laser sintering. Due to the varying oxygen solubility for high temperatures (90 °C, lower oxygen solubility) and low temperatures (25-40 °C, high oxygen solubility) the corrosion rate decreases with increasing temperature. Additionally the crystallinity of the oxide films increases with increased temperature. Adhering incompletely molten metal particles of the laser sintering process in the cooling channels lead to an increased roughness and hence to an increased surface and provide the possibility of dead zones in which the electrolyte has a higher probability of residence. Therefore the alloy composition of polished and unpolished samples is compared, before and after exposure to the electrolyte at different temperatures. XPS measurements reveal the alloy composition at the surface while EDX investigations provide a deeper view into the material. These results in combination with electrochemical investigations clearly show the corrosion behavior of the alloys as functions of the surface treatment and the influence of the electrolyte at different temperatures.

In this project, the mechanical, corrosive (in contact to the electrolyte) and adhesive (in contact to the polymer melt) properties of different laser melting alloys are been investigated: standard MS1 alloy (X3NiCoMoTi 18-9-5, high Ni-concentrations), alloy Orvar and conventionally moulded H13 (ca. 5%Cr + Mo, medium Cr-concentrations), and alloy Corrax (X3CrNiMoAl 12-9, high Ni- and Cr-concentrations).

Experimental

In this report, we have investigated the response of two different alloys (MS1 and Corrax) to the electrolyte as a function of surface polishing. The chemical changes induced in alloy composition were investigated by XPS, before and after polishing and before and after contact to the electrolyte.

Results

The elemental composition of the Corrax alloy can be seen in figure 1, as an example for the XPS investigations.

In the case of MS1, simple polishing (without electrolyte exposure) led to an increase in the C content and a decrease in the O content caused by an increase of the carbonate content and a decrease in the hydroxide content in the surface near area. Additional effects of polishing were the increase of Fe concentration and a change in the content of the alloying elements on the surface: the Ni content as well as the Si and Mo contents increased whereas the Ti, Al and Sn contents decreased. Contact with the electrolyte (in all surfaces) led to a decrease of nearly all alloying elements, except for the case of Zn and Mo concentrations, which increased in the near-surface layer. Hydroxide content was also observed to increase, while the Fe concentration was constant before and after contact to the electrolyte.

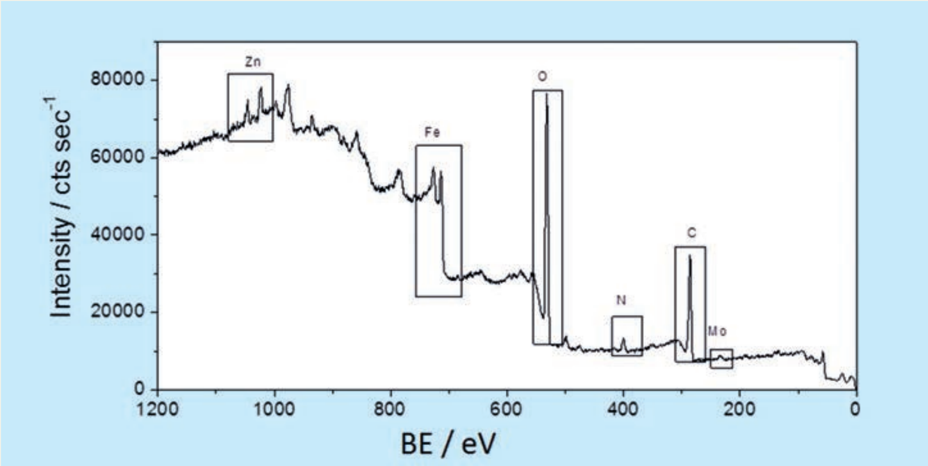


Figure 1: Surface composition as determined by XPS of the Corrax alloy.

By the formation of Zn- and Mo-hydroxides the results indicate that elements with low corrosion potential such as Mo and Zn can provide cathodic corrosion protection for steel substrates.

Polishing of the Corrax sample led to the increase of the C and O content and the increase in Cr, Ni, Si and Fe concentrations on the surface. Al concentration decreased. The increase in Cr, Ni and Si might be due to the physical exposure of stable and resistant carbides and Si-oxide scales initially within the bulk. After contact to the electrolyte the Fe concentration did not change. Zn concentration and hydroxide content increased on both polished and unpolished surfaces; the effect however, was stronger in the unpolished sample, where also no Cr or Ni were detected by XPS. As in the case of the MS1 alloy, the results indicate that a Zn-hydroxide layer formed on the unpolished surface. In the case of the polished surface a slight decrease of the Cr content accompanied by an increase in the O2- content and a slight increase in the Zn content indicated the formation of an incomplete thin Zn-hydroxide layer. In this case, it can be assumed that a protective Cr-oxide layer grew on the surface as well (in analogy to the well know healing effect of Cr).

Conclusions

XPS analysis of the surface near regions of MS1 and CORRAX alloys before and after polishing and before and after exposure of each surface to a model electrolyte used to cool the injection molding tool in the later production was performed.

The main result of contact to the electrolyte was the formation on hydroxide layers. The hydroxide layer coverage seem to be complete in the cases of both MS1 samples (polished and unpolished) and on the unpolished Corrax; in this case, the assumption is that cathodic corrosion protection was provided. For the polished Corrax sample the hydroxide layer was probably incomplete (or very thin). In this case, corrosion protection of the steel substrate might be due to the existence of a growing Cr-oxide layer.

All alloys after the manufacturing process showed surface enrichments of foreign elements which could lead to local corrosion attack.

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

Alexander Taube

Currently, one of the main industrial challenges is the reduction of the energy consumption of moving parts as well as of the total amount of the material used. In order to meet the demand for optimized light-weight parts, the development of load adapted structures has begun to play a key role in today's research. One approach is the employment of low density materials, such as the well-known aluminum foams. However, on small scale, these foam structures are stochastic and therefore not load optimized. At this point, Additive Manufacturing becomes highly beneficial as it enables for an unprecedented design freedom. By application of additively manufactured non-stochastic cellular structures, which can be locally adapted to the prevailing stresses, an optimized relative loading capacity becomes feasible.

Objectives

The first focal objective of this project is the creation of a robust Finite Element Analysis (FEA) model for complex loaded cellular light-weight structures. Based on a previously generated linear elastic simulation, the examinations will be extended to linear-plastic deformation behavior including several materials e.g., 316L stainless steel (ductile) and Ti-6Al-4V alloy (brittle). The second focal objective of the project addresses the experimental verification of the generated FEA model. Therefore, cellular structures will be additively manufactured by employing Laser Sintering (LS) and uniaxial and bending tests will be conducted.

Preliminary Analysis

For characterizing the fundamental behavior of cellular structures, the first

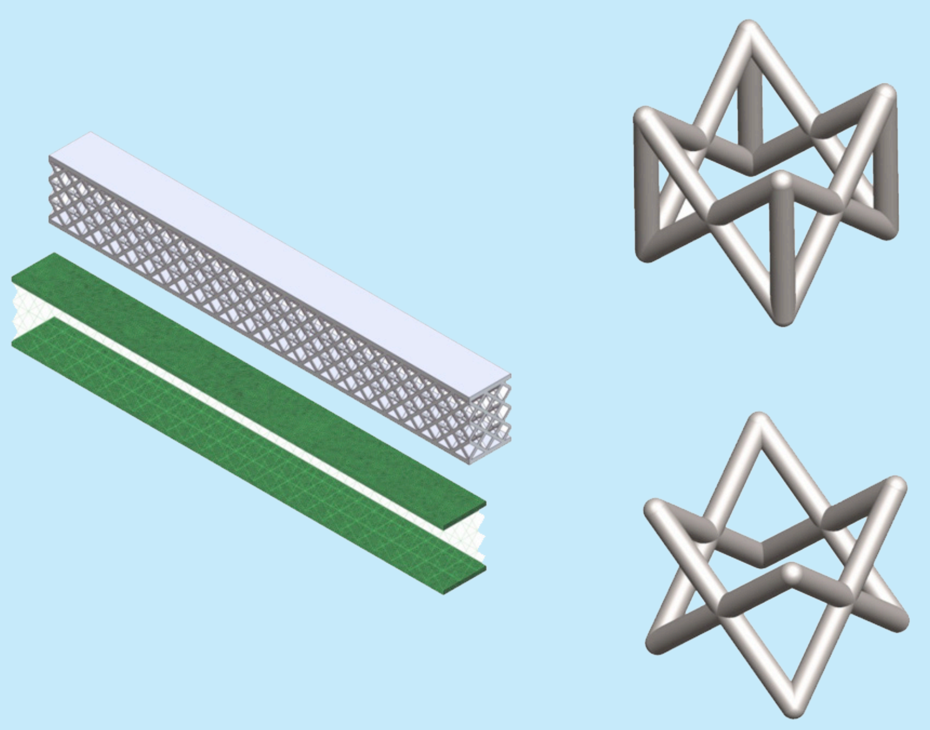


Figure 1: Sandwich structures with face-centered base cell with additional struts in loading direction (stretch-dominated) and face-centered base cell (bending-dominated).

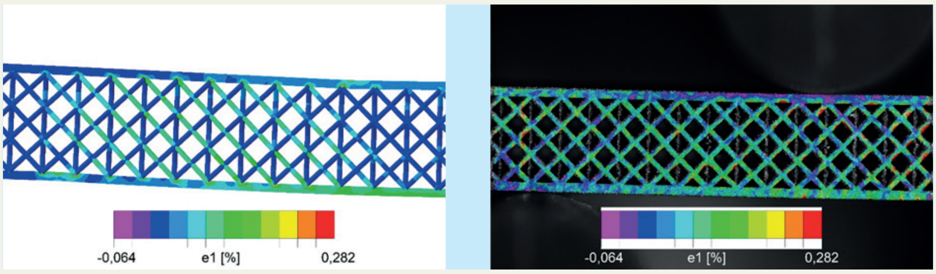


Figure 2: Comparison of FE-Analysis (left) and DIC (right) of the local maximum principal strain e1 shortly before the damage of fcc sandwich structures.

project was drafted with a focus on the occurring deformation mechanisms of metallic samples under uniaxial and bending load. The deformation behavior was determined by using Digital Image Correlation (DIC) and robust FEA. Based on theoretical analysis, the body-centered base cell is bending-dominated and the face-centered base cell is stretch-dominated. In this case, the chemical composition of the materials is pivotal for the ductile or brittle behavior of the base cells. The results proved a good specific loading capacity but also high influence of the cellular design on the resulting failure mechanisms. The results of simulation and mechanical tests for the face-centered base cell under uniaxial load showed good accordance between the observed and simulated local deformations. Considering the deformation behavior of a body-centered base, the results have been inconclusive. The linear-elastic model was incapable to emulate the mechanical properties. Therefore, a linear-plastic deformation model is required. Sandwich structures with different cell types will be tested utilizing DIC. As can be seen in Figure 1, stretch-dominated (fccz) and a bending-dominated (fcc) cell type which are in focus of the investigation.

In the current period, the focus of these analyses was the characterization of the mechanical behavior under uniaxial and bending load within the lattice structures. A sequence of one bending test is displayed in Figure 2. The comparison between the in situ images and local strain e1 for the lattice structures fcc reveals high local strains within the lattice structure. The local strain concentration within the struts and in force transmission points possess approximately equal strain values compared to the DIC analysis.

Approach

The main activities to reach a robust FEA model include the following aspects. At first, the base cells have to be analyzed by employing FEA simulation. Thereby, the elastic-plastic behavior must be implemented in the FE model. Due to different microstructural conditions of the material after post-treatments, diverse FE models will be extended in order to cover the latter aspects. Moreover, the verification of the FE model by mechanical testing including DIC will start. By doing this, samples with diverse local microstructural conditions will be examined.

KnowAM

Christian Lindemann

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 derived from product development case studies, a methodology for cost efficient design and planning is derived.

Project Goals

The following goals are targeted in the project:

(1) Enhancement of costing framework developed in the Project CoA2MPLy
(2) Achievement of comparability between machines and technologies regarding costing aspects and particularly building rates
(3) Development of an scalable IT-System with a costing calculation module, an AM Database and a presentation of advantages of the Additive Manufacturing technology
(4) Derive best practices for cost efficient design and planning

Enhancement of the SLM costing framework

The costing framework developed in the project CoAcMPLy focuses Selective Laser Melting (SLM) with its specific characteristics. Objective (1) comprises an adaption of the costing model to the Laser Sintering (LS) process and to Fused Deposition Modeling (FDM) as well, to provide cost calculations for the three most common Additive Manufacturing processes. This work will enhance the existing framework for costing analysis to be utilized by OEMs,

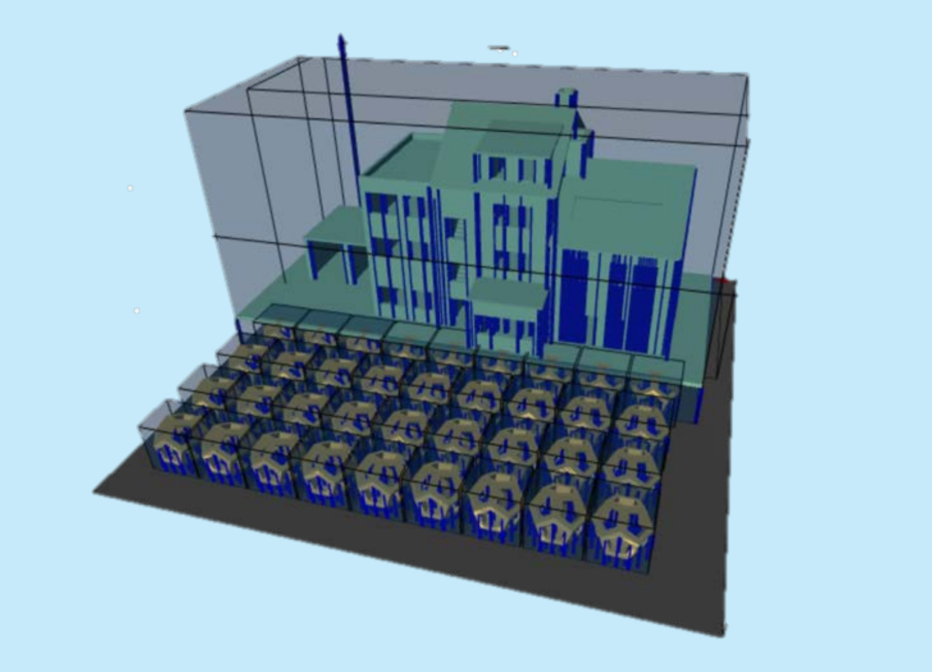


Figure 1: Screenshot of the IT-System

Additive Manufacturing part suppliers and Additive Manufacturing part users. Furthermore, the applicability for different branches and impacts on supply chain will be considered.

Comparability between AM machines and technologies

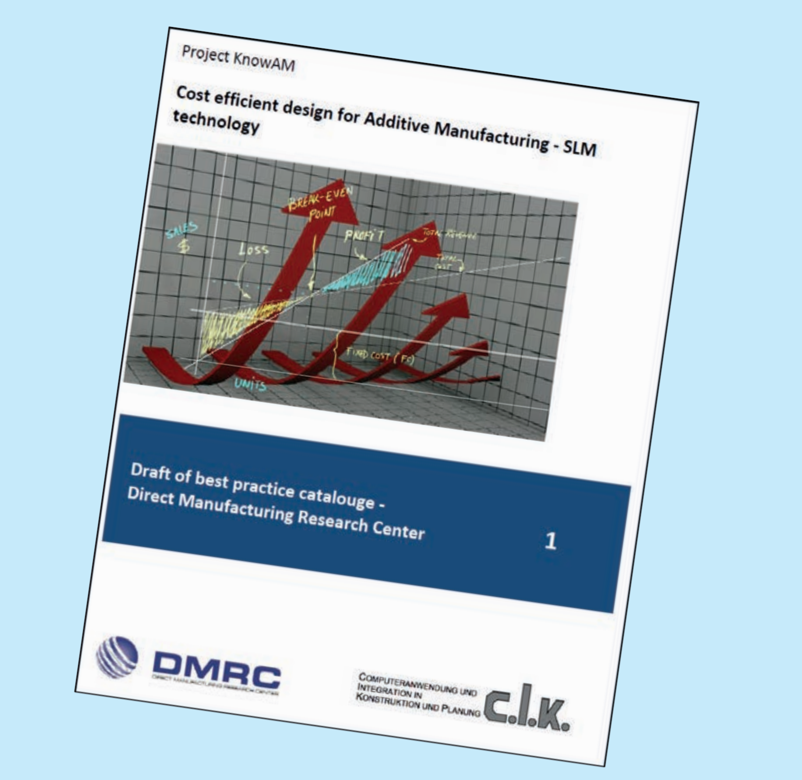
Objective (2) addresses the comparability between different types of machines and technologies. At the moment machine manufacturers measure the building rate in different ways and even specify these rates in different units – for instance cm³/h or mm³/h. To achieve comparability and transparency for potential customers facing a make or buy decision a proposal for standardization of measurement and specification of building rates will be elaborated starting with the determination of material properties that have to be one of the reference parameters.

Development of an IT System for costing calculation

This objective (3) is meant as development and implementation of a scalable IT-System concept. Due to web access to the IT-System no software will be needed for calculation. The enhancements stated in objective (1) will be considered so that users and potential customers will be able to compare costs in additive and traditional manufacturing. Thus, utilization of building chamber of the specific machine as well as the part orientation and the concrete part geometry can be considered in the calculation. Another module of the IT-System will be used to monitor build jobs and to gather process knowledge regarding cost data, material properties and quality aspects. The concept has to be developed with respect to prospective maintenance effort that has to be low.

Derive best practices for cost efficient design and planning

The overall results of the projects will help to define rules for the cost efficient utilization of Additive Manufacturing and therefore help to foster the growth of the technology. Furthermore, the outcomes will enable end users to compare different technologies in regard of building speed and efficiency. Also, best practices and a methodology for AM part candidate selection will help the designer to industrialize the AM technology.



Project KnowAM

Cost efficient design for Additive Manufacturing - SLM technology

Draft of best practice catalouge - Direct Manufacturing Research Center

1

DMRC

Computeranwendung und Integration in Konstruktion und Planung C.I.K.

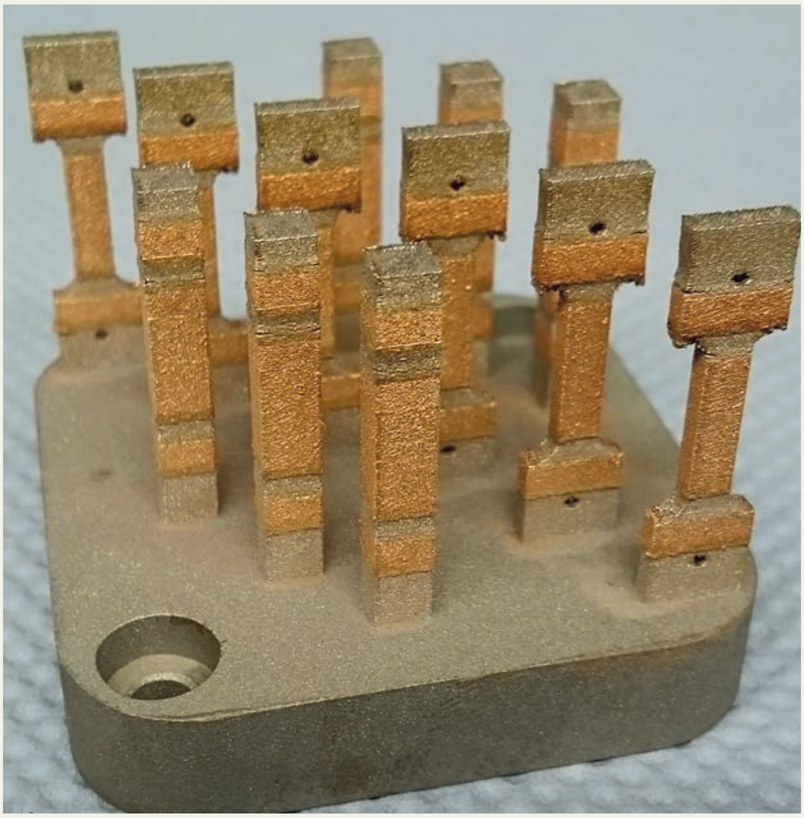
Figure 2: Best practice catalogue

Innovative SLM Materials

Peter Koppa

Previous DMRC projects in the field of the Selective Laser Melting (SLM) process promise a lot of new properties made from conventional materials. Single-material components manufactured by this production technique have been developed by different DMRC research groups. For example, tailored mechanical properties of components as well as high strength lattice structures. Thus, the outstanding potential of this innovative Additive Manufacturing technology was demonstrated for different metals and applications. Nevertheless, all these investigations have been carried out on more or less conventional materials, such as titanium alloy TiAl6V4 or stainless steel 316L.

Figure 1: Functionally Graded bronze-316L-specimens.



This circumstance leaves one huge potential of the SLM process unconsidered: An in situ combination and processing of different materials in order to obtain novel materials characteristics. The innovative idea is in contrast to other conventional production-routes and offers a new degree of freedom. During the latest investigations, two different types of new materials proved to be: The easiest way to create new materials is to mix different materials to one metal matrix composite (MMC). The second way is to combine them by variating it as the dimension varies to a functionally graded material (FGM). In order to enable a systematic procedure for this project, it has been subdivided into the following work packages.

WP01: Material-screening and definition of desired properties
WP02: Development of exposure parameters
WP03: Comprehensive characterization of the mechanical properties
WP04: Concept development “locally adapted material combinations”
WP05: Transfer analysis

Objectives

The establishment of innovative materials via the combination of different materials is the main goal of this project. The two different methods, on the one hand the MMC and on the other hand the functionally graded materials, require different processing routes. The main challenge for the MMC is to find a new way to process this combination by introducing them to new exposure parameters. In order to provide new parameters it is crucial to evaluate an efficient method for detecting the optimal exposure values. The main issue on the functional graded materials is to find a way to process it in a SLM 280 machine without having to stop the process in order to change the powder or to continuously change the parameters. Finally, the exposure results of the MMC materials will be used to optimize the interface between two functionally graded materials for the purpose of improving the transition area.

Preliminary Studies

The first MMC material consisting of boron carbide and AlSi7Mg was designed to evaluate the exposure parameters. After some improvement loops, it shows an advantage to the mechanical properties.

Due to this successful processing, the currently examined materials are 316L, H13 and bronze. Figure 1 shows a FGM made of bronze and 316L. To achieve that type of alternating structure at once, an inlay (see Figure 2) for the shaft recoater was developed. In combination with different slicing strategies, it is possible to change the material and the exposure parameters for every layer. According to the first microstructural and mechanical investigations, it is possible to attain good performance of the transitional area.

Approach

In the future the main activities will concentrate on further material combinations, which will be examined by additional optical deformation image correlation (DIC). With regard to the probable formation of new micro alloy systems, an EDX and EBSD analysis will be applied. Due to the development of a new generation of SLM build slide-recoaters, it will be necessary to design an entirely new recoater which fits the new system.

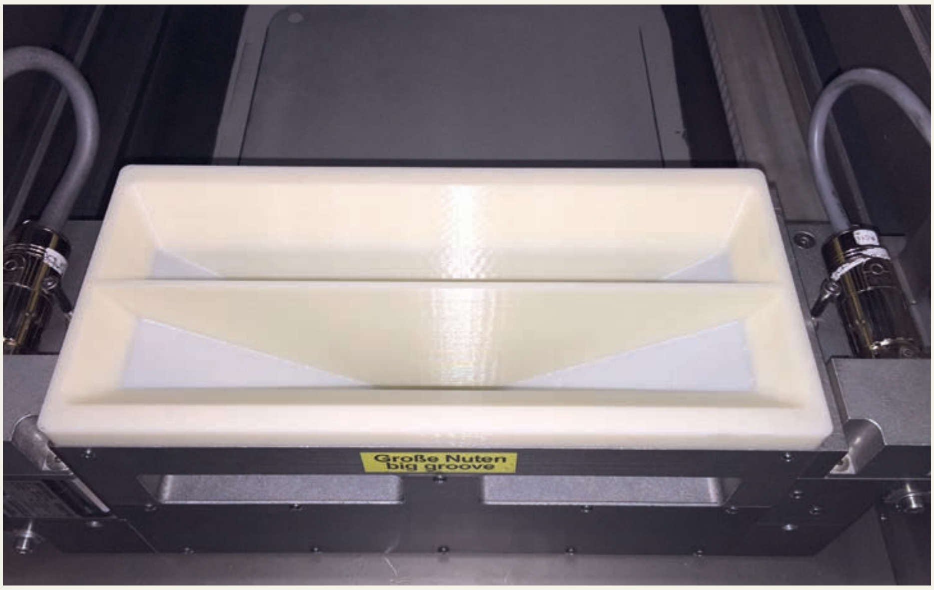


Figure 2: Standard SLM 280 HL shaft recoater with an in-house designed inlay for Functionally Graded Materials.

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

Nils Funke

During various completed as well as currently running projects, the DMRC has managed to obtain know-how in Polymer Laser Sintering. A wide range of data has served to gain a much better understanding of the process as well as the material and parts made from it. However, all of these tests have been performed on thermoplastic polymers, especially Polyamide 12. Polyamide has many technical applications, yet it only represents a fraction of the possibilities in the polymer range. Thermoplastic Elastomers (TPE) hold the potential to help fill in this gap. Their thermoplastic properties by principle allow them to be processed, while their more elastic ("rubberlike") qualities open up entirely new fields of applications. EOS's PrimePart ST is a PEBA (polyamide-based TPE) that was specifically developed for use in Laser Sintering. Since the material is a relatively new addition to the market, there is less in-depth knowledge about its processability and properties than for more established materials.

Goals

The goal of this project is to gather knowledge about PrimePart ST's process and material characteristics. First of all, a lot of process data has to be collected in order to fully control the process. Experience with process limits is needed to achieve a high level of process reliability. After that, various tests will be carried out to determine material properties. This is a crucial point in determining useful applications and

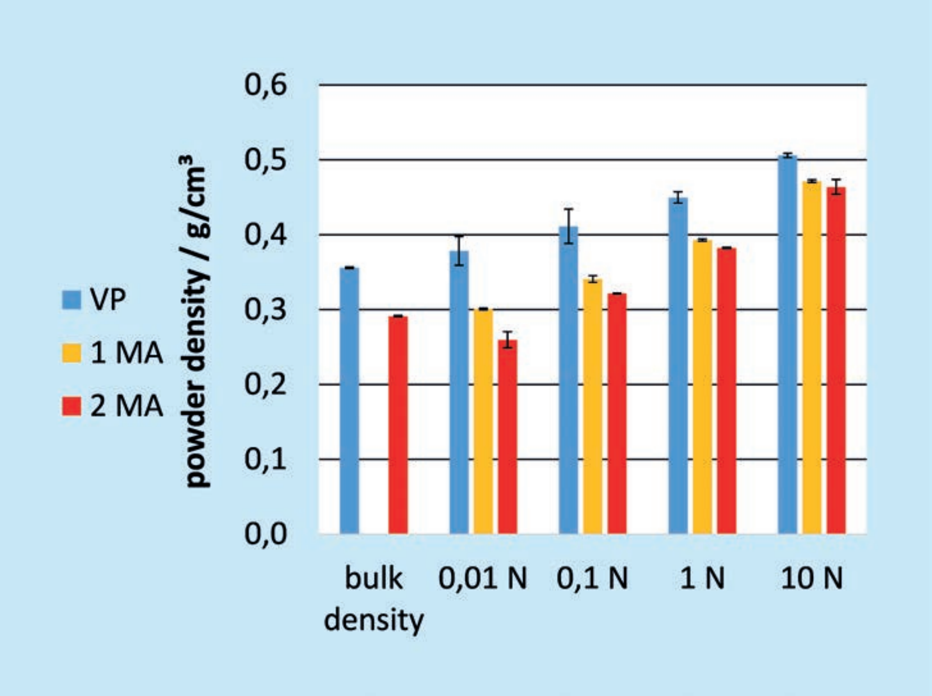


Figure 1: Bulk densitiy and compression densities for different compression forces for virgin, once, and twice machine aged powder.

how to make optimal use of the qualities of the material.

Powder Ageing

Powder ageing is an important factor in every polymer Laser Sintering process, and PrimePart ST is no exception. As the powder is repeatedly used, the quality of parts made from it declines over time. This effect is also known from Polyamide 12. In contrast to polyamide 12 however, the ageing mechanism is not yet fully understood. There is no established test to easily determine the thermal loading of the powder without building actual parts. The examination of powder ageing therefore plays an important role in this project. Samples of aged powder are created using an oven or the actual sintering machine. These samples are compared to virgin powder using different methods. Experimentation has so far not found essential chemical changes in aged material. There have however been changes in powder characteristics: In aged powder, agglomerates are found as well as a different particle size distribution. This also leads to different compression and bulk densities (see picture). Further tests will quantify the powder ageing and determine the impact on the part quality.

Parameter Variation

A second aspect of the project consists of varying process parameters in order to develop a better understanding of the process and its limits. The most important parameters are the build temperature, part thickness and laser parameters. The general build temperature is a crucial parameter that has to be well adjusted in order to be able to produce proper parts. The same is true for the laser parameters. The part thickness is especially important in thermoplastic elastomers, since part and material properties vary greatly depending on how massively the part is built. With parts built from all of these parameters, various tests will be performed.

Elastic Part Properties

Part properties are investigated using a wide variety of tests. This serves to learn about the material in more detail and qualify it for future applications. Another aspect is comparing parts built with similar parameters on different machines. Relevant possible tests have been researched. Apart from standard tests, TPE and elastomer-specific will also be investigated.

Case study

As a final part of the project, a case study will be performed. This offers the possibility to apply the gained knowledge and experience to an actual design. For partners participating in this study, this also offers the potential to get to know the material better and see how it can be implemented into their processes and how existing parts might profit from the new material. A study subject is selected and then adapted for Laser Sintering and PrimePart ST. It is then tested according to the requirements for its application. Finally, a comparison of the study part with conventional parts that have been manufactured using other processes (if applicable), in order to show advantages and disadvantages of the material.

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

Patrick Delfs

To quantitatively assess the surface quality (i.e. surface "roughness" on a number of scales) of laser sintered parts, a reliable characterization method has to be found. Using this method, the surface quality of laser sintered parts depending on different machine parameters has to be analyzed in order to describe the correlation between machine settings and surface quality. Further testing will cover post-processing methods to improve the surface finish with reasonable effort in terms of costs and labor. Furthermore, the effects of surface quality (due to sintering parameters as well as post-processing methods) on mechanical properties as well as aging by comparison of post-processed and untreated parts in long-time testing will be examined. The overall aim is a surface quality analysis of laser sintered parts.

Surface Quality Characterization Method

This part of the project includes the investigation of diverse existing methods to characterize the surface quality and their applicability to assess laser sintered parts. For characterization of laser sintered parts it is important to keep in mind imperfections at different levels of scale: shape deviations (i.e. mismatch of characteristic admeasurements with design), surface deviations (e.g. waviness, terrace formation) and surface roughness (ranging from sub-millimeter to micrometer scale). Different methods are investigated in order to test their ability to assess surface imperfections at these different scales. Tactile and non-tactile measurement systems are investigated as well. As an optical instrument Fringe Light Projection is investigated and evaluat-

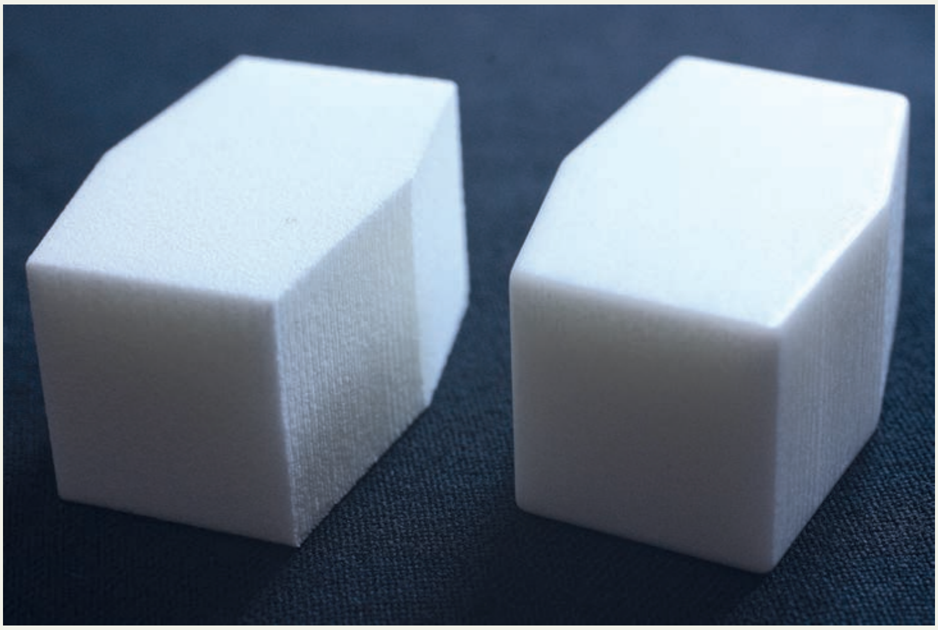


Figure 1: Sample parts for surface characterization, as-built condition (left) and smoothed by mass finishing (right).

ed. Thereby, the main emphasis is on suitable mathematical methods to extract valid information about surface defects on different scales from obtained data.

Another challenge is to get comparable information from completely different measurement techniques. Further on, a subjective assessment of the surface quality by haptic testing is aimed at. For this purpose suitable test specimens are used and assessed through blind-testing by different test persons. Finally, we aim to get a correlation of subjective and objective assessment of different surfaces. The resulting surface quality for different machine parameters (e.g. layer thickness, laser and scanning parameters) and powder quality (virgin powder vs. used powder) is tested with the methods developed previously. Especially the orientation of a surface in respect to the layer orientation has a huge influence on the surface quality as well.

Surface Finish according to Process Parameters

The post-process is an important factor when using the Laser Sintering. After the unpacking process the powder has to be removed from the parts, which is performed by using a blasting cabin. Next to the abrasive blasting method other promising methods like grinding and chemical etching will be used. The challenges here are also to find the right materials and parameters. Because of a lower surface quality, compared to injection molding, laser sintered parts are not used in visible areas of the manufacturing fields at the moment. The main focus is on a harder and smoother surface with a minimal effort of manual labor.

Longtime-Testing of Laser Sintered Parts

The last part of the project deals with the ageing of post-processed and untreated parts. Therefore, the test specimens will be exposed to light, humidity and various temperatures for different durations under laboratory conditions as well exposure to nature conditions. On one side, the ageing will be simulated with a defined exposure of above mentioned impacts and then compared to ageing by real weather of Paderborn. Measurements will be done to evaluate the influences on surface quality.

Recent Results

Promising mathematical analysis methods are identified. Intersections of these methods will be evaluated to set up an objective analysis for surface quality determination. Many parts for surface and detailed resolution testings are built on different machine generations. The analysis of these parts will show property dependencies regarding spatial positions inside one machine and the differences between different machines. For improving the surface quality of parts, a mass finishing process was examined and showed a high potential as a cost-effective post-process method.

Student Laboratory – 3D Printing

Johannes Lohn

By using 3D-Printing, a new solution space can be entered. Advantages such as design freedom, short production time and cheap and fast prototyping are well known, but in order to leverage the new possibilities for production and design, apprenticeship is needed. Vital questions are: How to deal with this new technology? How to get a high quality 3D model? How to reduce support structures and is a part capable or not for 3D-Printing? In this project, the DMRC will strengthen the knowledge transfer between industry and students. Particular areas and faculties in addition to mechanical engineering, like arts or electronics, shall be addressed. The combination of new areas and its perception shows radical new possibilities for additive manufacturing. New points of views can lead to alternative solutions to current shortcomings. New application fields of AM will be entered. The aim of the project is to enable students to work with AM. In the Student Laboratory theoretical knowledge can be extended by practically working with the machines. When starting a job after university, those students will be able to share their enthusiasm and knowledge with the industry. Knowledge will be multiplied and the impact of AM will grow.

UNIVERSITÄT PADERBORN
Die Universität der Informationsgesellschaft

URKUNDE

Das Präsidium der Universität Paderborn
verleiht

Anna Heggemann
Prof. Dr. Sara Hornäk
Dr. Eric Klemp
Prof. Dr. Hans-Joachim Schmid
Johannes Lohn

den

Förderpreis für Innovation und Qualität in der Lehre
2014

Der Titel des Projektes lautet:
„Studentenwerkstatt 3D-Druck – Integration in die Lehre"

Paderborn, den 03. Dezember 2014

Der Präsident

Prof. Dr. Nikolaus Risch

Figure 1: Award for Innovation and Quality in Teaching 2014.

Funded by the University of Paderborn – Award for innovation and quality in teaching

The project is funded by the University of Paderborn. The Direct Manufacturing Research Center won the "Award for Innovation and Quality in Teaching 2014". With this financial support, three FDM homeprinters and a handheld 3D Scanner can be offered to students for free.

Offers to students of the University of Paderborn

All students of the University of Paderborn are invited to visit and use the "Student Laboratory – 3D Printing". It is a great opportunity to get to know the world of 3D-Printing in reality and not only in theory. New faculties like electronics or arts shall be addressed. The required support and equipment is offered for free.

1. Introduction to 3D-Printing
2. Introduction to CAD
3. Free usage of 3D Printers
4. Free usage of 3D-Scanning Systems

Service for teaching staff of the University of Paderborn

Additionally, the teaching staff of all faculties of the University of Paderborn is invited to implement 3D-printing into their lessons and lectures. The DMRC provides knowledge and support which is needed for a successful implementation into their schedule.

1. Support for the integration of 3D-Printing in new faculties and their education
2. Preparation of lecture notes
3. Interdisciplinary projects
4. Free usage of the equipment of the Student-Laboratory “3D-Printing” for apprenticeship

Achievements

Since its opening in March 2015, more than 200 students have gotten to know the advantages of the student laboratory. For example, 130 students of mechanical engineering passed the class “Additive Manufacturing” and discovered the secrets of 3D-Printing at the Student Laboratory. In the area artic sculpture, three seminars where offered and about 50 arts students gained their first experiences in Computer Added Design (CAD), 3D-Scanning and printing. The results of these seminars will be presented in an art exhibition in 2016.

During the initial test phase of the student laboratory it became clear that a machine managing system is required. As a result, an online reservation system for the 3D Printers has been implemented to guarantee good working conditions without waiting times that, at the same time, allows a high occupancy rate.

In order to share further information about the student laboratory, a homepage has been set up. The booking system is easily accessible.

Efficient manufacturing process for metal bipolar plates for use in fuel cells

Dominik Ahlers

In a fuel cell, the conversion of chemical energy from a fuel into electricity takes place. The chemical reaction between hydrogen ions with oxygen releases clean energy. For this functionality a fuel cell stack is constructed with several bipolar plates. Bipolar plates are the key component of the considered proton exchange membrane (PEM) fuel cells. The aim of the project "Efficient manufacturing process for metal bipolar plates for use in fuel cells" is to answer the question, if the Fused Deposition Modelling (FDM) process is suitable for the production of tool inserts (negative molds), which enables the production of finely textured metallic bipolar plates (BPP).

Participating Partners and Funding

As an external project, the company Eisenhuth is a cooperation partner and Volkswagen AG an associated partner. The project is funded by the DBU – Deutsche Bundesstiftung Umwelt and led by Eisenhuth. The funding starts in Mai 2015 and ends in October 2016. Within this time several in-person meetings and teleconferences between the two cooperation partners were held and are planned regularly till the end of the project.

The project partner Eisenhuth has special experience in the fuel cell technology and in calculating, designing and manufacturing molds and dies for tooling and injection molding. The Volkswagen AG is well known as an innovative German automobile manufacturer and an end-user of such PEM fuel cells.

Proceeding within the project

In a first step, the new BPP design was developed by Eisenhuth and the negative forms were constructed at the

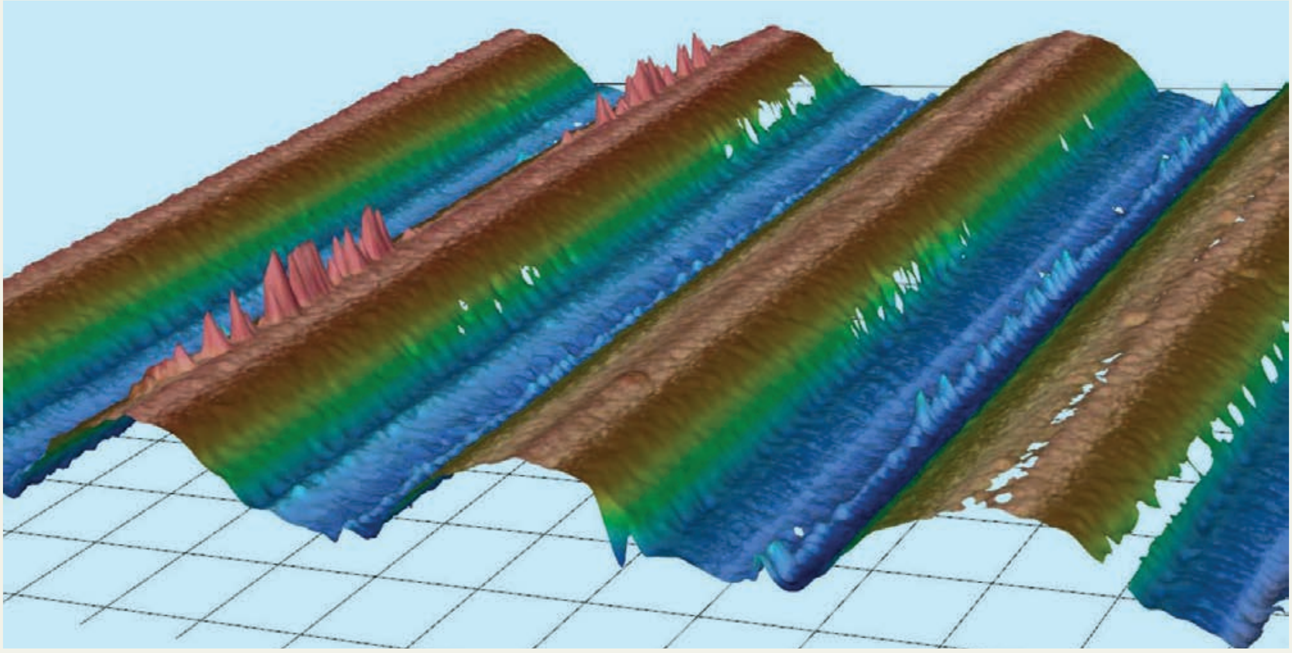


Figure 1 – Surface quality measurement of a metallic BPP with obvious measurement defects (Keyence macroscope).

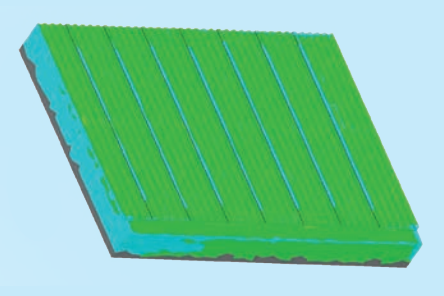


Figure 2 – Measurement of the manufacturing accuracy of the whole tool insert with the KolibriMulti System

DMRC with a particular attention to the interpretation of the finely structured hydrogen plenum (flow field). The requirements of the subsequent manufacturing steps take sufficient consideration already. Parallel to the described working steps, studies were carried out at the DMRC to identify a suitable thermoplastic material (ABS or ULTEM). Extensive testing with tactile and optical measurement systems (KolibriMulti, Keyence macroscope and coordinate measurement machine) has been obtained at the best process settings for the FDM printing process. Focused parameters were orientation in the building chamber and tip diameter (T12, T16). Other interesting parameters for the design of the negative forms are the hardness, abrasion resistance and roughness of the used materials. In addition, the produced BPPs are examined in terms of their mechanical properties and their characteristics will be compared with other available BPPs on the market.

Aims of the Project

The main aim of this project is to answer the question if thermoplastic materials processed on a FDM machine are suitable for producing tool inserts with sufficient mechanical properties for an industrial application. The main focus is on tolerances and part quality. First on the negative forms and, as a result, especially on the final metallic BPP. The BPP has to fit exactly in the whole stack to enable the chemical reaction between the hydrogen and the oxygen. Once the final negative forms are manufactured and the BPPs are embossed, the project will be completed with the construction and commissioning of a test object and recording a current-voltage characteristic. The material characteristics and an attached cost analysis answers the question if ABS or ULTEM should be used for an industrial use case. As a final step, the test object will be examined at VW, where the suitability of the BPP will be tested.

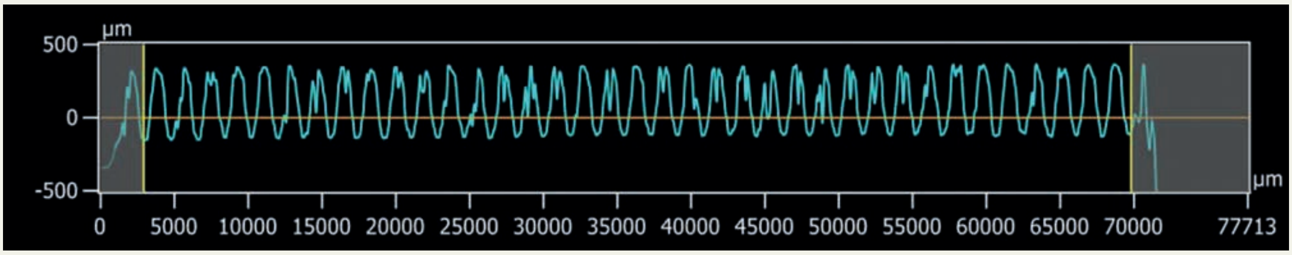


Figure 3 - Representation of the dimensional accuracy of the wave profile (Keyence macroscope)

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

Mehmet Esat Aydinöz

DFG

Nickel-based superalloys such as Inconel 718 (IN 718) alloy are widely used in several high temperature applications in aircrafts and gas turbines. The IN 718 is a precipitation-hardened superalloy and provides a good corrosion and oxidation resistances at high temperatures. Selective Laser Melting (SLM), a typical Additive Manufacturing technology, allows unlimited design freedom for complex geometric shapes from metal powder. It enables the production of dense metal parts direct from the sliced CAD files without the need of tooling. However, some defects like pores cannot be totally avoided although the process parameters are optimized. In order to reduce the porosity, hot isostatic pressing (HIP) is highly interesting. Thus, a promising approach for further improvement of the material properties is functional encapsulation by means of cathodic arc deposition (Arc-PVD), which uses an electric arc to evaporate a target material. In view of these aspects, the influences of the post processing such as HIP and Arc-PVD on the microstructural and mechanical properties at room temperature (RT) under cyclic loading are investigated.

Texture Analyses

Texture analyses were conducted by X-ray diffraction (XRD) measurements. As shown in Figure 1 for an IN 718 specimen (built vertical to the building platform), a preferred orientation along the <001> direction with respect to the building direction is present in the as-built condition (Fig.1a). Compared to the as-built condition, the texture is weaker after HIP (Fig. 1b), which is attributed to the effect of recrystallization during HIP treatment.

LCF tests with different specimens conditions

Figure 2 illustrates the hysteresis loops for ±0.5 % total strain amplitude in four different conditions at RT. Each pair of hysteresis loops are recorded for half

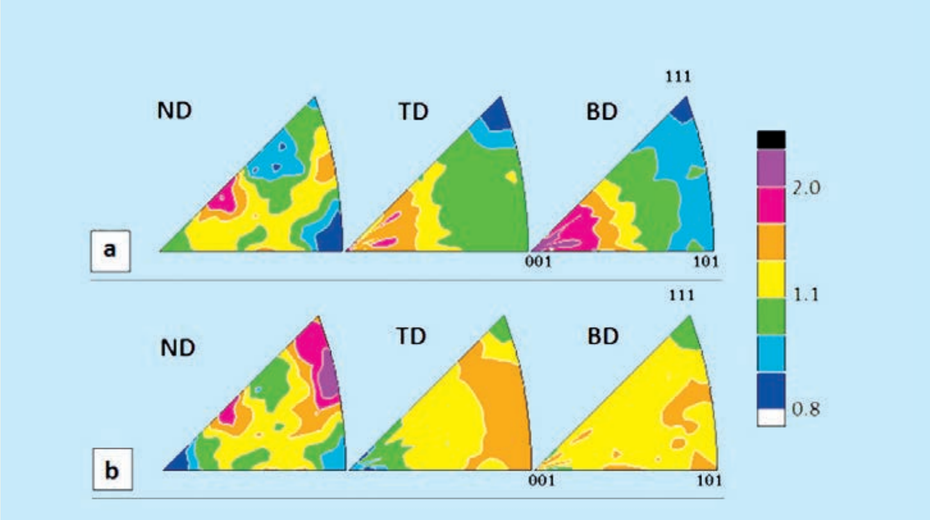


Figure 1 : Inverse pole figures obtained by XRD of IN 718 specimen in the as-built condition (a) and HIP-treated condition (b).

of the lifetime. The hysteresis loop in the solution annealed condition is in good agreement with the results from cyclic stress response for this condition which exhibited the highest fatigue life at ambient atmosphere. This behavior can be attributed to the initially almost sub-micron cell structures which are distinctly formed after solution annealing. The specimen in HIP condition shows more plastic deformation than the other conditions due to the coarse microstructures evolving by the recrystallization after HIP processing. In addition, the specimens have been solution annealed before PVD coating so the bonding of the coating is improved. A similar hysteresis behavior was obtained after PVD+HIP condition.

Figure 3 depicts the cyclic stress response of the SLM-processed IN 718 alloy in different specimen conditions at RT. It can be noted that the tendency for cyclic softening was similar in all conditions. The hardness values of these conditions are reported in the last period. Comparing to the as-built condition, the stress amplitudes of the other conditions are decreased after densification treatments. It was found that the HIP process leads to recrystallization so shape and orientation of the grains are changed. Although the compaction of pores inside the specimen has been successful, the pores near the surface were still open and visible after densification by HIP. Therefore, functional encapsulation is essential. In further experiments, it will be of high interest to understand the influence of different microstructural features and recrystallization on the fatigue life prediction of the material at high temperatures.

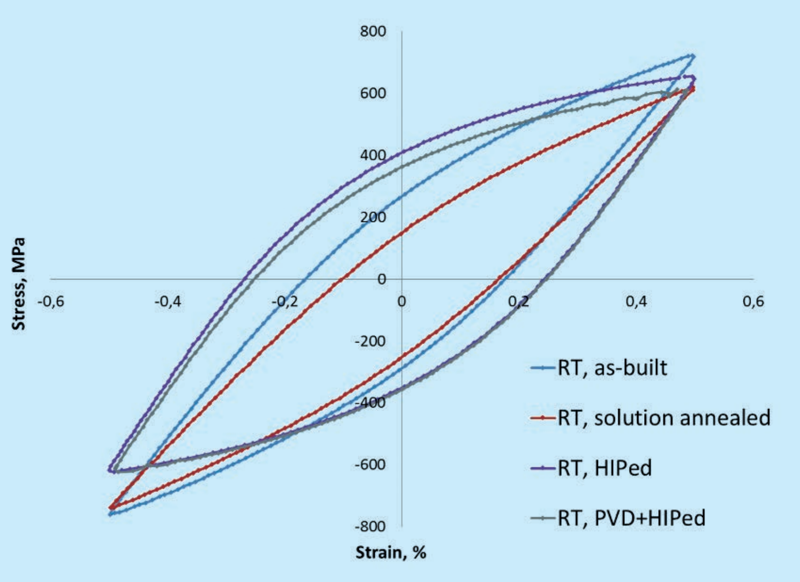


Figure 2 : Half-life saturation hystereses at Δε/2 = ±0.5 % at RT.

Tasks for the next period

For the evaluation of the material response, diverse microstructural features have to be accounted for, e.g. the development of well-defined sub-micron cell structures. One of the main activities during the next period will be investigating the influence of recrystallization after HIP processing on the high temperature mechanical properties.

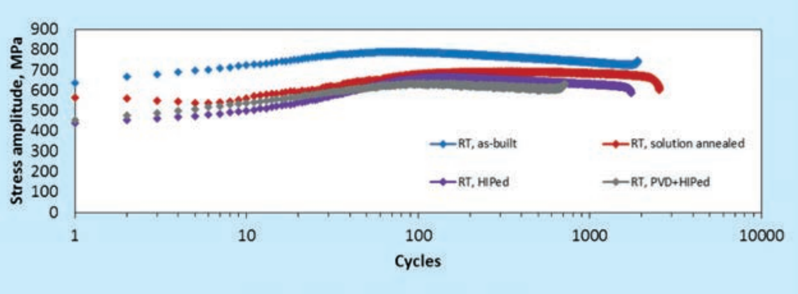


Figure 3 : Cyclic deformation response of additively manufactured IN 718 specimens in different conditions at RT.

it's OWL 3P:
Prevention of Product Piracy

Ulrich Jahnke

Manufacturers of innovative products and products of exceptional quality are often victims of product piracy. Imitators enter the market by copying developed products extensively and reducing the deserved turnover of the original creators. To fight this current threat, awareness of the topic and reliable protection measures are required. 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 "Prevention of Product Piracy" (it's OWL 3P) focuses on raising the awareness that legal measures are just one way to protect innovations and products against product piracy. Consideration of protection needs to be integrated into early stages of product development processes.

Protection during development

Nowadays a high percentage of companies try to counteract piracy just by the use of legal measures as registration of design and utility patents. These measures are important in the fight against counterfeits but they are more reactive than they appear. The imitations are already in the market and so the economic damage is already perceptible before companies can initiate formal complaints. Therefore the project focuses more on a preventive and therefore technical approach for the protection of products. In order to support protection purposes directly during the development process of a product, protective measures using AM have been consolidated in a catalogue (see figure 1). The catalogue lists a general description of the measure's effect as well as specific benefits by the use of AM and exemplary application. This document is available at the DMRC as a basis for further consulting regarding product protection:

Demonstration of AM measures

The measures developed during "it's OWL 3P" consider the early stages of the product development process and

Figure 1: Catalogue of protective measures by AM.

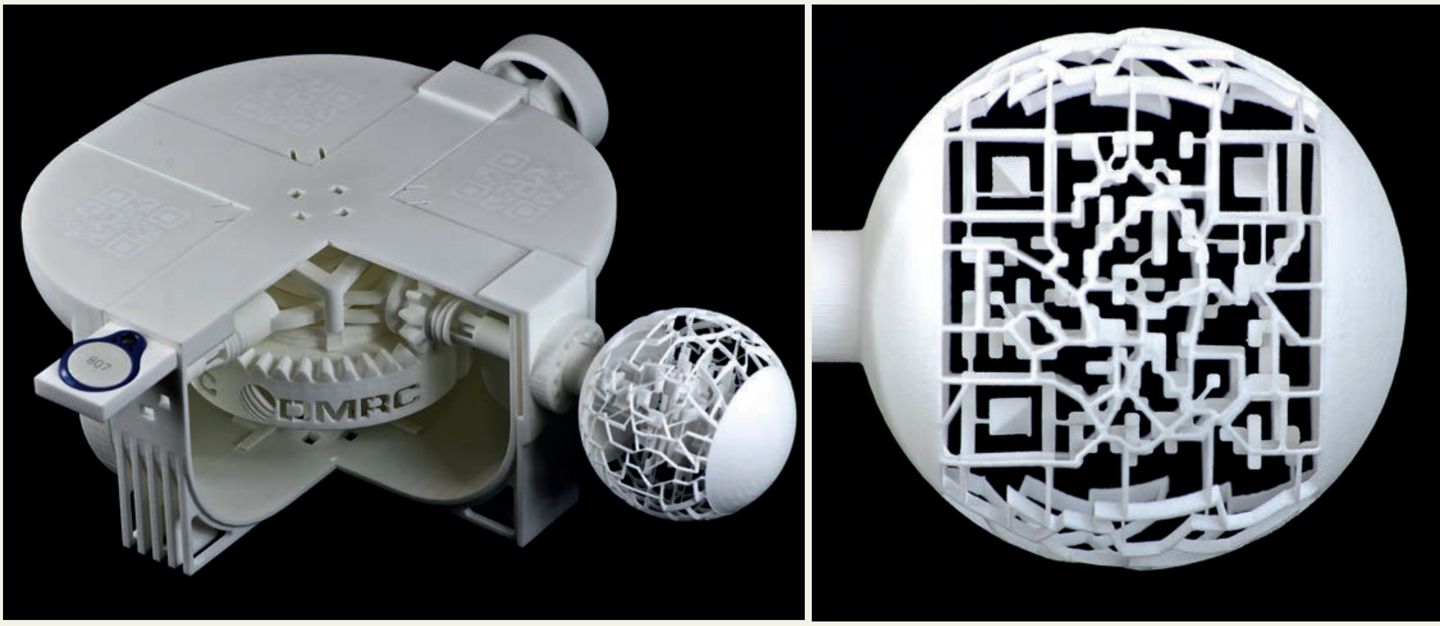


Figure 2: Demonstration of measures combined in one product.

will contribute preventively to the protection of products. Mostly the measures can be applied to a product or a part of a product without increasing the manufacturing costs in the later stages. Figure 2 shows a couple of measures combined in one product for demonstration purposes. Various product-related solutions such as functional integration and the implied and in this case unclosed black box help to imagine the potentials of AM in this context. In the left, figure markings are visible that are integrated in the housing as an internal QR code, an RFID chip is not directly producible in this manufacturing process but can be integrated by designing two parts fitting to each other. The ball with its internal structures on the right shows a peculiar design of a QR code so that it only becomes visible and scannable in the intended perspective.

The DMRC cooperates with the Heinz Nixdorf Institute (HNI) of the University of Paderborn, the Fraunhofer Project Group – Mechatronic System Design (IPT-EM) and the UNITY AG as project coordinator. The companies that are part of the technology network it'sOWL will directly benefit from the projects results. For some companies the threats of product piracy will be analyzed during the project and so they will receive the knowledge of how to counteract. Simultaneously this cooperation with the companies serves to evaluate the applicability and transferability of the projects results.

Feasibility study 3D Printing of electric motors

Stefan Lammers

The central aim of this research project is to investigate and to test the extent to which the technology of Additive Manufacturing is suitable for the production of rotors for encoderless regulated permanent magnetic synchronous machines (PMSM).
Often PMSM metal sheet laminations are difficult to produce with classical methods, for example, when the necessary magnetic saturation comes below the mechanically required minimum width.

Benefits of Additive Manufacturing (AM) in drive technology

Here the method of Additive Manufacturing offers three key advantages towards traditional manufacturing methods.

First, the leakage paths can be designed specifically so that they comply with the mechanical constraints and at the same time have a low magnetic conductivity. Another possibility here is the implementation of fine lattice structures. The design of the rotor is therefore no longer limited to the two-dimensional section, but can be directly three-dimensionally designed and manufactured.

The second point is eliminating the impact of the punching tools and the related uncertainties of the magnetic properties. The new fabrication technology offers significantly better prediction and reproducibility of the magnetic properties.

The last point is the fact, that additive processes such as Selective Laser Melting (SLM) or Selective Laser Sintering (SLS) generate components on the basis of a powdery raw material. This makes it possible in principle to use additively manufactured soft magnetic composites (SMC) within this project. SMCs are powdered materials, which are used in drive technology applications and which promise excellent electromagnetic characteristics.

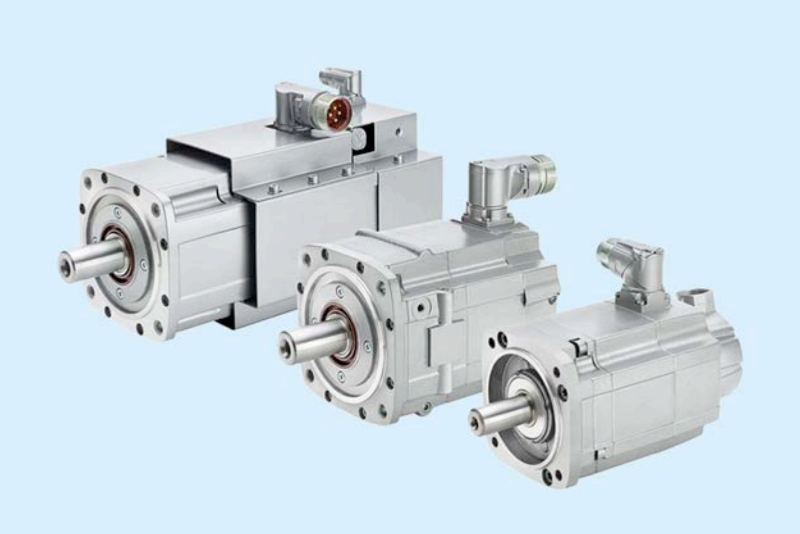


Figure 1: PMSM motors [Source: Siemens].

Planned actions

To take advantage of these benefits, metrological tests will be performed on specimens and on a prototype. So the feasibility of Additive Manufacturing will be demonstrated in drive technology.

For this purpose, fundamental knowledge of Additive Manufacturing will be combined with those of the drive technology to find synergies. In addition, the planned SMC must be investigated on its workability by means of Additive Manufacturing processes. If this is not possible, it has to be replaced by a suitable material. The selected material is studied in terms of its mechanical, process engineering and electromagnetic properties in order to use it subsequently for manufacturing a rotor demonstrator.

This demonstrator will be manufactured with a suitable Additive Manufacturing process at the DMRC. Therefore, design data will be provided with information about dimensions and shape. This design data will be adjusted for the SLM process. To ensure this the design rules of the DMRC provide the basis. Furthermore, the rotor will be machined and equipped with permanent magnets before it will be mounted into the existing stator housing. The assembly will be coupled with a load machine and the torque will be recorded. In addition, the usability for a sensorless operation of the rotor will be investigated and and overspeed tests will be performed.

Description of work performed so far and further proceed

In the early stage of the project it was detected that SMC material is not machinable with the SLM process. This is due to the fact that SMC materials are covered with an inorganic layer that cannot be melted defined. So a connection between nearby powder particles is not possible. In addition, the SMC material has to be processed under certain pressures, which cannot be realized within the SLM process. For these reasons, an alternative material was determined. For this purpose, process engineering, mechanical, electromagnetic, but also economic requirements and the availability of the material were considered. As a result of these requirements, the material H13, which is approved for the SLM process, has been selected for further investigations.

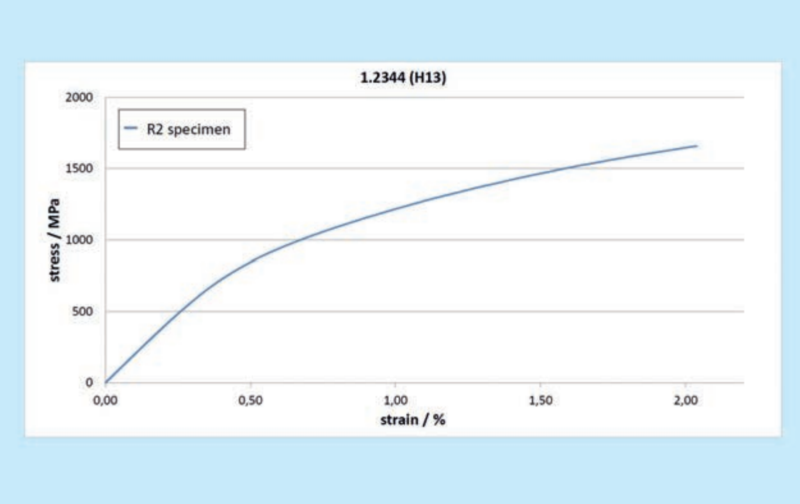


Figure 2: Stress-strain-diagram of the chosen material H13.

Since H13 has disadvantages in the electromagnetic characteristics, structural measures have been determined to compensate these disadvantages. The material properties of the additive condition were determined based on meaningful test specimens. Based on these results (e.g. Figure 2) and the DMRC design guidelines, a rotor demonstrator has been designed. This for AM- adjusted rotor was produced with the SLM process. In the next steps, the rotor will be machined and fitted with magnets. The finished rotor will then be installed in an existing stator. The resulting PMSM will be examined for its performance characteristics and subjected to various tests.

Project NewStructure: Direct Manufacturing of structure elements for the next generation platform

Thomas Reiher

The aim of the project “Direct Manufacturing of structure elements for the next generation platform” – initiated and funded by the European Space Agency (ESA) – is to examine the ability of using Additive Manufacturing for producing structural metallic parts mainly used in actual telecommunication satellites. Therefore trade-off methodologies to select feasible parts, test and verification plans as well as manufacturing strategies for space parts are to be developed.

Participating partners

There are four companies participating in this external project. The project is funded by the ESA and led by the DMRC, it started in November 2013. The project partner “Invent GmbH” works on structural parts for satellites made from composites or metals and brings in a lot of experience in designing and certification of these parts. Knowledge on satellite systems, potential components for the optimization and the needed requirements are provided by the system manufacturer “OHB Systems AG”. The manufacturing of the sample parts will be made by “citim GmbH”, an experienced manufacturer for prototypes and small series. For production of space flight-relevant metal parts machines of the “SLM Solutions GmbH” are used. SLM is the fourth partner in the project, bringing in the experience in Additive Manufacturing, as known from the work in the DRMC and with citim.

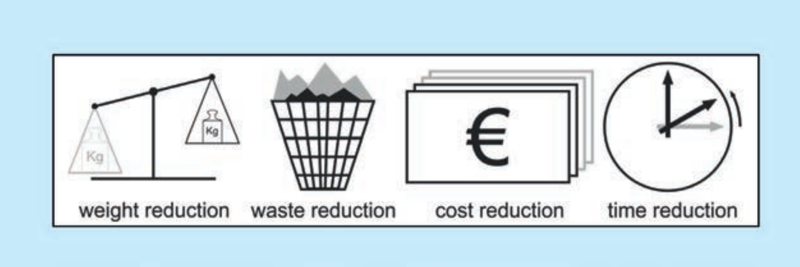


Figure 1: New Structure objectives in a nutshell

Project Goals

In a first step, a trade-off methodology was developed and used for selecting sample parts of already developed satellites. Based on this procedure, actual structure elements were identified and assigned:

- Case A parts: identical elements applicable to each platform
- Case B parts: more complex parts featuring a high buy-to-fly ratio

Typical relevant parts are those with a high buy-to-fly ratio and time-consuming or complex fabrication steps. For each case one part was examined in detail. These parts were built in the Selective Laser Melting (SLM) process. The resulting improvements gained by changing the manufacturing process regarding costs and weight were figured out.

Additive Manufacturing and testing of space parts

For manufacturing of space parts there are special requirements like an extremely high reliability and lightweight design demanded. Additive Manufacturing enables these lightweight designs but also requires a special quality assurance. Therefore, a space dedicated test and verification plan as well as a special manufacturing strategy for both parts was developed. This will help to ensure a certification for space use. The testing includes material tests for example regarding stress corrosion susceptibility, crack growth and tensile strength but as well part related process control like density and accuracy tests.

How are cost reductions possible?

It will be analyzed which cost reductions can be achieved by Additive Manufacturing due to three different reductions.

- Reduction of weight used in the satellite
- Reduction of waste in production do to fabrication processes
- Reduction of manufacturing time

Selected and redesigned parts

For the examination of cost reduction for near series production of identical parts applicable to each platform (case A) the “edge inserts” were selected. They are glued into CFRP-panels and are used to provide screw holes for mounting of further parts. Many of them fit into one build job and thereby a reduction of manufacturing time is expected.

Figure 2: Additive manufactured case A parts: “Edge Insert”

For the evaluation of weight, waste, time and cost reduction for complex parts with a high buy-to-fly ratio due to redesign of elements the “Reaction Wheel Bracket” is used. Four of these brackets are used per satellite to mount a reaction wheel for adjusting the orientation of the satellite without using propellant. The part was redesigned with a topology optimization to gain a huge weight reduction.

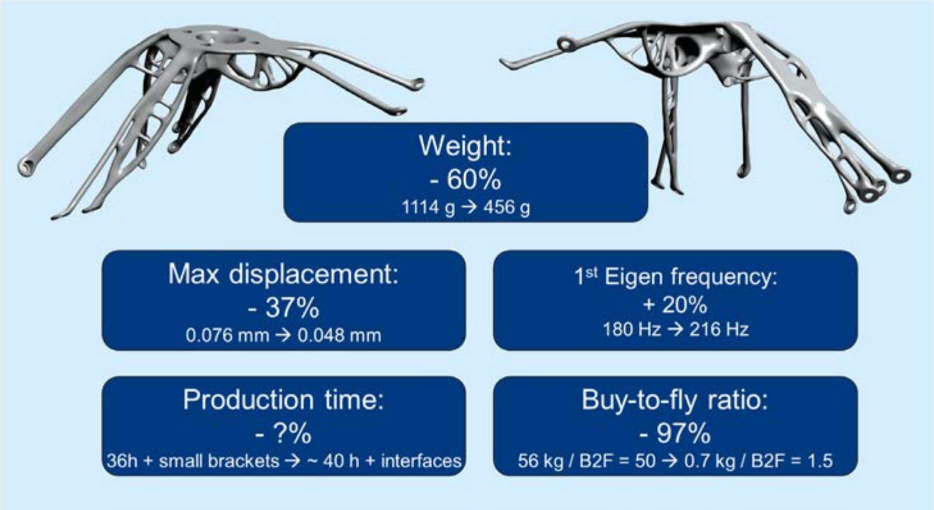


Figure 3: Optimized satellite part and achievements for “Reaction Wheel Bracket”

Project RepAIR: Future RepAIR and Maintenance for Aerospace industry

Gereon Deppe

The goal of this research project with twelve partners from all over Europe and from the US is the onsite maintenance and repair of aircrafts by integrated direct digital manufacturing of spare parts. Cost efficient and lightweight but robust reliable parts are obligatory for aircrafts. Additive Manufacturing allows completely new approaches: The main objective of RepAIR is to shift the 'make-or-buy' decision towards the 'make' decision by cost reduction in the remake and rework of spare parts and therefore to improve cost efficiency for maintenance repair in aeronautics and air transport.

To foster this development the RepAIR project receives funding from the European Union Seventh Framework Program with a total project budget of 5.971.421 EUR. The project aims to reduce the Maintenance, Repair and Overhaul (MRO) costs with the help of the Additive Manufacturing (AM) technology as its crucial advantage is the flexible availableness allowing ontime maintenance. The AM operations require a higher qualification and promote the preservation and expansion of highly qualified workplaces in Europe.

Moreover, the storage costs will be significantly reduced and less capital is locked up. Additionally, hardly any raw material will be wasted or destroyed, but will be used optimally. New business models will become sustainable. When applied in design of new parts, the technology allows significant weight savings. These weight savings will result in less fuel consumption, therefore in a more sustainable way of flying and in a reduced carbon footprint.

Additive Manufacturing in MRO

Competitive carriers focus intensely on low costs of repair services and materials while retaining consistent parts and service quality. The maintenance of complex components such as engines still takes place at nearly 100% in Europe. But for European MRO providers the danger of further displacement still endures.

To face this danger one has to keep and expand the advance through mastery of knowledge and technological lead. With the integration of functions more complex components emerge, whose maintenance could be taken over by technological leading MRO providers.

A particular prospective benefit is promised by the AM technology. It offers a considerably lower buy-to-fly ratio of material, an omission of harmful chemicals (e.g. cutting oil) and constant manufacturing efforts at an increasing complexity (single piece assembly). Further improvements of the technology concerning the processing time, accuracy and costs are foreseeable. However, a holistic integration in the MRO processes is not yet researched.

Description of work performed so far and main results

In order to achieve the project's objectives a roadmap for the further progress and research needs of the considered technologies has been generated. A prototype Decision Component tool has been developed to calculate an AM part repair or production. A test rig has been installed and a methodology has been developed to perform experiments in order to predict the remaining lifetime of a part. Improvements are made directly focusing on AM repair in MRO in processes for high batch repair of identical parts and in controlling an integrated 5-axis DMD/tooling machine. The high batch repair process has been demonstrated to work properly handling the chosen sample part. Based upon the previously summarized regulations and requirements on the certification process, a conceptual design for a qualification process using AM has been developed. A quality manual model with specific procedures for the newly developed workflow has been derived. Within the first RepAIR workshop, project results available up to that point have been evaluated. Key performance indicators (KPI) for management platform and subsystems have been established. For the dissemination and exploitation of the results various activities have been performed. Based on the dissemination strategy, several conference presentations were given and papers were published. The exploitation plan has continuously been synchronized with individual exploitation plans of each partner

Collaboration partners of DMRC in RepAIR

APR Srl (Italy), AIMME (ES), Avantys engineering (DE), ATOS (ES), The Boeing Company (US), Cranfield University (UK), Danish Aerotech (DK), Danish Technology Institute (DK), Lufthansa Technik (DE), O'Gayar Consulting 2009 (ES) and SLM Solutions (DE)

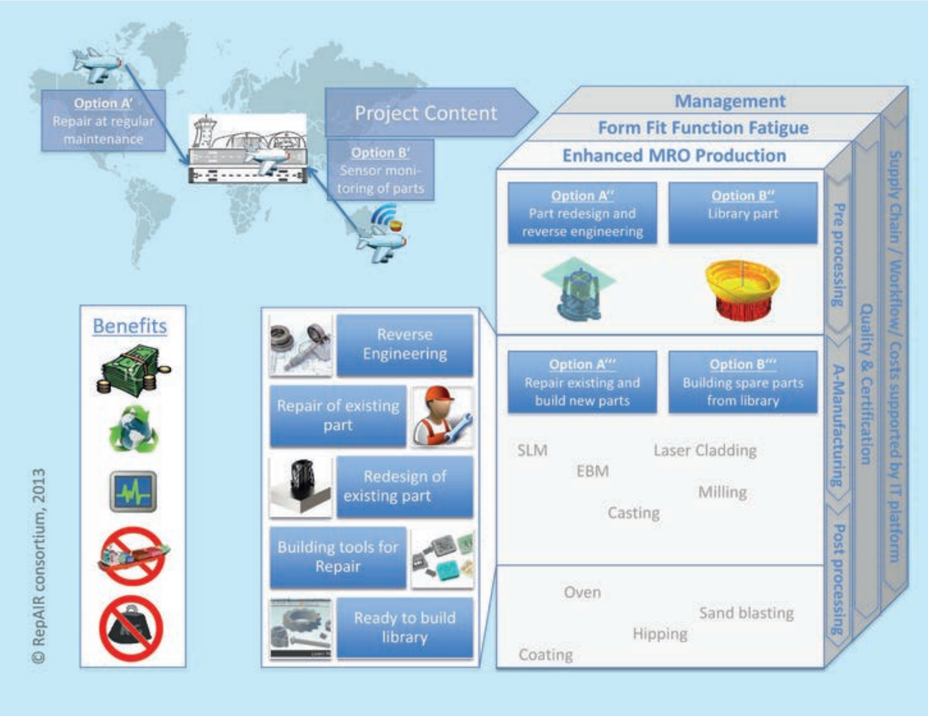


Figure 1: The RepAIR Concept

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

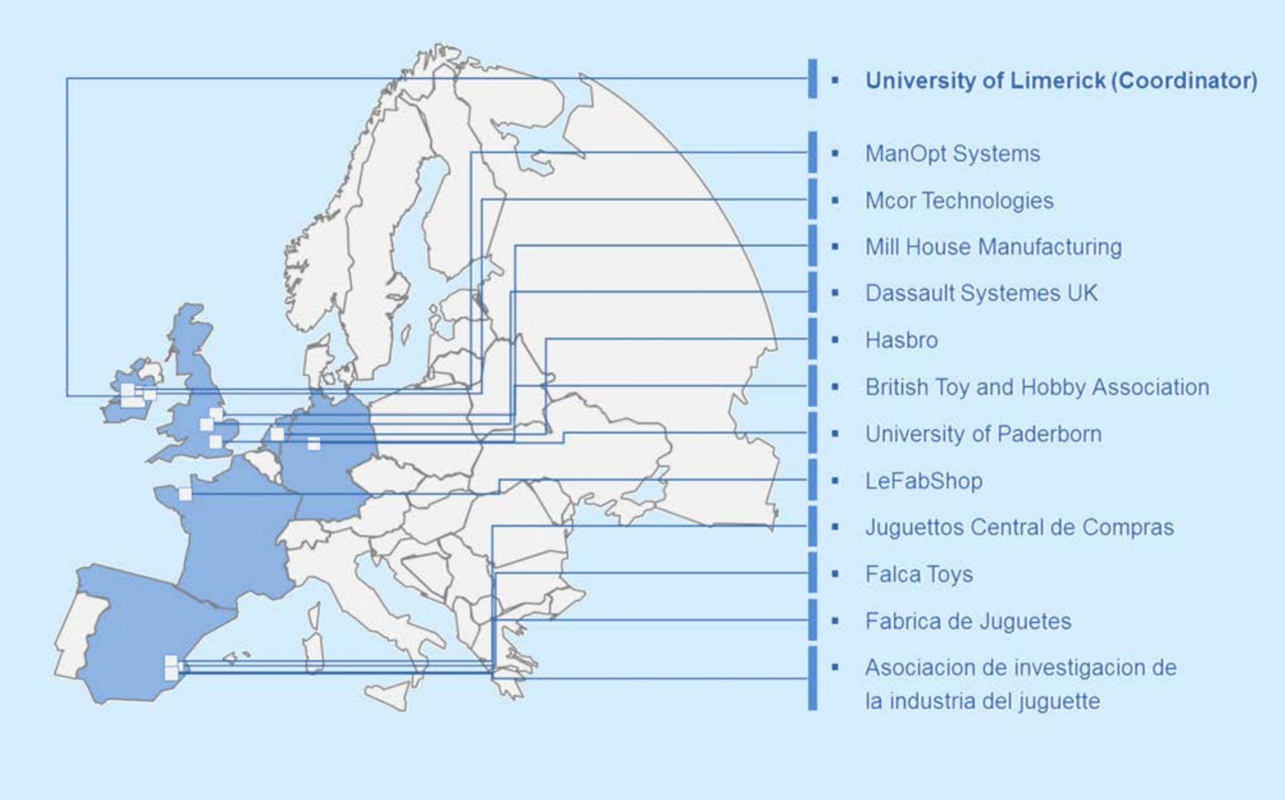
Thomas Reiher

The overall objective for iBUS is to develop and demonstrate by 2018 an innovative internet based business model for the sustainable supply of traditional toy and furniture products that is demand driven, manufactured locally and sustainably, meeting all product safety guidelines, within the EU. The iBUS model focuses on the capture, creation and delivery of value for all stakeholders – consumers, suppliers, manufacturers, distributors and retailers.

Project Goals

The main focus of iBUS is to drive sales for EU traditional toy and furniture manufacturers by leveraging internet based technologies, focusing on safe products, quality, design and innovation. In this new iBUS model consumers become designers, designing, customising and placing orders for their own products online in the iBUS cloud. They will be supported by embedded services in iBUS, 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 Manufacturing. Subsequently, parametric engineering design principles will take the design from concept to demand. This demand will then be synchronized and optimized across the supply chain, supported by the embedded supply chain optimization tools, to produce sustainable demand

Figure 1: iBUS –participating partners.



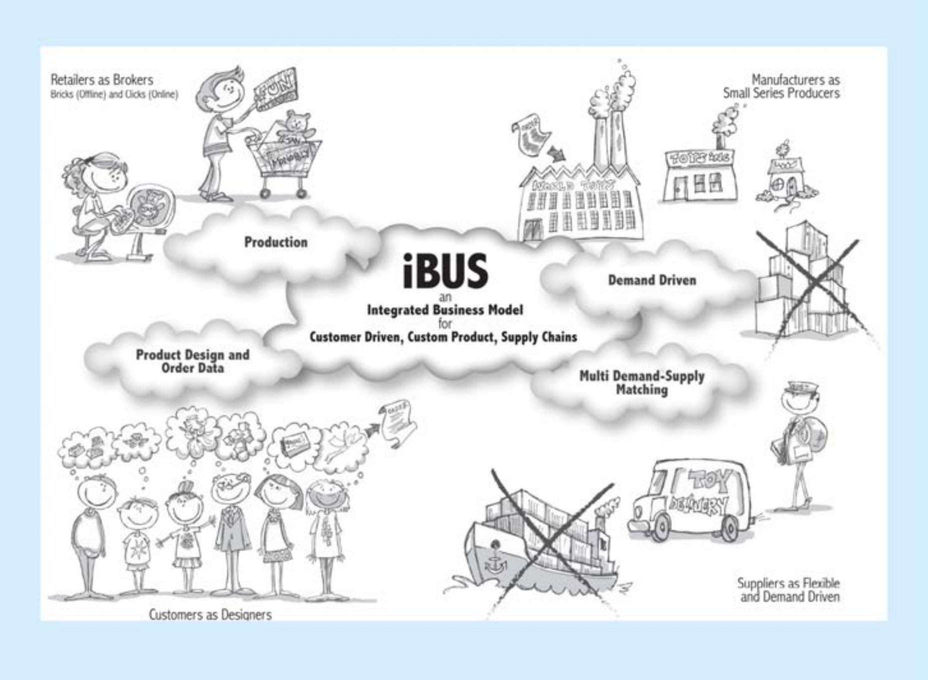


Figure 2: iBUS – an integrated business model for customer driven custom product supply chains.

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.

DMRC Participation

The main participation of DMRC is in "Customised Product Design Virtual Environment" (WP3). Here, a software system shall be developed enabling the customer to design the product himself. Self-designed products have to be manufacturable and to follow the European safety guidelines. Therefore the system has to check these requirements to ensure a safe production. 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.

4 Finished Projects


Guido Adam

Direct Manufacturing Design Rules

The research project “Direct Manufacturing Design Rules” (DMDR, 2010 - 2013) aimed at developing design rules for additive manufacturing processes. Therefore, geometrical standard elements were defined, manufactured and analyzed within experimental tests. Based on the results, design rules were developed and summarized in a design rule catalogue.


Matthias Fischer

FDM part quality manufactured with Ultem*9085

The material Ultem*9085 is an interesting material for aircraft and automotive industry, because of its good mechanical properties and in comparison to other materials its lower density. In this project material and mechanical properties were analyzed depending on the orientation of the setup in the FDM process. Sample parts were generated with the given parameters for the FDM plant Fortus 400mc. The mechanical tests conducted are tensile, flexural, compression and Izod Impact tests. Additionally, a comparison to injection molding was performed as well as an analysis of FDM process stability.


Agnes Bagsik

Ageing effect on FDM parts made of Ultem*9085

The aim of this research project was to analyze FDM parts relating to the long-term behavior. For this purpose, parts manufactured with the FDM technology and with the material Ultem*9085 were exposed throughout the whole year 2011 regarding to a systematic test plan to analyze the change of mechanical strength properties. The exposure was done for defined exposure times at different conditions, temperature levels and in multiple media.

Improvement of the FDM Process Quality

The aim of this project was to improve the layer-to-layer bonding by focusing on the fill geometry. Therefore, a design of experiments was conducted to determine the driving factors of the mechanical properties in the Z-axis of FDM parts. Furthermore, the impact of seams on the Z-axis mechanical properties, the effect to the aspect ratio and physical factors were analyzed. Additionally, an optimum build style was carried out.

Surface Treatment Methods for FDM Parts

Parts produced by Fused Deposition Modeling tend to have rough and undulating surfaces with stair stepping effects on rounded and slanting areas of the component. In many fields of application, high demands are placed on the optical quality of the component. Within this project different treatment methods of FDM Ultem*9085 parts were analyzed. The main methods were grinding by disc finishing, coating with a filler and chemical treatment.

Finished Projects


Matthias Fischer


Stefan Rüsenberg

Analysis of the FDM Part Quality manufactured with ABS M30 with the focus on the toy industry

In this project a database was established for parts manufactured with Fused Deposition Modeling and the material ABS. First mechanical properties were investigated with the aim of optimizing the FDM process parameters. Furthermore, the surface of ABS parts was analyzed and different smoothing methods were carried out. Additionally, the dimensional accuracy was determined for different standard elements and sample parts from the toy industry.

Polymer Laser Sintering Process Training Using a Landing Gear Wind Tunnel Model Part

The main goal of this first polymer Laser Sintering project at the DMRC is the training on the used equipment by manufacturing of aircraft landing gear models for wind tunnel tests. Material characterization has been performed on both models and specimens, for example tensile tests, surface characterization and dimensional accuracy. In addition, an FE analysis has been performed and compared to load tests on the model.

Influencing Factors on DM Part Quality by Polymer Laser Sintering

In this project, general influencing factors on the quality of Laser Sintered parts have been analyzed. Built with standard PA 2200 material, the influence of build orientation, placement within the build chamber, layer thickness and energy density has been figured out. In addition, the build repeatability over a period of one year has been examined. Performing industry visits and literature research, the state of the art in polymer Laser Sintering and needs for further research activities have been analyzed.

Determination of Material Properties by References to a Real Product, Optimized for Laser Sintering

To ensure a high quality production of Laser Sintered parts in industry, the whole process chain from the CAD data to the finished part is taken into account. Therefore, especially material qualification has been in focus of this project. A full set of advanced material properties has been obtained according to reference procedures that can be applied to new materials and machines. The results were used to perform a case study (re-design, FEA, build and test) on an air duct for application in aircraft.

Stefan Josupeit

AMP^2: Advanced Additive Manufacturing Material & Part Properties – Reduced Refresh Rates & Cooling Process regarding LS

This project treats two important challenges regarding polymer Laser Sintering: The first aim is the analysis and characterization of a recycling optimized material, PA 2221, which has been shown to be suitable for reduced refresh rates without disadvantages regarding part quality. The second aim is the analysis of the temperature history within the part cake and its influence on process quality. Therefore, a temperature measurement system has been implemented within the LS equipment to track individual, position dependent temperature histories.

Stefan Leuders

Characterization and comparison of mechanical properties of SLM materials with regard to process cycle time improvement

Since a high productivity is a crucial criterion for the use of a specific manufacturing process, the aim of this project was to develop optimal process parameters for a recently presented SLM system. By use of an additional laser and an adapted exposure strategy, significantly higher build-up rates have been achieved by this technique. Furthermore, also the material properties in terms of microstructural and mechanical features have been characterized for stainless steel 316L, processed by this new SLM system.

Andre Riemer

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 performed.

Markus Thöne

Influence of heat treatments on SLM components

Heat treatments during or after the SLM process strongly affect the microstructural and mechanical properties of the processed materials. Furthermore, residual stresses can be reduced or even completely avoided using an appropriate heat treatment. Therefore, the aim of this project was to analyze the influence of different heat treatments on the component properties and finally to deduce optimal parameters regarding the time-temperature-profile.

Product optimization for SLM-process

The major goal of this project was to characterize the material properties of a Nickel-based superalloy processed by Selective Laser Melting. Thus, the microstructural as well as the mechanical behavior of this alloy have been investigated. In order to optimize both aspects, material specific post treatments have been developed. Afterwards, the obtained results have been transferred to a demonstrator-component.

Opportunities and Barriers of Direct Manufacturing technologies for the Aerospace Industry and adapted others (OBaMa)

Goal of the project were technology roadmaps outlining the necessary technological development in the future. Therefore, scenarios for selected industries were developed, enabling us to think ahead future application. These applications impose requirements on Additive Manufacturing. With the help of experts we were able to determine a time scale when AM will be able to fulfil these requirements.


Marina Wall

Development of a Strategy for the DMRC

Following the results of OBaMa, research strategies for AM-institutes should be developed. To find promising research topics, a research landscape has been drawn encompassing leading institutes, research topics and technologies. By contrasting current research work with the necessary technological development (technology roadmaps) white spots could be identified. Based on this, consistent research strategies were designed.


Stefan Peter

CoA²mPLy: Costing Analysis for Additive Manufacturing (AM) during Product Lifecycle

The goal of this research-project was to understand and rate the cost drivers that act as the largest contributors to unit costs and to provide a focus for future cost reduction activities for the AM technology over the whole lifecycle. The results helped to identify success factors for cost reduction in the field of Additive Manufacturing. An exemplary metal part was used to collect data and to raise the understanding of AM cost drivers. This increased the fields of application for additive manufactured parts focusing on Metal Additive Manufacturing (MAM). A better understanding of the cost structure now helps to compare the AM costs with costs of traditional manufacturing technologies. This helps to justify the use of the AM technology.


Christian Lindemann

Optimization of lattice structures manufactured by Selective Laser Melting

The project aimed at characterizing the deformation behavior of metallic lattices structures produced by selective laser melting. As the part performance highly depends on the actual lattice type and the material employed, a bending dominated and a stretch dominated lattice type and two different materials, namely 316L stainless steel and Ti-6Al-4V alloy, were contemplated. Quasi-static and fatigue tests were carried out. The observed mechanical performance was correlated to the local strains distribution as determined by digital image correlation. Clearly different failure mechanisms were revealed and possibilities for an optimized design were opened up.


Florian Brenne

5 Involved Chairs and Institutes

KTP

LiA
www.Leichtbau-im-Automobil.de

University of Paderborn
Design and
Drive
Technology
KAt

PVT

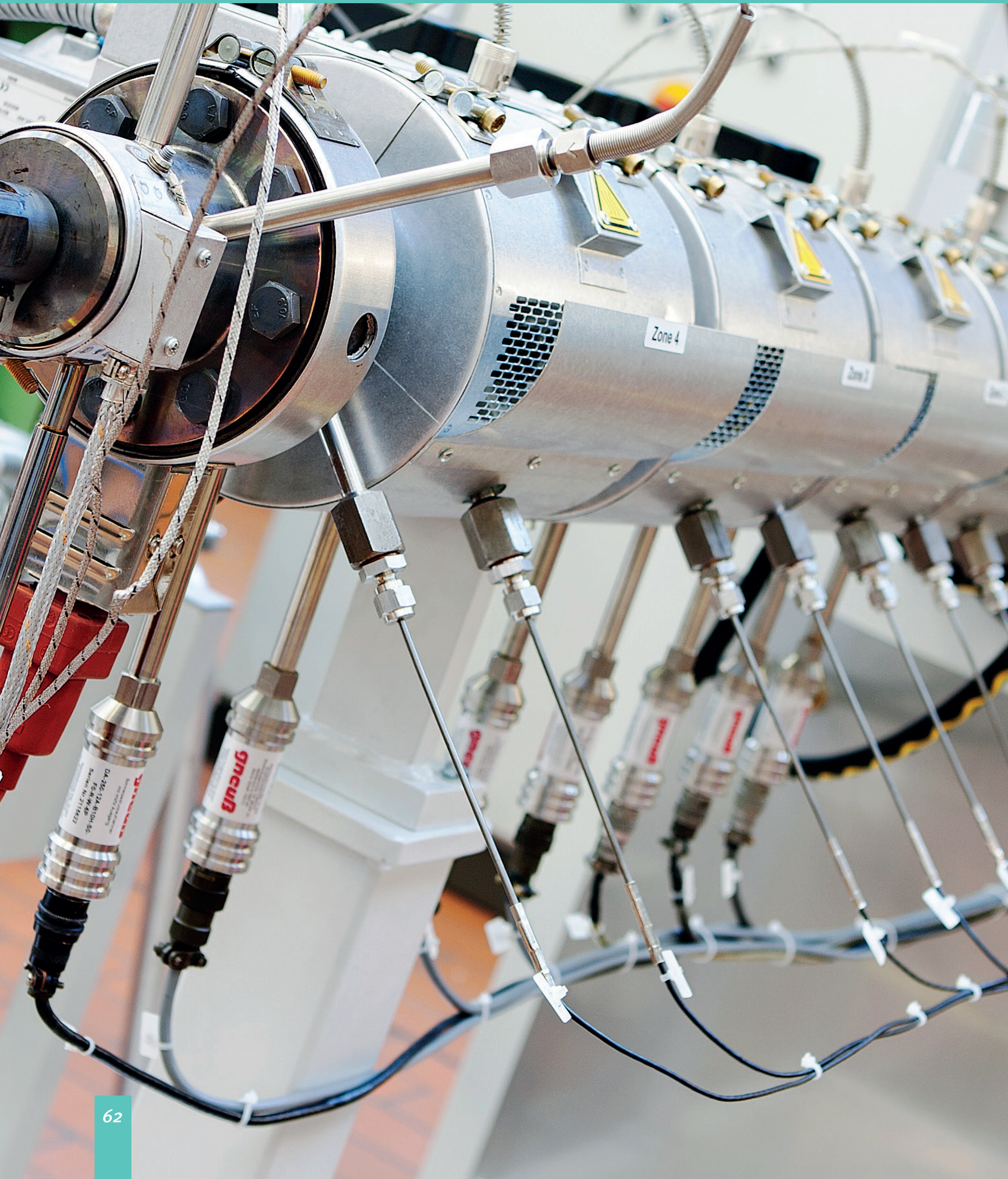
FAM

HEINZ NIXDORF INSTITUT
UNIVERSITÄT PADERBORN

LWK
Lehrstuhl
für Werkstoffkunde

c.l.k.

TMC
Chair for Technical and Macromolecular Chemistry


Zone 4
Zone 3

Polymer Processing

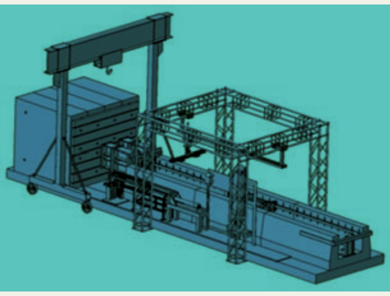
The KTP stands for thirty years of successful research and development of manufacturing processes in the field of polymers and rubbers. This results in a qualified training in the theoretical and practical field of polymer engineering as well as in an intensive cooperation with regional, national and international industrial companies. International congresses and conferences are regularly participated by the KTP staff. The KTP belongs to the faculty of engineering at the University of Paderborn and its two professorships 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 as innovative solid material, the potential of which is by far not exhausted. Polymers become more and more significant in the field of mechanical engineering, above all in the automobile industry, 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 foci have a special concentration on the transformation of process models, which have been built on the basis of process analyses (experimentally or theoretically), into tools to simulate polymer processing procedures. The central aim is the simulation of the process chain from the molecule to the end product. Due to the experimental verification of the models and 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 strongly feedback-oriented proceeding, real processes in the laboratory- and production measure – the latter often in cooperation with industrial partners – 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.

Komponentencrashanlage des Lehrstuhls



Chair of Automotive Lightweight Construction
-Endowed chair by Benteler AG since 2007-

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 efficiency 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.

Furthermore, the research focus is on materials and process fundamentals for the development and manufacturing of hybrid-components. Here, different materials, e.g. metals and fiber-reinforced plastics, are combined and processed in order to allow for a symbiotically usage of the specific advantages of each material.

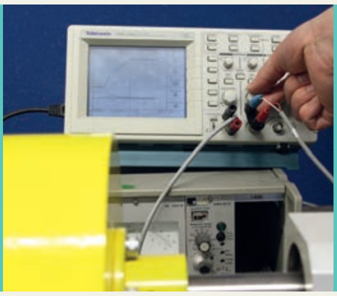
Equipment

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 SolidWorks, Abaqus, LS-Dyna and Hyperworks.

University of Paderborn

Design and
Drive
Technology



Chair for design and drive technology

The focus of our work lies on theoretical and experimental investigations regarding drive conceptions and on the extensions of drives' application limits.
Thereby, key aspects are

- the reduction of the resources needed for the operation of drive systems, and
- the modularity of drive systems in the context of an intelligent variant management.

The optimization of components, assemblies and machines by
- systematic, function-oriented and production-oriented design is another area of work of our chair. Thereby, an important aspect forms the
- tolerance management.

Regardless of the task field, we often work with industry partners on joint projects.
Primarily, we deal with
- drive systems, such as „energy-efficient spring-applied brakes“, „self-optimizing air gap adjustment“, „multi-drive concepts“, „modular drive systems“
- drive components, such as „power loss reduced sealing systems“, „reduction of fretting corrosion“ and
- design technology, such as „development of design rules for additive manufactured parts“ and „tolerance management“.

For our work we usually use software tools to create geometry (CAD), for modeling and calculating the motion behavior (multi-body simulation). In parallel, we develop and use test equipment to conduct experimental studies.
In teaching, we offer courses on the following topics:

- Basic bachelor studies: Technical drawing, machine elements - fundamentals, machine elements - joints, machine elements – drive components, design drafts.
- Deepening bachelor and master studies: Methodology of design, technical design, industrial drives and geometrical tolerancing.

PVT

Particle Technology Group (PVT)

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 product property. Therefore, doing fundamental, publicly funded research is considered to be equally important as cooperations with companies on very specific projects to develop solutions in the field of particle technology. The Particle Technology Group performs research and offers expertise in the following fields:

Particle synthesis

- Aerosol particle formation
- Precipitation / crystallization in liquids

Characterization of particles and dispersed systems

- 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

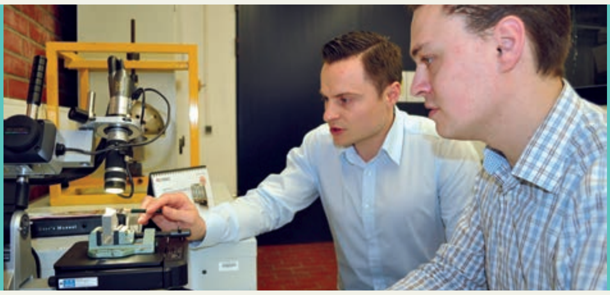
Handling and manipulation of particulate systems and products

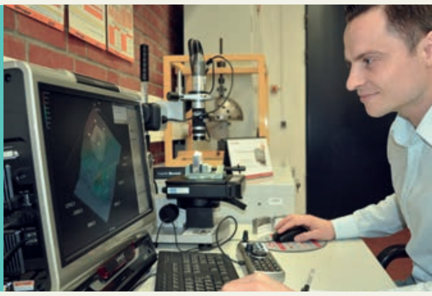
- Production of composite materials
- Filtration and separation
- Dispersion and mixing technology
- Interface phenomena and nano-particulate systems

Simulation of particulate systems

- Particle level (e.g. simulation of evolution of particle properties)
- Unit operation level (e.g. Computational Fluid Dynamics, Population Balance Modeling)
- Process level (e.g. flow-sheet simulation of complete particulate processes)

FAM





Institute of Applied Mechanics FAM

Teaching and training

The lectures of the institute of applied mechanics impart basic knowledge and procedures to assess stress conditions and the course of movements of components as well as of machines. Model design, which identifies the process of transferring real components into abstract models for calculation purposes, plays an important role. During the undergraduate study period the courses impart basic knowledge concerning technical mechanics (static, strength theory, dynamics). During the advanced study period teaching results of basic research and practically oriented knowledge especially with respect to strength optimized and fracture save design, methods of structure analysis, the Finite-Element Method, computer supported product optimization and biomechanics is essential.

Research

The FAM conducts application oriented and pure 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 Finite-Element-Method 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 extension 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 designing of the human bone structure with the help of computers over the simulation of courses of movement up to the optimization of implants and prostheses and the development of intelligent healing aids. The aims are the evaluation of injury risks, the avoiding of resulting injuries and the optimized use of prostheses and implants. The third area of research “Optimization and new development of products in cooperation with industrial partners” deals with the solving of concrete problems which occur in practice by implementing the above mentioned core competences.

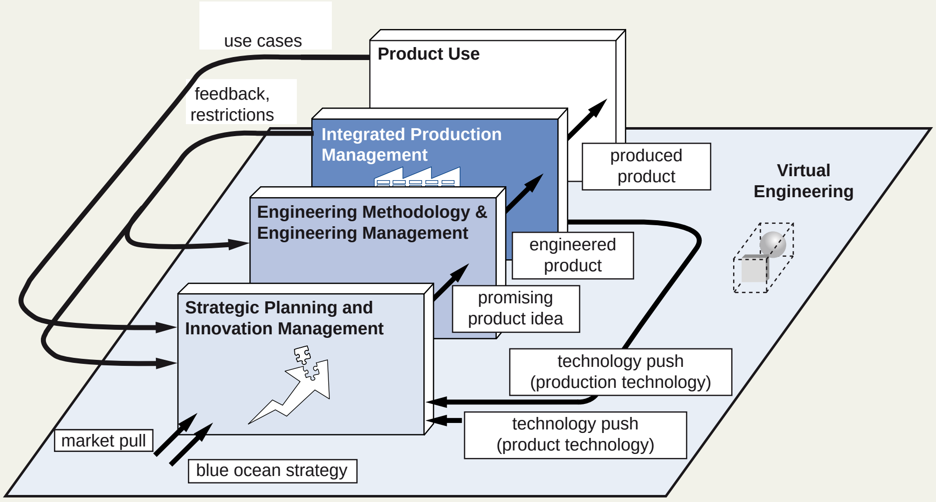
HEINZ NIXDORF INSTITUT
UNIVERSITÄT PADERBORN

Chair for Product Creation

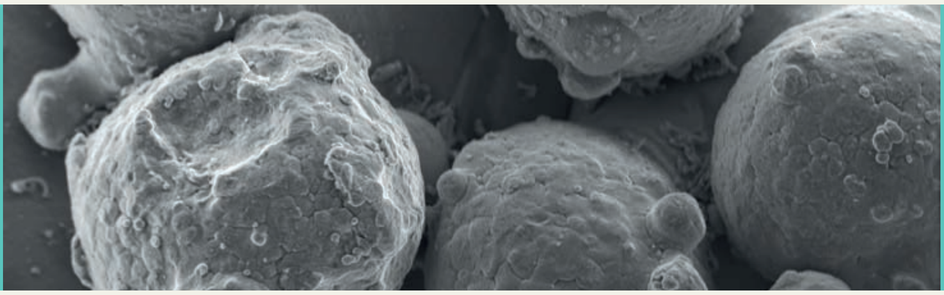
The chair's field of action spans from planning business strategy to the produced product (figure 1). Within strategy planning and innovation management, promising product ideas are generated by systematically forecasting markets, technologies and business periphery. In addition, strategic business segments are planned and creativity techniques are applied. Strategy planning is triggered either by the market or by new technologies.

Additive Manufacturing is an impressive example of product technology push as well as production technology push. On the one hand, new business chances result from innovative core products, characterized for example by outstanding material properties or 3-dimensional geometries which cannot be manufactured by conventional dissipating production technologies, such as milling or turning. On the other hand, new services can be offered, such as provision with a component's 3D geometry for end production at the customer's 3D-printer. Therefore, we support companies in identifying and measuring their specific potential of using additive manufacturing as product or production technology.

In case of a sufficient potential of Additive Manufacturing for a specific business segment at a company, we support strategic orientation, product program planning, engineering methodology, production planning and implementation of additive manufacturing. Engineering methodology provides tools and methods of functional realization of the product. Virtual and Augmented reality is used as an enabler. Early consideration of production constraints, such as production site or degree of automation, is supported by integrated production management.



LWK
Lehrstuhl
für Werkstoffkunde



Chair for materials science

As the majority of innovations is based on the development of new materials or on enhancements of materials already used, the field of materials science is one of the key activities of today´s research in academia and industry. Under the impact of the increasingly scarce resources the efficient use of materials is the central theme for actual developments. Different strategies can be observed in order to improve the energy consumption of moving parts as well as the overall material amount used in any kind of construction. Depending on the actual requirements in the application the research efforts aim at improving the specific strength or ductility of the materials (light-weight concept) or at integration of additional functions to the materials, as for example can be observed in case of shape-memory alloys. Other approaches comprise the combination of different materials in order to obtain completely new properties or the enhancement of the material behavior through an optimized microstructural design by advanced proce ssing techniques.

Consequently, the major objective of research at the chair of materials science is to develop validated material models, which allow for predicting the behavior of materials and components under actual loading conditions. In the experiments the stress-strain response and damage evolution of various materials under superimposed mechanical, corrosive and thermal loading conditions is studied. Most of the materials tested are high-performance metallic engineering alloys.

The research projects cover following subject areas:

- Production of aluminum-steel clad strips by means of twin-roll casting
- High temperature fatigue behavior of nickel based superalloys
- High temperature shape memory alloys
- Microstructural investigations of aluminum and copper wire bonds
- Optimization of materials processed by selective laser melting
- Heat treatment of high strength steels for the production of hybrid metal structures with tapered properties and its microstructural characterization
- Development of new materials for additive manufacturing
- Intrinsic manufacturing of hybrid structural components in a modified RTM-process
- Investigation on the influence of architecture and doping of diamond like carbon coatings - damage behavior under cyclic mechanical stress

c.l.k.

Computer Application and Integration in Design and Planning

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 the related methodologies. Specific research and work priorities are:

- Analysis of requirements in close cooperation with stakeholders based on the adaption and advancement of approved requirement engineering methods.
- Application of software engineering methods from conceptual design to im-plementation of information systems.
- Evaluation of research results and quality management in the product de-velopment with focus on usability of software solutions.

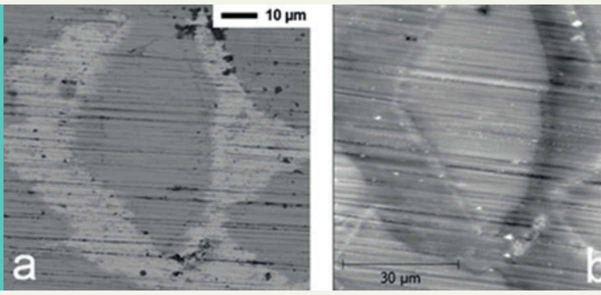
In collaborative research projects the C.I.K. bridges the gap between science, in-dustry and user. This is emphasized by close connections with manufacturing and service companies including small and medium sized enterprises as well as glob-al players. The focus on requirements and goals of human stakeholders supports the transfer of research results into practice.
In the context of decision support and expert systems as well as knowledge based approaches and information management various methods are applied and scientifically analysed. The IT-based collection, processing and target orient-ed 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 identifi-cation and utilization of hidden knowledge as well as IT support in complex envi-ronments.

The research group C.I.K. is one of the leading German institutes for research on civil 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 re-search has been enhanced with the beginning of scientific projects in the field of Additive Manufacturing. The C.I.K. is currently attracting international attention with the coordination of the EU funded project “RepAir” and the ESA project “New Structure”. The gained expertise is the base for our ideas, systems and technolo-gies in the context of planning, coordination support, training and decision sup-port.
Today fourteen 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.

TMC

Chair for Technical and Macromolecular Chemistry



Chair for Technical and Macromolecular Chemistry (TMC)

The chair of Technical and Macromolecular Chemistry TMC leaded by Prof. Dr.-Ing. Guido Grundmeier is organized into three research fields namely

- "Interface Science and Adhesion"
- "Surface Technology and Corrosion"
- "Nanobiomaterials".

Structures, forces and processes at interfaces are of utmost importance for materials development in various technological fields. Examples of modern applications of interface-dominated materials are polymer/metal composites, biomaterials, particle technology or energy conversion.

Researchers at the TMC are developing new analytical methods and surface technologies in the fields of

- in-situ analysis of interfacial processes (e.g. adsorption, desorption, self-organization, corrosion),
- analysis of molecular interfacial forces and mechanics,
- coating and adhesive bonding of metals and polymers
- biomaterials and biosensors

The interdisciplinary work is combining spectroscopy, microscopy and electrochemistry. Molecular defined systems are investigated by optical in-situ spectroscopy, electron spectroscopy, atomic force microscopy as well as electrochemistry regarding their structure-property-correlation. Based on the special research approach we are on the one hand able to understand macroscopic processes on a molecular level and on the other hand to create new materials and composited bottom-up.

The new research field "Nanobiomaterials" is focused on DNA-nanotechnology and bio-surface interactions. The DNA origami technique enables the fast, high-yield synthesis of well-defined nanostructures which we employ to study biochemical reactions at a single-molecule level. Furthermore, these structures can be functionalized with various organic and inorganic entities for applications in molecular electronics and sensing. The second topic investigates the influence of physicochemical surface properties and in particular surface topography on the adsorption and specific immobilization of medically relevant proteins, and the resulting effects on cellular response, with the aim of improving biocompatibility of implant materials.

6 Staff

Directors

Scientific Director

Prof. Dr.-Ing. Hans-Joachim Schmid

Tel.: +49/5251/602404

E-Mail: hans-joachim.schmid@upb.de

Commercial Director

Dr.-Ing. Eric Klemp

Tel.: +49/5251/605415

E-Mail: eric.klemp@dmrc.de

Project Leaders

Strategic Product Planning and Systems Engineering

Strategische Produktplanung und Systems Engineering

Senior professor

Prof. Dr.-Ing. Jürgen Gausemeier

Tel.: +49/5251/606267

E-Mail: juergen.gausemeier@hni.upb.de

HEINZ NIXDORF INSTITUT
UNIVERSITÄT PADERBORN

Product Creation

Produktentstehung

Prof. Dr.-Ing. Iris Gräßler

Tel.: +49/5251/606275

E-Mail: iris.graessler@hni.uni-paderborn.de

HEINZ NIXDORF INSTITUT
UNIVERSITÄT PADERBORN

Technical and Macromolecular Chemistry (TMC)

Technische und Makromolekulare Chemie (TMC)

Prof. Dr.-Ing. Guido Grundmeier

Tel.: +49/5251/605700

E-Mail: g.grundmeier@tc.upb.de

TMC

Computer Application and Integration in Design and Planning

Computeranwendung und Integration in Konstruktion und Planung

Univ.-Prof. Dr.-Ing. Rainer Koch

Tel.: +49/5251/602258

E-Mail: r.koch@cik.upb.de

Applied Mechanics

Fachgruppe Angewandte Mechanik

Prof. Dr.-Ing. habil. Gunter Kullmer

Tel.: +49/5251/605320

E-Mail: kullmer@fam.upb.de

Polymer Engineering

Kunststofftechnik Paderborn

Prof. Dr.-Ing. Elmar Moritzer

Tel.: +49/5251/602300

E-Mail: elmar.moritzer@ktp.upb.de

Staff

Applied Mechanics

Fachgruppe Angewandte Mechanik

Seniorprofessor

Prof.-Dr.-Ing. habil. Hans Albert Richard

Tel.: +49/5251/605324

E-Mail: richard@fam.upb.de

Material Science

Lehrstuhl für Werkstoffkunde

Prof. Dr.-Ing. habil. Mirko Schaper

Tel.: +49/5251/603855

E-Mail: schaper@lwk.upb.de

Particle Technology Group

Lehrstuhl für Partikelverfahrenstechnik

Prof. Dr.-Ing. Hans-Joachim Schmid

Tel.: +49/5251/602404

E-Mail: hans-joachim.schmid@upb.de

Polymer Processing

Kunststofftechnik Paderborn

Prof. Dr.-Ing. Volker Schöppner

Tel.: +49/5251/603057

E-Mail: volker.schoeppner@ktp.upb.de

Automotive Lightweight Construction

Leichtbau im Automobil

Prof. Dr. rer. nat. Thomas Tröster

Tel.: +49/5251/605331

E-Mail: thomas.troester@upb.de

Design and Drive Technology

Lehrstuhl für Konstruktions- und Antriebstechnik

Prof. Dr.-Ing. Detmar Zimmer

Tel.: +49/5251/602257

E-Mail: detmar.zimmer@upb.de

Technical Staff

Dipl.-Ing. Michael Brand

Direct Manufacturing Research Center

Tel.: +49/5251/605413

E-Mail: michael.brand@dmrc.de

Administrative Staff

Dipl.-Kffr. Angela Zörner

Finances and Organization

Tel.: +49/5251/605421

E-Mail: angela.zoerner@dmrc.de

Scientific Staff

Dr.-Ing. Guido Adam

Design and Drive Technology

Field of Research: Design Rules

Tel.: +49/5251/605541

E-Mail: guido.adam@upb.de

M.Sc. Dominik Ahlers

Direct Manufacturing Research Center

Field of Research: Metal Laser Melting

Tel.: +49/5251/605422

E-Mail: dominik.ahlers@dmrc.de

M.Sc. Mehmet Esat Aydinöz

Material Science

Field of research: Metal Laser Melting

Tel.: +49/5251/603019

E-Mail: aydinoez@lwk.upb.de

Dipl.-Ing. Florian Brenne

Material Science

Field of Research: Metal Laser Melting

Tel.: +49/5251/605235

E-Mail: florian.brenne@upb.de

M.Sc. Jan-Peter Brüggemann

Applied Mechanics

Field of research: Metal Laser Melting

Tel.: +49 5251/604388

E-Mail: brueggemann@fam.upb.de

M.Sc. Johannes Büsching

Computer Application and Integration in Design and Planning

Field of research: Technology deployment in non-engineering areas

Tel.: +49 5251/605473

E-Mail: buesching@cik.upb.de

M.Sc. Patrick Delfs

Particle Technology Group

Field of Research: Surface characterization and post treatment

Tel.: +49/5251/605419

E-Mail: patrick.delfs@upb.de

M.Sc. Gereon Deppe

Computer Application and Integration in Design and Planning

Field of Research: Decision Support for Additive Manufacturing in terms of Quality, Costs and Time

Tel.: +49/5251/602263

E-Mail: deppe@cik.upb.de

M.Sc. Matthias Fischer

Polymer Processing

Field of Research: Fused Deposition Modeling

Tel.: +49/5251/605542

E-Mail: Matthias.Fischer@ktp.upb.de

Dipl.-Ing. Nils Funke

Particle Technology Group

Field of Research: Polymer Laser Sintering

Tel.: +49/5251/605414

E-Mail: Nils.Funke@dmrc.de

Dipl.-Ing. Ulrich Jahnke

Computer Application and Integration in Design and Planning

Field of Research: Product Protection

Tel.: +49/5251/605563

E-Mail: jahnke@cik.upb.de

M.Sc. Stefan Josupeit

Particle Technology Group

Field of Research: Polymer Laser Sintering

Tel.: +49/5251/605410

E-Mail: stefan.josupeit@upb.de

M.Sc. Martin Kage

Strategic Product Planning and Systems Engineering

Field of Research: Strategic Planning and Innovation Management

Tel.: +49/5251/606237

E-Mail: martin.kage@hni.uni-paderborn.de

M.Sc. Frederick Knoop

Polymer Processing

Field of Research: Fused Deposition Modeling

Tel.: +49/5251/605518

E-Mail: frederick.knoop@dmrc.de

M.Sc. Peter Koppa

Automotive Lightweight Construction

Field of research: Metal Laser Melting

Tel.: +49 5251/605470

E-Mail: peter.koppa@dmrc.de

M.Sc. Thomas Künneke

Design and Drive Technology

Field of Research: Damping Structures

Tel.: +49/5251/605420

E-Mail: thomas.kuenneke@dmrc.de

M.Sc. Stefan Lammers

Direct Manufacturing Research Center

Field of research: Design technology (drive technology)

Tel.: +49/5251/605472

E-Mail: stefan.lammers@dmrc.de

Dipl.-Wirt.-Ing. Stefan Leuders

Automotive Lightweight Construction

Field of Research: Metal Laser Melting

Tel.: +49/5251/605543

E-Mail:stefan.leuders@upb.de

M.Sc. Tobias Lieneke

Design and Drive Technology

Field of Research: Dimensional Tolerances

Tel.: +49/5251/605471

E-Mail: tobias.lieneke@upb.de

Dipl.-Wirt.-Ing. Christian Lindemann

Computer Application and Integration in Design and Planning

Field of Research: Lifecycle Costs and Process Analysis

Tel.: +49/5251/605563

E-Mail: lindemann@cik.upb.de

M.Sc. Johannes Lohn

Direct Manufacturing Research Center

Field of research: Laser Sintering

Tel.: +49/5251/605417

E-Mail: johannes.lohn@dmrc.de

Dipl.-Wirt.-Ing. Stefan Peter

Strategic Product Planning and Systems Engineering

Field of Research: Strategic Planning and Innovation Management

Tel.: +49/5251/606264

E-Mail: stefan.peter@hni.upb.de

Dr.-Ing. Jens Pottebaum

Computer Application and Integration in Design and Planning/Product Creation

Field of research: Information and Product Data Management

Tel.: +49/5251/602234

E-Mail: pottebaum@cik.upb.de

M.Sc. Thomas Reiher

Computer Application and Integration in Design and Planning

Field of research: Part design optimization

Tel.: +49/5251/602263

E-Mail: reiher@cik.upb.de

M.Sc. Wadim Reschetnik

Applied Mechanics

Field of Research: Metal Laser Melting

Tel.: +49/5251/605325

E-Mail: reschetnik@fam.upb.de

Dr.-Ing. Andre Riemer

Applied Mechanics

Field of Research: Metal Laser Melting

Tel.: +49/5251/605326

E-Mail: riemer@fam.upb.de

M.Sc. RWTH Philipp Scholle

Product Creation

Field of research: Strategic Planning and Innovation Management

Tel.: +49/5251/606263

E-Mail: philipp.scholle@hni.uni-paderborn.de

M.Sc. Christian Schumacher

Polymer Processing

Field of research: Fused Deposition Modeling

Tel.: +49/5251/605469

E-Mail: christian.schumacher@dmrc.de

M.Sc. Alexander Taube

Material Science

Field of Research: Metal Laser Melting

Tel.: +49/5251/605235

E-Mail: taube@lwk.upb.de

7 Publications

Publications 2015

Gefahr für das geistige Eigentum? Additive Fertigungsverfahren ermöglichen innovativen technischen Produktschutz
U. Jahnke, J. Buesching
ke-NEXT, 06 (2015)

Towards a sustainable and economic selection of part candidates for additive manufacturing
C. Lindemann, U. Jahnke, T. Reiher, R. Koch
Rapid Prototyping Journal, 21/2 (2015), pp. 216-227

Processing of New Materials by Additive Manufacturing: Iron-based Alloys Containing Silver for Biomedical Applications
T. Niendorf, F. Brenne, P. Hoyer, D. Schwarze, M. Schaper, R. Grothe, M. Wiesener, G. Grundmeier, H.J. Maier
Metallurgical and Materials Transactions A, 46/7 (2015), pp. 2829-2833

Microstructural Characterization and Mechanical Performance of Hot Work Tool Steel Processed by Selective Laser Melting
M. Holzweißig, A. Taube, F. Brenne, M. Schaper, T. Niendorf
Metallurgical and Materials Transactions B, 46/2 (2015), pp. 545-549

Fatigue Strength Prediction for Titanium Alloy TiAl6V4 Manufactured by Selective Laser Melting
S. Leuders, M. Vollmer, F. Brenne, T. Tröster, T. Niendorf
Metallurgical and Materials Transactions A, 46/9 (2015), pp. 3816-3823

Richtige Oberfläche beim Polymerlaser-Sintern
P. Delfs
CNC-Arena eMagazine, 1 (2015), pp. 10-11

Design rules for additive manufacturing – basic elements
G. Adam, D. Zimmer
Rapid Prototyping Journal, 21/6 (2015)

Conference Proceedings 2015

Einsatz additiver Fertigung zur Optimierung des Ermüdungsverhaltens von gekerbten Strukturen
W. Reschetnik, A. Riemer, H. A. Richard
DVM-Arbeitskreis Bruchvorgänge, pp. 63-72
Freiberg, February 10-11, 2015

Analysis and Optimization of the Dimensional Accuracy for FDM parts manufactured with ABS-M30
F. Knoop, V. Schöppner
ASPE Spring Topical Meeting, pp. 26-31
Raleigh, April 26-29, 2015

Entwicklung einer Methode zur systematischen Erarbeitung von Maßtoleranzen für additive Fertigungsverfahren
T. Lieneke, G.A.O. Adam, S. Leuders, F. Knoop, S. Josupeit, P. Delfs, N. Funke, D. Zimmer
Proceedings of the RapidTech 2015
Erfurt, June 10-11, 2015

Powder ageing and material properties of laser sintered polyamide 12 using low refresh rates
S. Josupeit, S. Tutzschky, M. Gessler, H.-J. Schmid
Proceedings of the RapidTech 2015
Erfurt, June 10-11, 2015

Exploring the supply chain opportunities of Additive Manufacturing in aviation's spare part industry
G. Deppe, R. Koch
Proceedings of the RapidTech 2015
Erfurt, June 10-11, 2015

Systematical Determination of Tolerances for Additive Manufacturing by Measuring Linear Dimensions
T. Lieneke, G.A.O. Adam, S. Leuders, F. Knoop, S. Josupeit, P. Delfs, N. Funke, D. Zimmer
26th Annual International Solid Freeform Fabrication Symposium
Austin, August 10-12, 2015

Material properties of laser sintered polyamide 12 as function of build cycles using low refresh rates
S. Josupeit, J. Lohn, E. Hermann, M. Gessler, S. Tenbrink, H.-J. Schmid
26th Annual International Solid Freeform Fabrication Symposium
Austin, August 10-12, 2015

Publications

Temperature history within laser sintered part cakes and its influence on process quality
S. Josupeit, H.-J- Schmid
26th Annual International Solid Freeform Fabrication Symposium
Austin, August 10-12, 2015

Mechanical and Thermal Properties of FDM-Parts Manufactured with Polyamide 12
F. Knoop, V. Schöppner
26th Annual International Solid Freeform Fabrication Symposium
Austin, August 10-12, 2015

Surface Roughness optimized Alignment of Parts for Additive Manufacturing Processes
P. Delfs, M. Töws, H.-J. Schmid
26th Annual International Solid Freeform Fabrication Symposium
Austin, August 10-12, 2015

Mass Finishing of Laser Sintered Parts
P. Delfs, Z. Li, H.-J. Schmid
26th Annual International Solid Freeform Fabrication Symposium
Austin, August 10-12, 2015

Development of an economic decision support for the application of Additive Manufacturing in aerospace
G. Deppe, C. Lindemann, R.Koch
26th Annual International Solid Freeform Fabrication Symposium, pp. 1560-1563
Austin, August 10-12, 2015

Protection measures against product piracy and application by the use of AM
U. Jahnke, J. Buesching, T. Reiher, R. Koch
26th Annual International Solid Freeform Fabrication Symposium, pp. 1601-1611
Austin, August 10-12, 2015

FE-Optimization and data handling for Additive Manufacturing of structural parts
T. Reiher, R. Koch
26th Annual International Solid Freeform Fabrication Symposium, pp. 1092-1103
Austin, August 10-12, 2015

Exploring the cost and lifetime benefits of a topology optimized aerospace part applying additive manufacturing
G. Deppe, T. Reiher, R. Koch
International Conference Production Engineering and Management 2015
Trieste, October 1-2, 2015

Presentations 2015

Laser Sintering of Multimaterial Parts
J. Lohn
3D Printing Materials Conference
Maastricht, January 26, 2015

Guidelines for a sustainable and economic selection of part candidates for space applications using additive manufacturing
C. Lindemann, T. Reiher, R. Koch
Paris Space Week
Paris, February 4-5, 2015

FE-optimization and design of additive manufactured structural metallic parts for telecommunication satellites
T. Reiher, R. Koch
Paris Space Week
Paris, February 4-5, 2015

Technology Update 2015 for Metals
Eric Klemp
SLM-Usermeeting
Lübeck, 24. März 2015

Current Trends and Challenges in Industrial Polymer AM
S. Josupeit, M. Fischer
Inside 3D Printing Conference and Expo
Berlin, March 4, 2015

On tolerances for additive manufacturing: Pre-study and motivation for the tolerance development
G. Adam
Inside 3D Printing Conference and Expo
Berlin, March 4, 2015

Sustainable Part Selection for the Use of Additive Manufacturing in Companies Focussing on Prevention of Product Piracy
U. Jahnke, C. Lindemann
Inside 3D Printing Conference and Expo
Berlin, March 4, 2015

Fatigue life prediction for metals processed by Selective Laser Melting using finite element analyses
W. Reschetnik, S. Leuders, A. Riemer, T. Tröster, H.A. Richard, T. Niendorf
TMS2015 144th Annual Meeting & Exhibition
Orlando, March 15-19, 2015

Analysis and Optimization of the Dimensional Accuracy for FDM parts manufactured with ABS-M30
F. Knoop, V. Schöppner
ASPE Spring Topical Meeting
Raleigh, April 26-29, 2015

AM-Verfahren - Möglichkeiten in der industriellen Fertigung
Eric Klemp
VDMA – Symposion auf der Hannover Messe Industrie
Hannover; 14. April 2015

Industrial applications in AM – aerospace and overhaul
Eric Klemp
ASME AM3D Conference and Expo
Pune, India, 20. April 2015

Additive Manufacturing - Potenziale, Zukunftschancen und Hürden
Eric Klemp
Messe Interzum
Cologne, 8. Mai 2015

Analysis and Optimization of the Dimensional Accuracy for FDM parts manufactured with ABS-M30
V. Schöppner, F. Knoop
68th IIW – Annual Assembly and International Conference
Helsinki, June-July 28-3, 2015

Exploring the supply chain opportunities of Additive Manufacturing in aviation's spare part industry
G. Deppe
RapidTech 2015
Erfurt, June 10-11, 2015

Entwicklung einer Methode zur systematischen Erarbeitung von Maßtoleranzen für additive Fertigungsverfahren
T. Lieneke, G.A.O. Adam, S. Leuders, F. Knoop, S. Josupeit, P. Delfs, N. Funke, D. Zimmer
RapidTech 2015
Erfurt, June 10-11, 2015

Pulveralterung und Materialeigenschaften von lasergesintertem Polyamid 12 bei reduzierten Auffrischraten
S. Josupeit, S. Tutzschky, M. Gessler, H.-J. Schmid
RapidTech 2015
Erfurt, June 10-11, 2015

Paradigmenwechsel mit Additiven Fertigungsverfahren – Möglichkeiten und Chancen
Eric Klemp
Generatives Fertigen und 3D-Drucken: Industrielle Revolution oder Hype? Wissenschaftliches Kolloquium
Clausthal-Zellerfeld, 5. Juni 2015

Möglichkeiten, Chancen und Mythen additiver Fertigungsverfahren
Eric Klemp
Hanse-Aerospace -Themennachmittag im Hause SLM
Lübeck, 26. Juni 2015

Surface Roughness optimized Alignment of Parts for Additive Manufacturing Processes
P. Delfs, M. Töws, H.-J. Schmid
13th US National Conference on Computational Mechanics
San Diego, July 26-30, 2015

Surface Roughness optimized Alignment of Parts for Additive Manufacturing Processes
P. Delfs, M. Töws, H.-J. Schmid
26th Annual International Solid Freeform Fabrication Symposium
Austin, August 10-12, 2015

Mass Finishing of Laser Sintered Parts
P. Delfs, Z. Li, H.-J. Schmid
26th Annual International Solid Freeform Fabrication Symposium
Austin, August 10-12, 2015

Systematic approach for the economic application and comparison of AM part-candidates
C. Lindemann,U. Jahke, T. Reiher, R.Koch
26th Annual International Solid Freeform Fabrication Symposium
Austin, August 10-12, 2015

Development of an economic decision support for the application of Additive Manufacturing in aerospace
G. Deppe, C. Lindemann, R.Koch
26th Annual International Solid Freeform Fabrication Symposium
Austin, August 10-12, 2015

Protection measures against product piracy and application by the use of AM
U. Jahnke, J. Buesching, T. Reiher, R. Koch
26th Annual International Solid Freeform Fabrication Symposium
Austin, August 10-12, 2015

Development of an Economic Decision Support for the Application of Additive Manufacturing in Aerospace
G. Deppe
26th Annual International Solid Freeform Fabrication Symposium
Austin, August 10-12, 2015

Mechanical and Thermal Properties of FDM-Parts Manufactured with Polyamide 12
F. Knoop, V. Schöppner
26th Annual International Solid Freeform Fabrication Symposium
Austin, August 10-12, 2015

Systematical Determination of Tolerances for Additive Manufacturing by Measuring Linear Dimensions
T. Lieneke, G.A.O. Adam, S. Leuders, F. Knoop, S. Josupeit, P. Delfs, N. Funke, D. Zimmer
26th Annual International Solid Freeform Fabrication Symposium
Austin, August 10-12, 2015

Material properties of laser sintered polyamide 12 as function of build cycles using low refresh rates
S. Josupeit, J. Lohn, E. Hermann, M. Gessler, S. Tenbrink, H.-J. Schmid
26th Annual International Solid Freeform Fabrication Symposium
Austin, August 10-12, 2015

Temperature history within laser sintered part cakes and its influence on process quality
S. Josupeit, H.-J- Schmid
26th Annual International Solid Freeform Fabrication Symposium
Austin, August 10-12, 2015

FE-Optimization and data handling for Additive Manufacturing of structural parts
T. Reiher, R. Koch
26th Annual International Solid Freeform Fabrication Symposium
Austin, August 10-12, 2015

Systematic approach for the economic application and comparison of AM part-candidates
C. Lindemann, T. Reiher, U. Jahnke, R. Koch
26th Annual International Solid Freeform Fabrication Symposium
Austin, August 10-12, 2015

Fatigue Behaviour of a Structural Component Manufactured by Selective Laser Melting and Investment Casting
S. Leuders, S. Meiners, A. Taube, T. Tröster, T. Niendorf
Ti-2015: The 13th World Conference on Titanium
San Diego, August 16-20, 2015

The Direct Manufacturing Research Center at the University of Paderborn – Opportunities and Chances of Additive Manufacturing
Eric Klemp
ATSE Workshop – Implementing Additive Manufacturing
Adelaide, Australia, 29. September 2015

Publications

Additiv gefertigte Strukturen unter zyklischer Belastung - Einfluss von Prozessparametern und Nachbehandlungen auf die Eigenschaften
J. Günther, F. Brenne, M.E. Aydinöz, S. Leuders, A. Riemer, T. Niendorf
Werkstoffwoche
Dresden, September 14-17, 2015

Inconel 718 Processed by Selective Laser Melting
M.E. Aydinöz, M. Schaper, C. Schaak, W. Tillmann, T. Niendorf
Materials Science & Technology 2015
Columbus, October 4-8, 2015

Mechanical performance of notched Ti-6Al-4V structures processed by Selective Laser Melting
F. Brenne, M. Schaper, T. Niendorf
Materials Science & Technology 2015
Columbus, October 4-8, 2015

Exploring the cost and lifetime benefits of a topology optimized aerospace part applying additive manufacturing
G. Deppe, T. Reiher
International Conference Production Engineering and Management 2015
Trieste, October 2, 2015

Holistic approach for industrializing AM technology - from part selection to test and verification
C. Lindemann, T. Reiher, U. Jahnke, G. Deppe, R. Koch
Advances in Materials and Processing Technologies
Madrid, December 14-17, 2015

Methodik zur FE-gestützten Optimierung und Konstruktion von Strukturbauteilen für das Additive Manufacturing
T. Reiher
DKG FA 3 - Symposium 2015 - “Additive Fertigung: Verfahren und Anwendungen in der KERAMIK”
Nürnberg-Erlangen, December 1-2, 2015

Books 2015

Einfluss von Werkstoff, Prozessführung und Wärmebehandlung auf das bruchmechanische Verhalten von Laserstrahlschmelzbauteilen
A. Riemer
Paderborn, Shaker Verlag, 2015

Prozessqualifizierung zur verlässlichen Herstellung von Produkten im Polymer Lasersinterverfahren
S. Rüsenberg
Paderborn, Shaker Verlag, 2015

Systematische Erarbeitung von Konstruktionsregeln für die additiven Fertigungsverfahren Lasersintern, Laserschmelzen und Fused Deposition Modeling
G. Adam
Paderborn, Shaker Verlag, 2015

Publications 2014

Exploring the influence of an Additive Manufacturing integration on future MRO processes in aeronautics
G. Deppe, R. Koch
RTejournal - Forum für Rapid Technologie, 11 (2014)

Potenzial additiver Fertigungsverfahren zur Prävention gegen Produktpiraterie
U. Jahnke; F. Wigge
CNC-Arena eMagazine, 3 (2014)

On the fatigue properties of metals manufactured by selective laser melting – The role of ductility
S. Leuders, T. Lieneke, S. Lammers, T. Tröster, T. Niendorf
Journal of Materials Research, 29/17 (2014), pp. 1911-1919

On the fatigue crack growth behavior in 316L stainless steel manufactured by selective laser melting
A. Riemer, S. Leuders, M. Thöne, H.A. Richard, T. Tröster, T. Niendorf
Engineering Fracture Mechanics, 120 (2014), pp. 15-25

A Method to Characterize the Quality of a Polymer Laser Sintering Process
S. Rüsenberg, S. Josupeit, H.-J. Schmid
Advances in Mechanical Engineering, 2014 (2014), Article ID 185374

Functionally graded alloys obtained by additive manufacturing
T. Niendorf, S. Leuders, A. Riemer, F. Brenne, T. Tröster, H.A. Richard, D. Schwarze
Advanced Engineering Materials, 16/7 (2014), pp. 857-861

Lattice structures manufactured by SLM: On the effect of geometrical dimensions on microstructure evolution during processing
T. Niendorf, F. Brenne, M. Schaper
Metallurgical and Materials Transactions B, 45/4 (2014), pp. 1181-1185

Conference Proceedings 2014

Impact of Energy Input on the Microstructural Evolution in 316L Stainless Steel Processed by Selective Laser Melting
F. Brenne, A. Riemer, S. Leuders, D. Schwarze, M. Schaper, T. Niendorf
Proceedings of the Fraunhofer Direct Digital Manufacturing Conference, on CD
Berlin, March 12-13, 2014

Extension of prior developed design rules' range of validity for different boundary conditions in laser sintering - Dimensional Accuracy and Surface Finish in Additive Manufacturing
G. Adam, D. Zimmer, M. Müller
ASPE Spring Topical Meeting, pp. 30-35
Berkeley, April 13-16, 2014

Thermal Ageing of Polyamide 12 used for Polymer Laser Sintering - Influence on Part Quality Characteristics
S. Josupeit, S. Rüsenberg, N. Rupp, M. Gessler, H.-J. Schmid
ANTEC, pp. 2383-2388
Las Vegas, April 28-30, 2014

Effects of a mass finishing process on parts produced from Ultem*9085 by Fused Deposition Modeling
M. Fischer, V. Schöppner
ANTEC, pp. 2331-2336
Las Vegas, April 28-30, 2014

Optimization of SLM structures with respect to crack growth and lifetime
W. Reschetnik, A. Riemer, H. A. Richard
ASPE Spring Topical Meeting, pp. 190-195
Berkeley, April 13-16, 2014

Exploring the supply chain opportunities of Additive Manufacturing in aviation's spare part industry
G. Deppe, R. Koch
Proceedings of the RapidTech 2014
Erfurt, May, 2014

Simulation of the Surface Topography on Laser Sintered Polymer Parts
P. Delfs, A. A. Herale, Z. Li, H.-J. Schmid
25th Annual International Solid Freeform Fabrication Symposium, pp. 1250-1258
Austin, August 4-6, 2014

Three-Dimensional In-Process Temperature Measurement of Laser Sintered Part Cakes
S. Josupeit, H.-J. Schmid
25th Annual International Solid Freeform Fabrication Symposium, pp. 49-58
Austin, 4-6, 2014

Finishing of ABS-M30 Parts Manufactured with Fused Deposition Modeling With Focus on Dimensional Accuracy
M. Fischer, V. Schöppner
25th Annual International Solid Freeform Fabrication Symposium, pp. 923-934
Austin, August 4-6, 2014

Towards a sustainable and economic selection of part candidates for Additive Manufacturing
C. Lindemann, U. Jahnke, T. Reiher, R. Koch
25th Annual International Solid Freeform Fabrication Symposium
Austin, August 4-6, 2014

Functional Encapsulation of Laser Melted Inconel 718 by Arc-PVD and HVOF for Post Compacting by Hot Isostatic Pressing
W. Tillmann, C. Schaak, J. Nellesen, M. Schaper, M.E. Aydinöz, T. Niendorf
Euro PM 2014
Salzburg, September 21-24, 2014

Development of a Basic Model to Simulate the Laser Sintering Cooling Process
S. Josupeit, L. Ordia, H.-J. Schmid
International Conference on Additive Technologies (iCAT), pp. 222-227
Vienna, October 15-17, 2014

RepAIR – European collaborative research on Additive Manufacturing for MRO in aeronautics
J. Pottebaum, C. Lindemann
Rapid Tech
Erfurt, 2014

Presentations 2014

On design for AM: Systematic investigation of minimum feature sizes and geometrical accuracies
J. Lohn
3D Printing Materials Conference
Maastricht, January 26, 2014

Impact of plasticity on the deformation behavior and loading capacity of non-stochastic cellular structures
F. Brenne, T. Niendorf, M. Schaper
International Symposium on Plasticity and its Current Applications
Freeport, January 3-8, 2014

Impact of Energy Input on the Microstructural Evolution in 316L Stainless Steel Processed by Selective Laser Melting
F. Brenne, A. Riemer, S. Leuders, D. Schwarze, M. Schaper, T. Niendorf
Fraunhofer Direct Digital Manufacturing Conference
Berlin, March 12-13, 2014

Material Properties of Additive Manufactured Polymer Parts
M. Fischer, S. Josupeit
Inside 3D Printing Conference and Expo
Berlin, March 11, 2014

Design for additive manufacturing: From the idea to the design
G. Adam
Inside 3D Printing Conference and Expo
Berlin, March 11, 2014

High performance metals manufactured by selective laser melting
W. Reschetnik
Inside 3D Printing Conference and Expo
Berlin, March 11, 2014

Selective-Laser-Melting materials under cyclic loading: Influence of process-inherent defects on the initiation and propagation of fatigue cracks
S. Leuders, A. Riemer, H.A. Richard, T. Tröster, T. Niendorf
25th Colloquium on Fatigue Mechanisms
Erlangen, March 27-28, 2014

Fatigue behaviour of Ni-base superalloy processed by SLM
M.E. Aydinöz, M. Schaper, C. Schaak, W. Tillmann, T. Niendorf
25th Colloquium on Fatigue Mechanisms
Erlangen, March 27-28, 2014

Economic Aspects in Additive Manufacturing
C. Lindemann, U. Jahnke
Inside 3D Printing Conference and Expo
Berlin, March 11, 2014

Extension of prior developed design rules’ range of validity … for different boundary conditions in laser sintering
G. Adam
ASPE Spring Topical Meeting
Berkeley, April 13-16, 2014

Evaluation of the Effect of Defects on the Mechanical Performance of Components Manufactured by Selective Laser Melting

S. Leuders, T. Tröster, F. Brenne, A. Riemer, H.A. Richard, T. Niendorf

ASPE Spring Topical Meeting

Berkeley, April 13-16, 2014

Thermal Ageing of Polyamide 12 used for Polymer Laser Sintering - Influence on Part Quality Characteristics

S. Josupeit, S. Rüsenberg, N. Rupp, M. Gessler, H.-J. Schmid

ANTEC

Las Vegas, April 28-30, 2014

On the mechanical performance of structures manufactured by selective laser melting: Damage initiation and propagation

S. Leuders, T. Tröster, F. Brenne, A. Riemer, H.A. Richard, T. Niendorf

AMPM 2014 - Additive Manufacturing With Powder Metallurgy

Orlando, May 18-20, 2014

Erweiterung des Gültigkeitsbereichs zuvor erarbeiteter Konstruktionsregeln

G. Adam

RapidTech 2014

Erfurt, May 15, 2014

Exploring the influence of an Additive Manufacturing integration on future MRO processes in aeronautics

G. Deppe

RapidTech 2014

Erfurt, May 15, 2014

FE-Optimierung und Konstruktion von additiv gefertigten Strukturbauteilen für Telekommunikationssatelliten

T. Reiher

RapidTech 2014

Erfurt, May 15, 2014

RepAIR – European collaborative research on Additive Manufacturing for MRO in aeronautics

J. Pottebaum, C. Lindemann

RapidTech 2014

Erfurt, May 15, 2014

Ökonomische Aspekte und Einflussfaktoren der additiven Fertigung
C. Lindemann
RapidTech 2014
Erfurt, May 11, 2014

Die DMRC Perspektive zu additiven Herstellungsverfahren für Raumfahrtanwendungen
C.Lindemann, T.Reiher, U. Jahnke, E. Klemp
DLR Workshop zum Thema „Additive Herstellungsverfahren für Raumfahrtanwendungen“
Bonn, May 8, 2014

Evolving Technology - Additive Manufacturing
C. Lindemann, U. Jahnke
International Intellectual Porperty Enforcement Summit
London, June 11, 2014

AM Anwendungen in der Luft- und Raumfahrt
C. Lindemann
Haus der Technik - Direct Manufacturing/ Additive Fertigung vom Modell bis zum Produkt - Seminar und Workshop
Paderborn, July 3, 2014

Low-Cycle Fatigue Behavior of IN 718 Superalloy processed by SLM
M.E. Aydinöz, M. Schaper, C. Schaak, W. Tillmann, T. Niendorf
Junior Euromat 2014
Lausanne, July 21-25, 2014

Simulation of the Surface Topography on Laser Sintered Polymer Parts
P. Delfs, A. A. Herale, Z. Li, H.-J. Schmid
25th Annual International Solid Freeform Fabrication Symposium
Austin, August 4-6, 2014

Towards a sustainable and economic selection of part candidates for Additive Manufacturing
C. Lindemann, U. Jahnke, T. Reiher, R. Koch
25th Annual International Solid Freeform Fabrication Symposium
Austin, August 4-6, 2014

Three-Dimensional In-Process Temperature Measurement of Laser Sintered Part Cakes
S. Josupeit, H.-J. Schmid
25th Annual International Solid Freeform Fabrication Symposium
Austin, August 4-6, 2014

Additive Manufacturing NRW
Eric Klemp
Standortseminar: „Next Generation Production Technology- Industry 4.0: Innovative Solutions for Tomorrow's Industry, Best Practice in Germany/ NRW"
Seoul, South-Korea, 29. September 2014

Additive Manufacturing - Innovative Solutions for Tomorrow's Industry
Eric Klemp
Best Practice in Germany/NRW
Tokyo, Japan, 27. September 2014

Vertrauen in Additive Fertigungsverfahren – mit dem richtigen Ansatz zum richtigen Produkt D-Druck Potenziale, Chancen und Herausforderungen
Eric Klemp
Konferenz des VTH Verband Technischer Handel e.V.
Neumünster, 22. Oktober 2014

Laser Sintering of Multimaterial Parts
G. Adam, D. Zimmer
1st ESA and Industry Workshop on Additive Manufacturing for Space Applications
Noordwijk, October 29, 2014

Methodological Selection and Redesign of Structure Elements for Additive Manufacturing Focusing on Space Applications
T. Reiher, C. Lindemann, U. Jahnke, R. Koch
1st ESA and Industry Workshop on Additive Manufacturing for Space Applications
Noordwijk, October 29, 2014

Development of a Basic Model to Simulate the Laser Sintering Cooling Proces
S. Josupeit, L. Ordia, H.-J. Schmid
International Conference on Additive Technologies (iCAT)
Vienna, October 15-17, 2014

Exploring the influence of an Additive Manufacturing integration on future MRO processes in aeronautics
G. Deppe
Euromold
Frankfurt am Main, November 28, 2014

Make or buy? Economics based decision support
G. Deppe, C. Lindemann
Euromold
Frankfurt am Main, November 28, 2014

Opportunities, Chances and Risks – AM for Industrial Use", Additive Manufacturing state of the industry
Eric Klemp
Conference at Elmia
Jönköping, Sweden, 11. November 2014

Additive Manufacturing and its product capabilities for industrial use
Eric Klemp
Inside 3D Printing Conference and Expo
Shanghai, 4. November 2014

Publications 2013

Additive Manufacturing als serienreifes Produktionsverfahren
C. Lindemann, U. Jahnke, E. Klemp, R. Koch
Industrie Management, 2 (2013), pp. 25-28

Verhalten von lasergeschmolzenen Bauteilen aus der Titan-Aluminium-Legierung TiAl6V4 unter zyklischer Beanspruchung
A. Riemer, S. Leuders, H.A. Richard, T. Tröster
Materials Testing, 55 (2013), pp. 537-543

Highly Anisotropic Steel Processed by Selective Laser Melting
T. Niendorf, S. Leuders, A. Riemer, H.A. Richard, T. Tröster, D. Schwarze
Metallurgical and Materials Transactions B, 44 (2013), pp. 794-796

On the mechanical behaviour of titanium alloy TiAl6V4 manufactured by selective laser melting: Fatigue resistance and crack growth performance

S. Leuders, M. Thöne, A. Riemer, T. Niendorf, T. Tröster, H.A. Richard, H.J. Maier

International Journal of Fatigue, 48 (2013), pp. 300-307

Konstruktionsregeln für Additive Fertigungsverfahren

D. Zimmer, G. Adam

Zeitschrift Konstruktion, 7/8 (2013), pp. 77-82

Additively manufactured cellular structures: Impact of microstructure and local strains on the monotonic and cyclic behavior under uniaxial and bending load

F. Brenne, T. Niendorf, H.J. Maier

Journal of Materials Processing Technology, 213/9 (2013), pp. 1558-1564

Steel showing twinning-induced plasticity processed by selective laser melting - An additively manufactured high performance material

T. Niendorf, F. Brenne

Materials Characterization, 85 (2013), pp. 57-63

Design for Additive Manufacturing - Element transitions and aggregated structures

G. Adam, D. Zimmer

CIRP Journal of Manufacturing Science and Technology, 7/1 (2013), pp. 20-28

Inconel 939 processed by selective laser melting: Effect of microstructure and temperature on the mechanical properties under static and cyclic loading

P. Kanagarajah, F. Brenne, T. Niendorf, H.J. Maier

Materials Science and Engineering A, 588 (2013), pp. 188-195

Conference Proceedings 2013

Bruchmechanische Charakterisierung zyklisch belasteter SLM-Bauteile

A. Riemer, H.A. Richard

DVM-Arbeitskreis Bruchvorgänge, pp. 167-176

Berlin, February 19-20, 2013

Fracture mechanical investigations on SLM materials
H.A. Richard, A. Riemer, E. Klemp
13th International Conference on Fracture, pp. 1-8
Beijing, June 16-21, 2013

Mechanical analysis of lightweight constructions manufactured with fused deposition modeling
A. Bagsik, S. Josupeit, V. Schöppner, E. Klemp
AIP Conference Proceedings, pp. 696-701
Nuremberg, July 15-19, 2013

Opportunities and influence of Additive Manufacturing on MRO-processes in aeronautics
C. Lindemann, U. Jahnke, M. Plass, R. Koch
Rapid Tech
Erfurt, 2013

A Material Based Quality Concept for Polymer Laser Sintering
S. Josupeit, S. Rüsenberg, H.-J. Schmid
24th Annual International Solid Freeform Fabrication Symposium, pp. 44-54
Austin, August 12-14, 2013

Some Investigations Regarding the Surface Treatment of Ultem*9085 Parts Manufactured with Fused Deposition Modeling
M. Fischer, V. Schöppner
24th Annual International Solid Freeform Fabrication Symposium, pp. 805-815
Austin, August 12-14, 2013

Impact and Influence Factors of Additive Manufacturing on Product Lifecycle Costs
C. Lindemann, U. Jahnke, M. Moi, R. Koch
24th Annual International Solid Freeform Fabrication Symposium
Austin, August 12-14, 2013

An event-driven software architecture for process analysis in Additive Manufacturing
M. Moi, C. Lindemann, U. Jahnke, R. Koch
24th Annual International Solid Freeform Fabrication Symposium
Austin, August 12-14, 2013

Potentials of Additive Manufacturing to Prevent Product Piracy
U. Jahnke, C. Lindemann, M. Moi, R. Koch
24th Annual International Solid Freeform Fabrication Symposium
Austin, August 12-14, 2013

Presentations 2013

Bruchmechanische Charakterisierung zyklisch belasteter SLM-Bauteile
A. Riemer, H.A. Richard
DVM-Arbeitskreis Bruchvorgänge
Berlin , February 19-20, 2013

Die Potentiale Additiver Fertigung nutzen - Praktische Hinweise für eine optimale Konstruktion
G. Adam
12. Rapid Prototyping Fachtagung
Hamburg, April 19, 2013

Fracture mechanical investigations on SLM materials
H.A. Richard, A. Riemer, E. Klemp
13th International Conference on Fracture
Beijing, June 16-21, 2013

Mechanical analysis of lightweight constructions manufactured with fused deposition modeling
A. Bagsik, S. Josupeit, V. Schöppner, E. Klemp
PPS
Nuremberg, July 15-19, 2013

Impact and Influence Factors of Additive Manufacturing on Product Lifecycle Costs
C. Lindemann, U. Jahnke, M. Moi, R. Koch
24th Annual International Solid Freeform Fabrication Symposium
Austin, August, 2013

An event-driven software architecture for process analysis in Additive Manufacturing
M. Moi, C. Lindemann, U. Jahnke, R. Koch
24th Annual International Solid Freeform Fabrication Symposium
Austin, August, 2013

Potentials of Additive Manufacturing to Prevent Product Piracy
U. Jahnke, C. Lindemann, M. Moi, R. Koch
24th Annual International Solid Freeform Fabrication Symposium
Austin, August, 2013

Mechanische und rheologische Untersuchungen neuer Laser Sinter Materialien
S. Josupeit, S. Rüsenberg, H.-J. Schmid
7. Merseburger Rapid Prototyping Forum
Merseburg, October 7, 2013

Characterization of fatigue crack growth in 316L stainless steel processed by selective laser melting
A. Riemer, S. Leuders, T. Niendorf, T. Tröster, H.A. Richard
Materials Science & Technology 2013
Montreal, October 27-31, 2013

On the Fatigue Behavior of TiAl6V4 Manufactured by Selective Laser Melting – Influence of Process Induced Defects
S. Leuders, A. Riemer, T. Niendorf, H.A. Richard, T. Tröster
Materials Science & Technology 2013
Montreal, October 27-31, 2013

Local deformation mechanisms and mechanical performance of metallic lattice structures manufactured by Selective Laser Melting
F. Brenne, T. Niendorf, H.J. Maier
Materials Science & Technology 2013
Montreal, October 27-31, 2013

Konstruktionsregeln für Additive Fertigungsverfahren - Eine Grundlage für die Ausbildung und Lehre
G. Adam
OptoNet-Workshop
Jena, November 6, 2013

Onsite maintenance and repair of aircraft by integrated direct digital manufacturing of spare
C. Lindemann
AIRTEC International Aerospace Supply Fair
Frankfurt, November 15, 2013

Exploring The Capabilities And Costs Of Additive Manufacturing Technologies For Production
C. Lindemann
3D Printing & Additive Manufacturing Industrial Applications Global Summit 2013
London, November 19, 2013

Ti-6Al-4V processed by Selective Laser Melting – fatigue life, crack growth behavior and structural performance
F. Brenne, S. Leuders, A. Riemer, T. Niendorf, M. Schaper
International Titanium Powder Processing, Consolidation and Metallurgy Conference
Hamilton, December 2-5, 2013

Opportunities and influence of Additive Manufacturing on MRO-processes in aeronautics
C. Lindemann, U. Jahnke, M. Plass, R. Koch
RapidTech 2013
Erfurt, 2013

Publications 2012

Conference Proceedings 2012

Analyzing Product Lifecycle Costs for a Better Understanding of Cost Drivers in Additive Manufacturing
C. Lindemann, U. Jahnke, M. Moi, R. Koch
23rd Annual International Solid Freeform Fabrication Symposium
Austin, August, 2012

Untersuchung zyklisch belasteter SLM-Bauteile aus der Titan-Aluminium-Legierung TiAl6V4
A. Riemer, S. Leuders, T. Tröster, H.A. Richard
DVM-Arbeitskreis Betriebsfestigkeit, pp. 293-306
Paderborn, October 10-11, 2012

Damage evolution in truss structures manufactured by selective laser melting – effect of loading condition
T. Niendorf, F. Brenne, H.J. Maier
Proceedings CELLMAT2012, on CD
Dresden, November 7-9, 2012

Presentations 2012

Elementbasierte Erarbeitung von Konstruktionsregeln für die additive Fertigung
D. Zimmer, G. Adam
RapidTech 2012
Erfurt, May 8, 2012

Analyzing Product Lifecycle Costs for a Better Understanding of Cost Drivers in Additive Manufacturing
C. Lindemann, U. Jahnke, M. Moi, R. Koch
23rd Annual International Solid Freeform Fabrication Symposium
Austin, August, 2012

Festigkeitsrelevante und bruchmechanische Charakterisierung zyklisch belasteter SLM-Bauteile
A. Riemer, S. Leuders
6. Merseburger Rapid Prototyping Forum
Merseburg, September 13, 2012

Untersuchung zyklisch belasteter SLM-Bauteile aus der Titan-Aluminium-Legierung TiAl6V4
A. Riemer, S. Leuders, T. Tröster, H.A. Richard
DVM-Arbeitskreis Betriebsfestigkeit
Paderborn, October 10-11, 2012

Publications 2011

In situ characterization of the deformation and failure behavior of non-stochastic porous structures processed by selective laser melting
B. Gorny, T. Niendorf, J. Lackmann, M. Thoene, T. Troester, H.J. Maier
Materials Science and Engineering A, 528/27 (2011), pp. 7962-7967

Conference Proceedings 2011

Direct Manufacturing Design Rules – Erarbeitung von applikationsunabhängigen Konstruktionsregeln
D. Zimmer, G. Adam
Proceedings of the RapidTech 2011, on CD
Erfurt, May 24-25, 2011

Direct Manufacturing Design Rules

D. Zimmer, G. Adam

Proceedings of the 5th International Conference on Advanced Research in Virtual and Rapid Prototyping, pp. 550–575

Leiria, September-October 28-1, 2011

Presentations 2011

Direct Manufacturing Design Rules - Erarbeitung von applikationsunabhängigen Konstruktionsrichtlinien für additive Fertigungsverfahren

D. Zimmer, G. Adam

RapidTech 2011

Erfurt, May 25, 2011

8 Equipment

DMRC
DIRECT MANUFACTURING RESEARCH CENTER

Additive Manufacturing Systems

Polymer Laser Sintering Machine, EOSINT P396, EOS GmbH

Polymer Laser Sintering Machine, EOSINT P395, EOS GmbH

Fused Deposition Modeling Machine, Fortus 400mc, Stratasys

Additive Manufacturing Systems

Selective Laser Melting Machine, SLM 250HL, SLM Solutions GmbH

Selective Laser Melting Machine, SLM 280HL, SLM Solutions GmbH

Thermal Treatment and Analysis

Climate chamber WK3-180/70, Weiss Umwelttechnik GmbH

Furnace, UT6, Thermo Electron LED GmbH

Outdoor weathering frame, Q-Lab

Thermal Treatment and Analysis

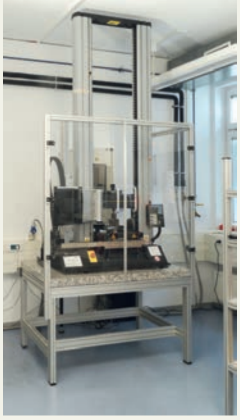
Annealing furnace N30/85HA(-K), Nabertherm GmbH

Annealing furnace N41/H, Nabertherm GmbH

Thermographic camera, P640, FLIR Systems, Inc.

Equipment

Mechanical Analysis



Universal testing system, Instron 5569, Instron

Servo-hydraulic testing machine, HB 250, Zwick GmbH & Co. KG

Servo-hydraulic testing machine, Amsler HC 10 Compact, Zwick GmbH & Co. KG

Optical Analysis

Particle size analyser, Mastersizer 2000, Malvern Instruments Ltd.

Scanning Electron Microscope (SEM), Phenom SEM, Phenom World

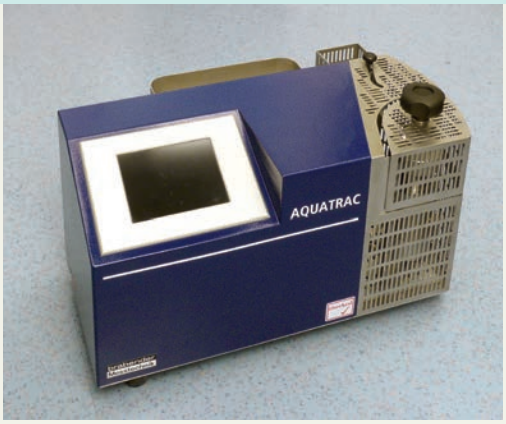
Optical Analysis


3D scanning device, kolibriMulti, FhG IOF


3D Measuring Macroscope, VR-3100, Keyence

Physical Analysis


Mechanical profilometer, Hommel Etamic T8000, Jenoptik AG



Moisture measurement device, AQUATRAC, Brabender Messtechnik GmbH


Precision balance, CPA 224s, Satorius AG

Equipment

Physical Analysis

Broadbrand dielectric spectrometer, Novocontrol GmbH

Rheometer, Physica MCR 501, Anton Paar GmbH

Melt Flow Tester, Mflow, Zwick GmbH

Surface Treatment

Centrifugal force device, ECO 18, OTEC Präzisionsfinish GmbH

Sputter coater, SC7620, Quorum Technologies Ltd.

Ultrasonic clean station, UW90, German Sonic Ultraschallanlagen GmbH

Surface Treatment

Glass sphere blasting cabin, Normfinish Junior, Arteka

Glass sphere & Corundum blasting cabin, SMG 25DUO, MHG Strahlanlagen GmbH

Trough Vibrator, 210/530 TE-30 PU, Rösler Oberflächentechnik GmbH

Geometrical Analysis

Coordinate Measuring Machine, Nikon Modell “Altera 8.7.6”

Equipment

Mechanical Analysis

Pendulum impact tester, HIT5.5P, Zwick Roell

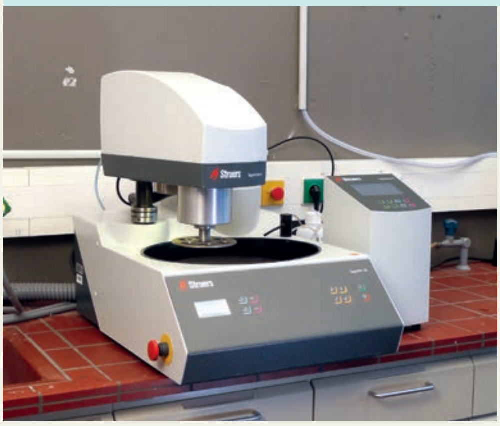
Optical Analysis

Thin Cutting device, Polycut, Reichert Jung

Digital microscope, VHX- 600, Keyence

Confocal laser microscope, VK - 9710, Keyence

Physical Analysis



Grinding and polishing device, Tegral/ Force -5, Streurs

Computer tomograph (CT), Phoenix nanotom s, GE

Thermal Analysis

thermoanalytical testing devices, TGA/DSC 1 Star-System + TMA/SDTA841, Mettler Toledo Intl. Inc.

Equipment

Joining Laboratory

Hot plate welding machine, K2150, Bielomatik Leuze GmbH

Ultrasonic welding machine, LV 2020-CPC, KLN Ultraschall AG

Equipment

LWK
Lehrstuhl
für Werkstoffkunde

Mechanical Analysis

Servo-hydraulical testing system, MTS Systems

Servo-hydraulical testing System, MTS 858 Table Top System, MTS Systems

Servo-hydraulical testing system, MTS Landmark, MTS Systems

Testing system, Electro-Force 3550, Bose

Microstructural Analysis

Confocal laser scanning microscope, OLS3100, Olympus

Scanning electron microscope, XL 40 ESM TMP, Philips

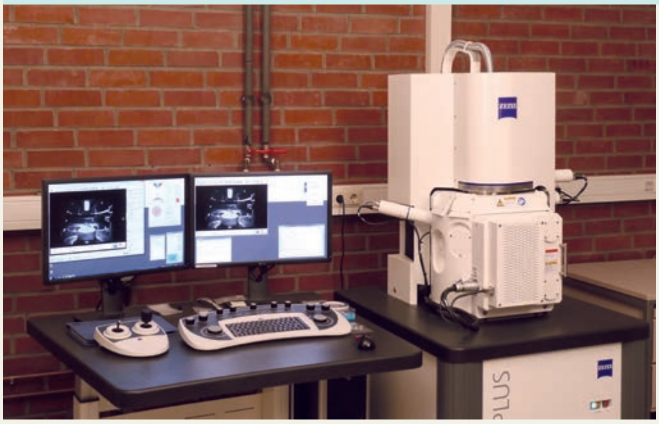
Equipment

Microstructural Analysis

Transmission electron microscope, CM200STEM, Philips

X-Ray diffractometer, X‘pert Pro, Philips

Microstructural Analysis



Field Emission SEM, Ultra Plus, Zeiss

Equipment

Mechanical Analysis

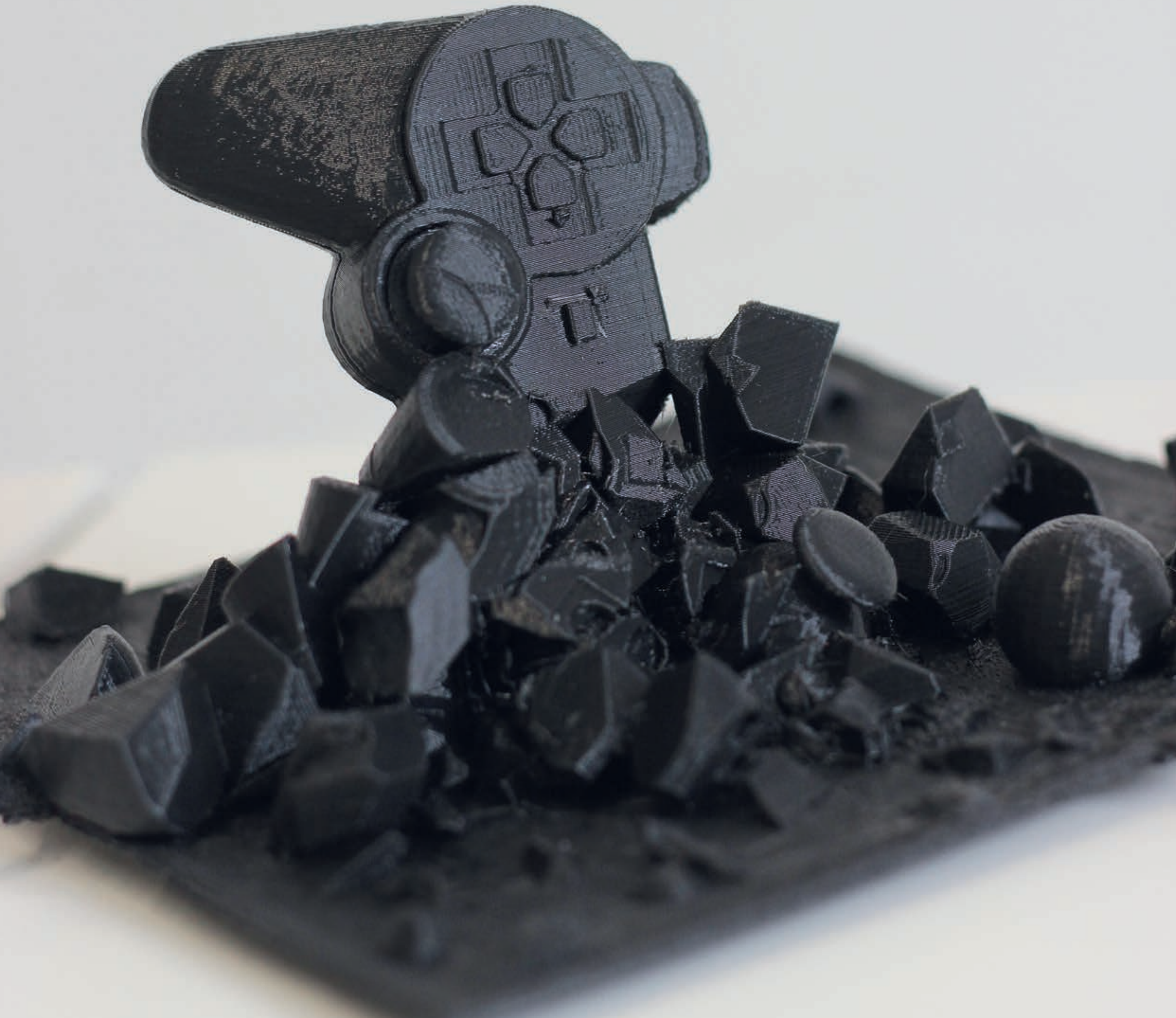
Electrodynamic testing system, ElectroPuls E10000, Instron

Servo-hydraulical testing system, HYDROPULS, PSA, Schenck”

Servo-hydraulical testing system, HYDROPULS SINUS, Schenck

Optical Analysis

Digital microscope, VHX-2000, Keyence”



How to find us...

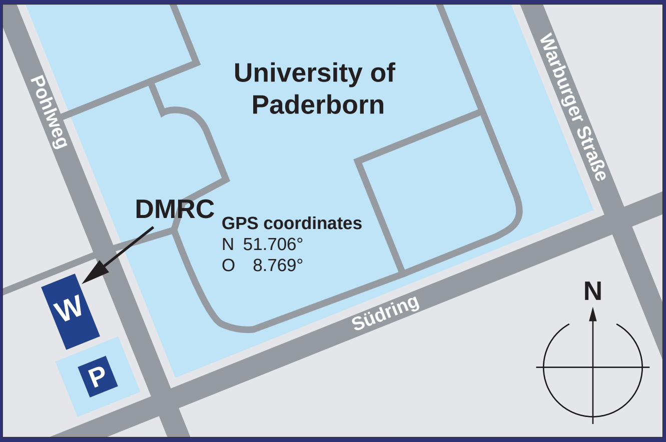
University of Paderborn

DMRC

Mersinweg 3

33098 Paderborn

Germany



www.DMRC.de