Direct Manufacturing Research Center

Annual Report 2014

DMRC
DIRECT MANUFACTURING RESEARCH CENTER

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Annual Report 2014

Imprint

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1 Preface

Dr.-Ing. Eric Klemp

Prof. Dr.-Ing. Hans-Joachim Schmid

Dear Reader!

We are very proud to provide the third Annual Report of the Direct Manufacturing Research Center to you. This will give you a comprehensive overview of the DMRC, the current projects and the scientific output in 2014 – and with this it shows the benefit for our industrial partners.

This spring it has been 5 years since the official opening of the DMRC. Right from the beginning the DMRC is a joint effort of academia and industry with the main goal to advance the existing additive manufacturing technologies into dependable and production rugged standard manufacturing technologies. At the moment there is a tremendous amount of public attention to 3D printing including some unrealistic expectations in public media. In parallel we see an extensive growth of interest in industry and academia in ‚serious' Additive Manufacturing – and we are very happy about this fact, as it shows, we have done the right things some years ago, when the DMRC was founded. Besides the opportunities and chances, there are still considerable risks and challenges to be considered. And that's the approach of DMRC – we want to contribute to the field of AM by doing fundamental as well as applied research which is readily transferred into industrial practice.

So meanwhile we have 16 industrial partners who participate in the research of DMRC and we generate a turnover of approx. 1.9. Mio € in research projects. This research is being performed by now 28 researchers (i.e. PhD candidates) from 11 different chairs of University – all to be seen in detail in this report. We are particularly proud to announce our new partners who joined the DMRC in the last year, namely Liebherr Aerospace, HuH, Phoenix Contact and last but not least Baker Hughes.

Besides the industrial driven projects, we have a growing success in getting additional projects, funded by the European Commission (FP7), ESA, BMBF and DFG.

Since we are convinced that Additive Manufacturing can only succeed if people get the know-how to effectively use these technologies, education is another major issue of DMRC besides research. In the last semester we had 60 mechanical engineering master students who participated in our module called "Additive Manufacturing". Furthermore we had more than 100 students working on different AM projects as student fellows or working for their Master Thesis, Bachelor Thesis or other students projects. Furthermore, we are currently trying to incorporate teaching of AM knowledge to students of other programmes.

In order to show our activities and to provide knowledge tot he public, we are participating in the most important events in Germany, like Euromold, RapidTech or the Inside 3D printing event. Much more know-how is being transferred into public by a strong participation in multiple national and international conferences all over the word. Please take a look at the publication list at the end of this report. Furthermore, as Standardisation is still an important topic, we are member of ASTM and DIN, VDI and VDMA.

We are very happy about the development of the DMRC during the last years. This fosters us to put even more effort for a continuing and ever growing success of the DMRC.

We are looking very forward to the next year and would be very glad if we could find a good way of cooperating with you and providing value to you as well! There are many opportunities awaiting and so we gratefully invite you to join us at the DMRC!

Kind regards

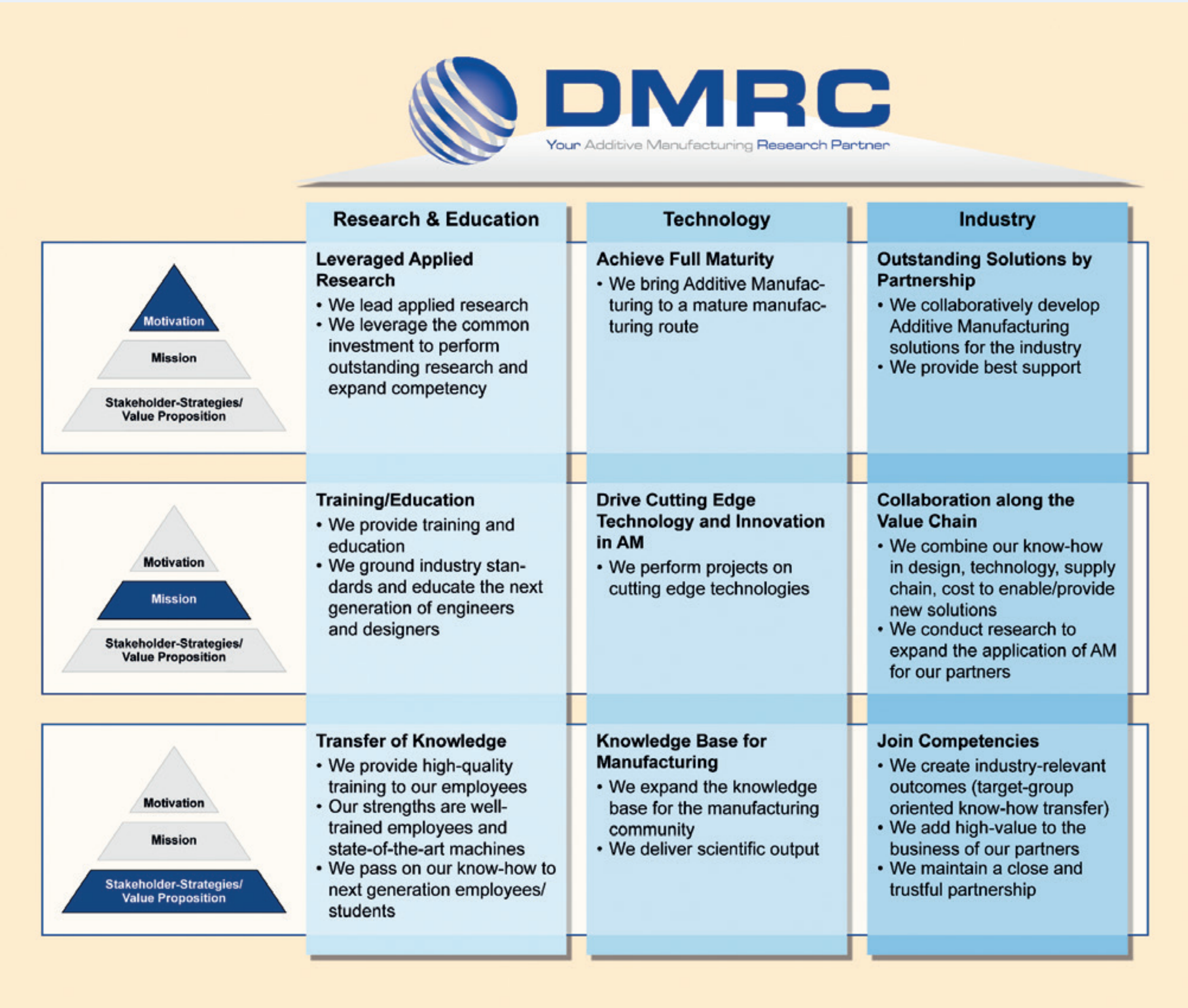
Dr.-Ing. Eric Klemp

Prof. Dr-Ing. Hans Joachim Schmid

2 Direct Manufacturing Research Center

Organization

The DMRC is an institution within the faculty of mechanical engineering at University of Paderborn. Under one roof 28 researchers from 9 different chairs are performing projects co-funded by the State Government of NRW, industrial partners are from public sources. All projects are steered and controlled by DMRC partners. This allows all partners to generate a huge amount of output, especially in respect of science.
By using this kind of organization the DMRC is able to allocate the knowledge needed from any chair of the University - as seen by the 11 participating professors.



Aim of the DMRC

The aim of the DMRC is to get reliable, repeatable and production capable Direct Manufacturing Systems. This is on the basis of machines, products and very much on properties. To achieve this, a continuous development of process chains is performed. In order to get the complete field of applications, partners are involved with the DMRC along the entire value chain. This model seems to be very successful as we see a prosperous growth with 12 new partners being integrated into the DMRC. By sharing our know-how, we perform a huge and sustainable outcome for each partner.

Motivation, Mission and Stakeholder Strategies

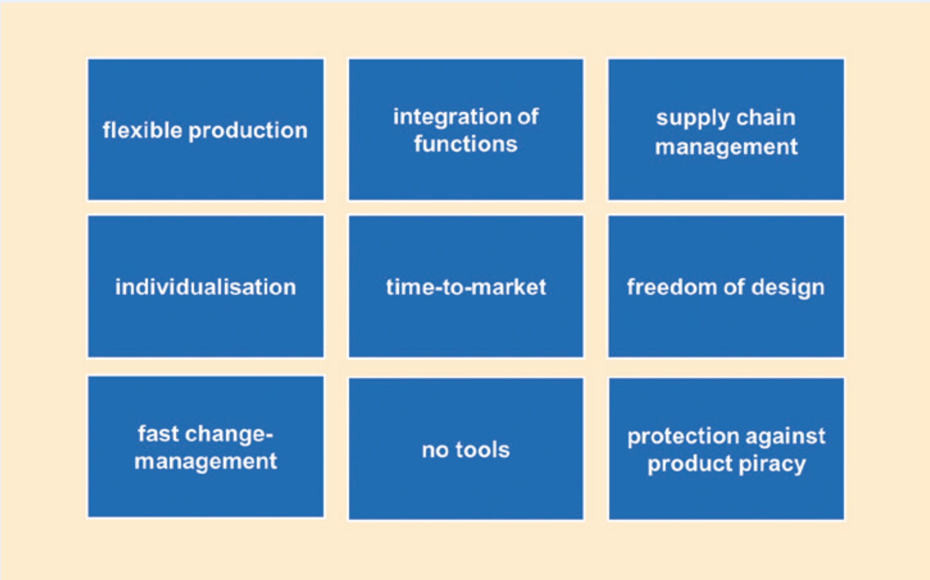
The Mission of the DMRC is divided into three areas: Research and education, Technology and Industry.

As the DMRC is a part of a university, a lecture about AM has been installed within the study of mechanical engineering. This lecture is a part of a master studies and includes – under the topic of AM – 7 detailed lectures, each of which includes at least 20% of AM content. In 2014, we had 60 students taking part at the lecture, so here the University of Paderborn does underpin the demand of AM-specialist or at least those who do have a knowledge about the technologies itself.

Additionally, a knowledge transfer into the industry takes place: the DMRC performed two seminars, one was the "Haus der Technik" and the second one was the DGM seminar. Here, we had in total 50 participants, who wanted to gain more knowledge about AM.

In order to fulfill the needs of the industrial partners and market, technology has to be developed along the entire value chain to achieve this goal.

The DMRC takes part in different organizations, so we are member of the standardization - organizations like ASTM, DIN, VDI and VDMA. Besides this, many local activities are supported like the Spitzencluster "It's OWL (Intelligent technical systems) and NMWP (NanoMikroWerkstoffePhotonik.NRW).



Vision

The vision of the DMRC combines the strength of the organization at the university as well as with the partners. So there are different fields to be approached. On the one side, there is technology gained for different kinds of projects, which comes directly to best practice applications (Know-How) for our partners. This can only be performed by interdisciplinary research among the partners and the chairs of the university.

Main Challenges / Main Advantages

In order to bring AM to a state of the art production system, the main challenges have to be overcome. Customers and users expect a reliable, repeatable system which is able to be used in production. Therefore, a continuous development of the technologies has to be fulfilled. As a result, the parts will be able to use the advantages of AM. As has been seen, there are several challenges which foster industry in the use of AM. Items such as those with a flexible production have had unseen functions, until now. The freedom of design, having no need for tools, allows for a much faster development of products, if done correctly. Consequently, a much faster time to the market is achievable. The chance to produce your product without fear of being copied is not something to forget. The possibility to have a protection against product piracy will become more interesting in the future.

The Model of DMRC

The DMRC was founded in 2009 by the 4 partners Boeing, EOS, Evonik and MCP-HEK. The idea behind this was to perform a collaborative and pre-competitive research along the value chain of product development. With a funding of € 5.5M by State government of Northrhein Westfalia, the partners found an environment with scientific expertise at University of Paderborn in combination with the commit of collaborative development.

Over time, 12 more partners have entered the DMRC, and now 16 partners are under one roof at the DMRC. These partners include: Stratasys, Blue Production, Stükerjürgen Aerospace Composites, Phoenix Contact, HuH, Liebherr, the LEGO Group, Siemens and recently Baker Hughes joined the consortium. This main / core-consortium is completed by the SMEs Eisenhuth, Rembe and Janson und Even.

With these partners the DMRC performs projects which are technology driven, as well deal with so called cross cutting topics. Within the next pages, detailed explanations will be given about the outcome.

The DMRC is an applied research centre, in which the demand of the partners are performed. Therefore, all partners meet 4 times a year in order to discuss the outcome of the projects, control the research and steer the near and distant future. The research is a pre-competitive and collaborative research, so all partners get all results, which allows them to gain an overall leverage. With sharing the project costs between the partners and with contribution from the State Government of NRW, all partners get a huge scientific output for a well-arranged amount of money.

It’s part of the DMRC philosophy, that research in this complex field should not be performed by one single institute or group. Moreover, the diverse expertise across the University shall be used according to the specific demands of each project. Therefore, at the DMRC 9 chairs are currently working together very closely. It is the know-how of very talented members of staff, the commitment and expertise of the professors and the existing equipment of the chairs which let the DMRC perform so well.

As the DMRC is participating in public funded projects as well, the DMRC involved industrial partners have the chance to come into collaboration within the consortium. Within the following pages you will also be presented with information about the content of the projects being performed under the funding conditions.

Involved institutes at DMRC

KTP

LWK
Lehrstuhl
für Werkstoffkunde

PVT

University of Paderborn
Design and Drive Technology
KAt

c.l.k.

LiA
www.Leichtbau-im-Automobil.de

HEINZ NIXDORF INSTITUTE
University of Paderborn

FAM

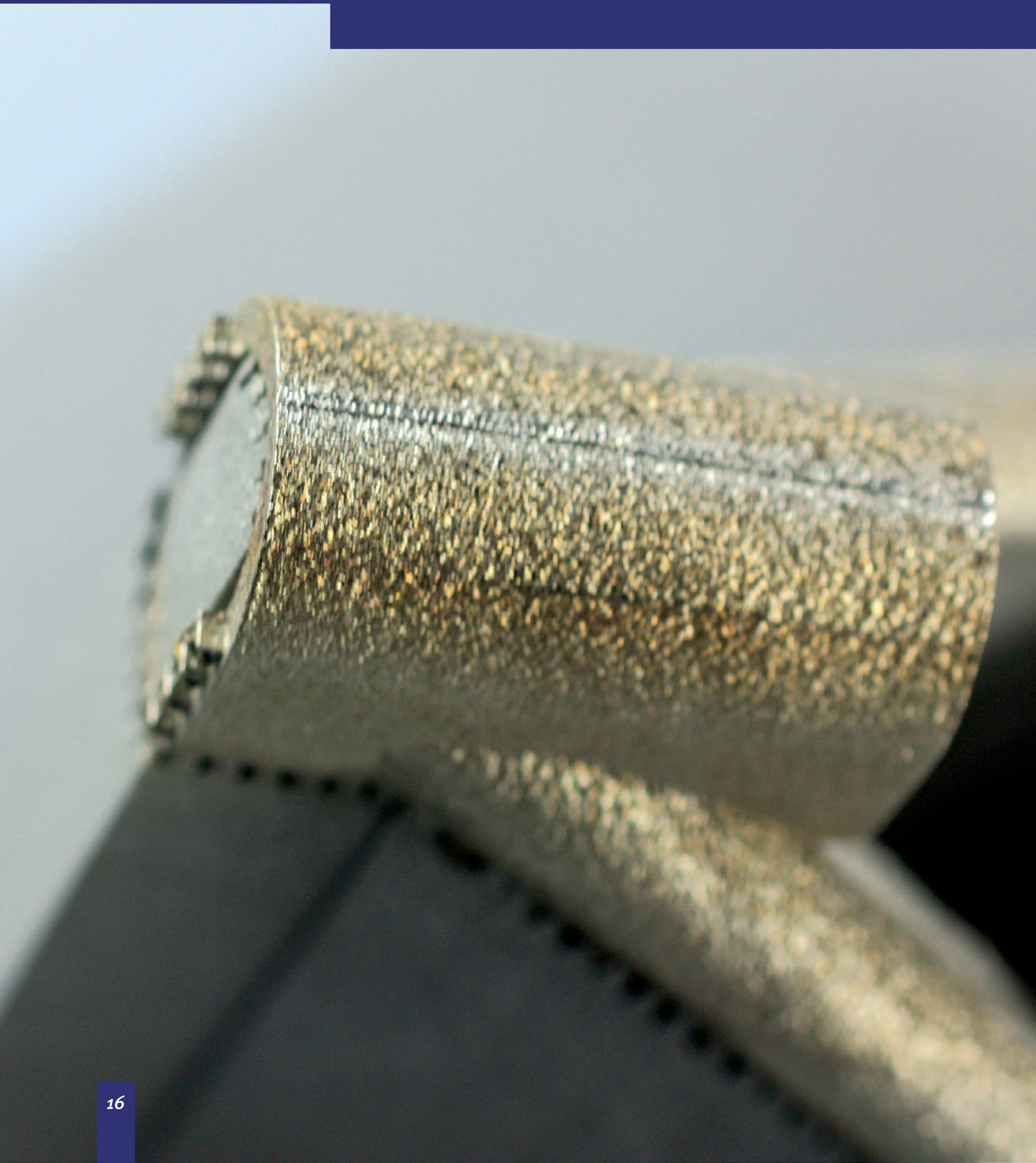
TMC
Technische und Makromolekulare Chemie

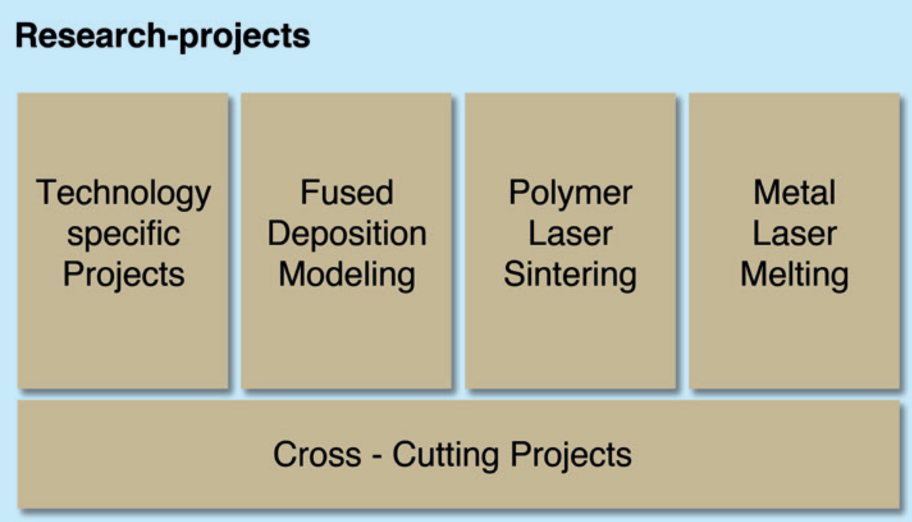
Numbers

With increasing number of partners, as the partners are paying their contribution to the DMRC and the projects are co-funded by State of NRW, the annual turnover rises yearly.

Having started in 2009 with only € 50,000, the yearly budget spent in DMRC-projects now comes to nearly € 1.9 M per year – and that is just the amount being spent within the industrial consortium without external funding projects.

3 Current Projects




Research-projects
Technology specific Projects
Fused Deposition Modeling
Polymer Laser Sintering
Metal Laser Melting
Cross - Cutting Projects

Characterization and Comparison of Mechanical Properties of SLM Materials with Regard to Process Cycle Time Improvement

Stefan Leuders

Andre Riemer

Since a high productivity is a crucial criterion for the use of a specific manufacturing process, it is the goal of this project to find optimal exposure parameters of the SLM process with regard to required cycle time and component quality. In this study design of experiments is used as a method to characterize the influencing factors and their influence on specific target values. The best parameter set is used to produce test specimens for mechanical testing. To perform analyses of the build-up rate, a real-time data collection software was developed within this project.

Design of Experiments

The sensitivity analysis as a first major issue within this project aims at shedding light regarding the influence of exposure parameters on the mechanical properties such as

- Porosity
- Material density
- Hardness

of SLM manufactured stainless steel 316L, cf. Figure 1a. In order to obtain a deeper understanding regarding the effects of exposure parameters, design of experiments (DoE) was used to allow for a systematic approach concerning this multi-parameter problem. Based on the findings of this process parameter study samples for mechanical analyses and build-up rate studies are produced with a set of process parameters that results in optimal material condition towards porosity, material density and hardness.

SLM parts under monotonic and cyclic loading

This work package deals with the characterization and comparison of SLM components regarding its mechanical properties such as:

- Monotonic properties
  - Tensile strength
  - Yield strength
  - Elongation at break

- Cyclic properties
  - fatigue behavior
  - crack growth performance

Test samples for this investigation were manufactured on the SLM 250^{HL} and SLM 280^{HL} using optimized set of process parameters.

As an example, Figure 2a shows mono-

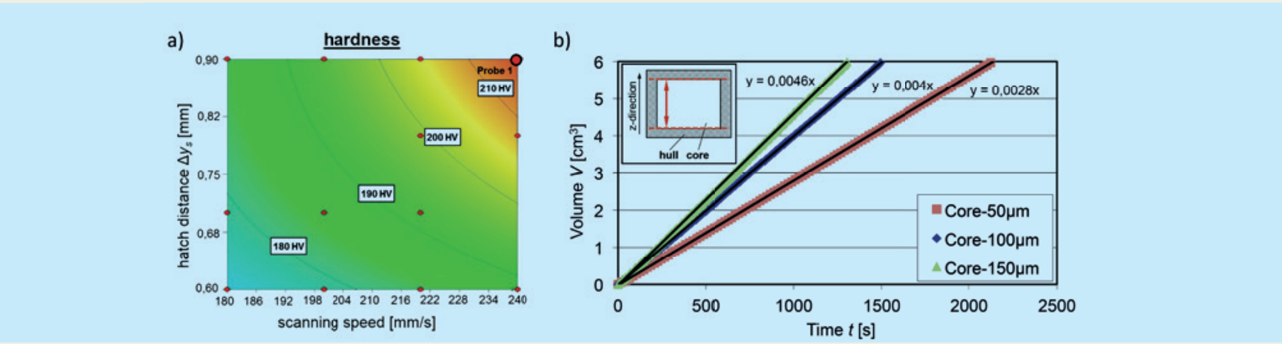


Figure 1: Results obtained by Design of Experiments (a) and the output of the real build-up rate study (b)

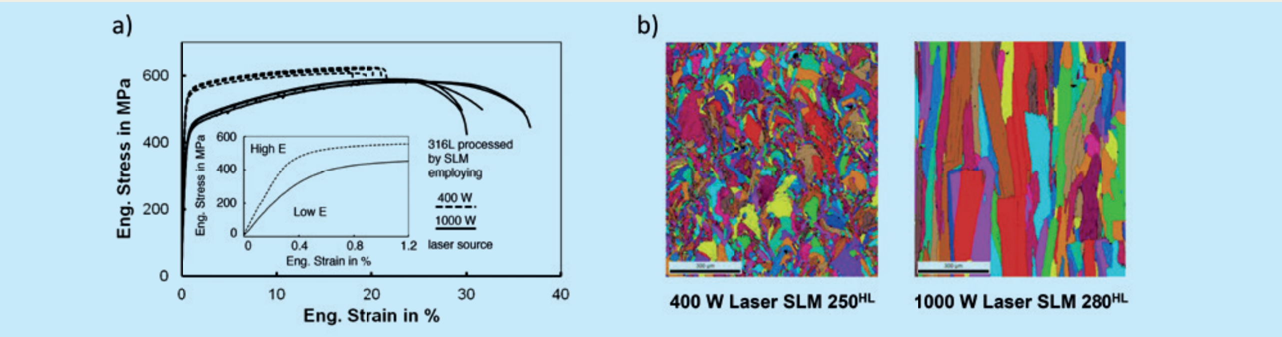


Figure 2: Monotonic stress-strain curves for the SLM processed 316L (a) and EBSD maps for 316L obtained by 400 W Laser (SLM 250^{HL}) and 1000 Watt Laser (SLM 280^{HL}) (b)ments (a) and the output of the real build-up rate study (b)

tonic stress-strain curves for 316L processed on SLM 250^{HL} and SLM 280^{HL}. It can be seen, that both processes result in fundamentally different behaviour under monotonic loading. By analyzing the microstructure in Figure 2b, the differences in strength and ductility can be explained according to the hall-petch relationship. It can be seen, that the evolution of the local microstructure is strongly dependent on the exposure parameters. While the conventional 400 W laser results in a weakly textured fine grain structure, the 1000 W laser causes significantly larger grains strongly elongated in build direction.
Similar to the monotonic properties, also in case of cyclic loading different behaviour for both laser systems are established. Here the material performance is affected in a negative way by increased laser power and consequently increased build-up rate.

Determination and analysis of the real build-up rate

This work package is focussed on the comparison between SLM 250^{HL} and SLM 280^{HL} with respect to the build-up rate and the resulting component quality. Therefore, cubic test samples were created in order to measure the process cycle time of both SLM systems, cf. Figure 1(b). Three layer thicknesses (50µm, 100µm and 150µm) were considered in this study. In order to obtain detailed values for exposure and recoating times, a real-time data collecting script was developed which is able to scan the SLM-log-files for the time data required for recoating and exposuring in each layer and to sum them up. Recent investigations have shown the possibility to increase the build-up rate by about 39% using the SLM 280^{HL} compared to the conventional SLM-250^{HL} system.

Application of findings

Finally, all project results regarding an optimal balance between build-up rate and component quality was transferred to a real component in order to demonstrate the performance of this innovative AM technology.

Project responsibility

This research project is being processed by the two departments “Automotive Lightweight Construction” and “Institute of Applied Mechanics”.

Drafting a Quality and Process Control System for the AM Processes in DMRC

Michael Brand

Based on the available knowledge and results from the Year 2012 new approaches were initiated to optimize the processes available at the DMRC which should lead to better quality control methods. The aim was to avoid or minimize possible sources of failure which would lead to the crashing of jobs or part failure due to process problems.
In the project "QM System for the additive processes installed at the DMRC" during the year 2014 following points were examined and developed:

- Analysis of order processing in DMRC
- Traceability of production orders
- Extending the DMRC QM Handbook on the basis of DIN 9001

Analysis of order processing in DMRC

The order processing includes all the administrative information right from the customer enquiry to the final invoicing. Fig 1 shows the actual process sequence in DMRC

Traceability of production orders

After the acceptance of the order it will be assigned to a suitable manufacturing process and a corresponding order number will be generated, see Fig 2: process traceability.
Then the order with the order number and other relevant information like customer data, address, processing status, date of possible delivery etc. will be entered in the order list.

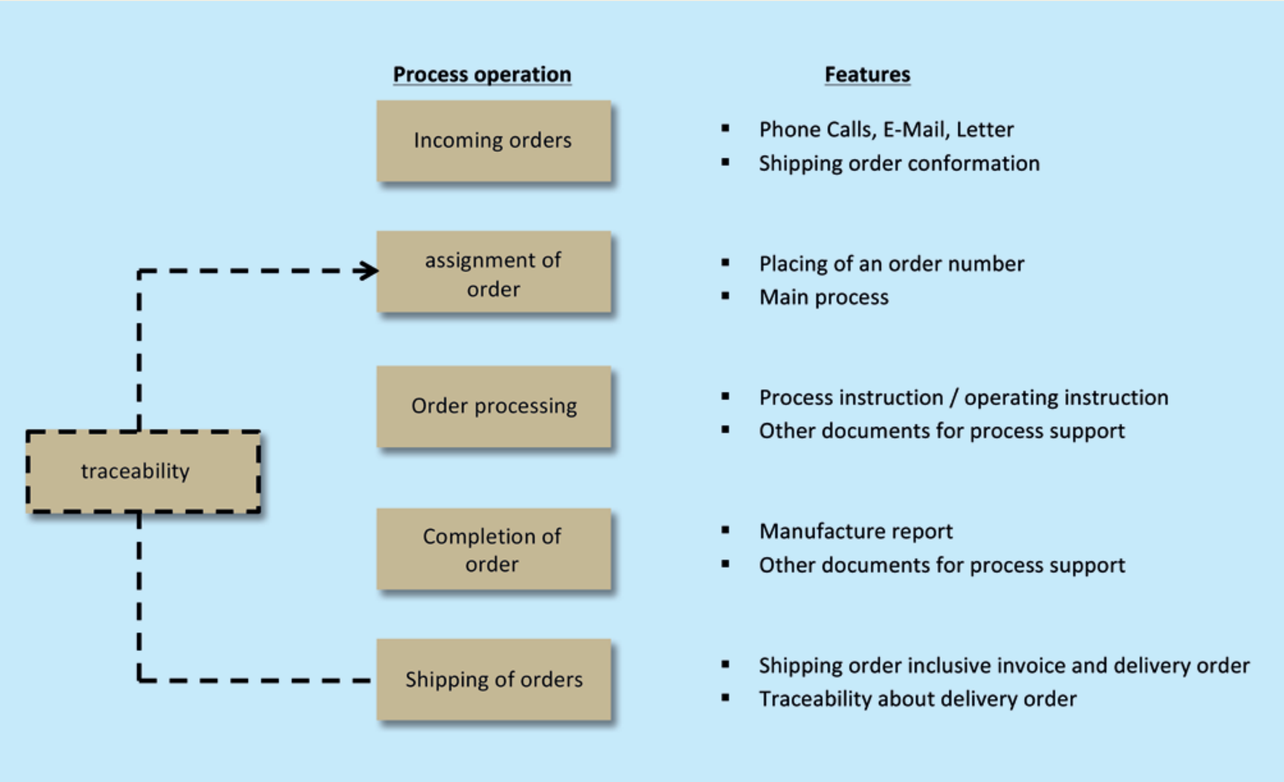


Fig 1: Actual process sequence in DMRC

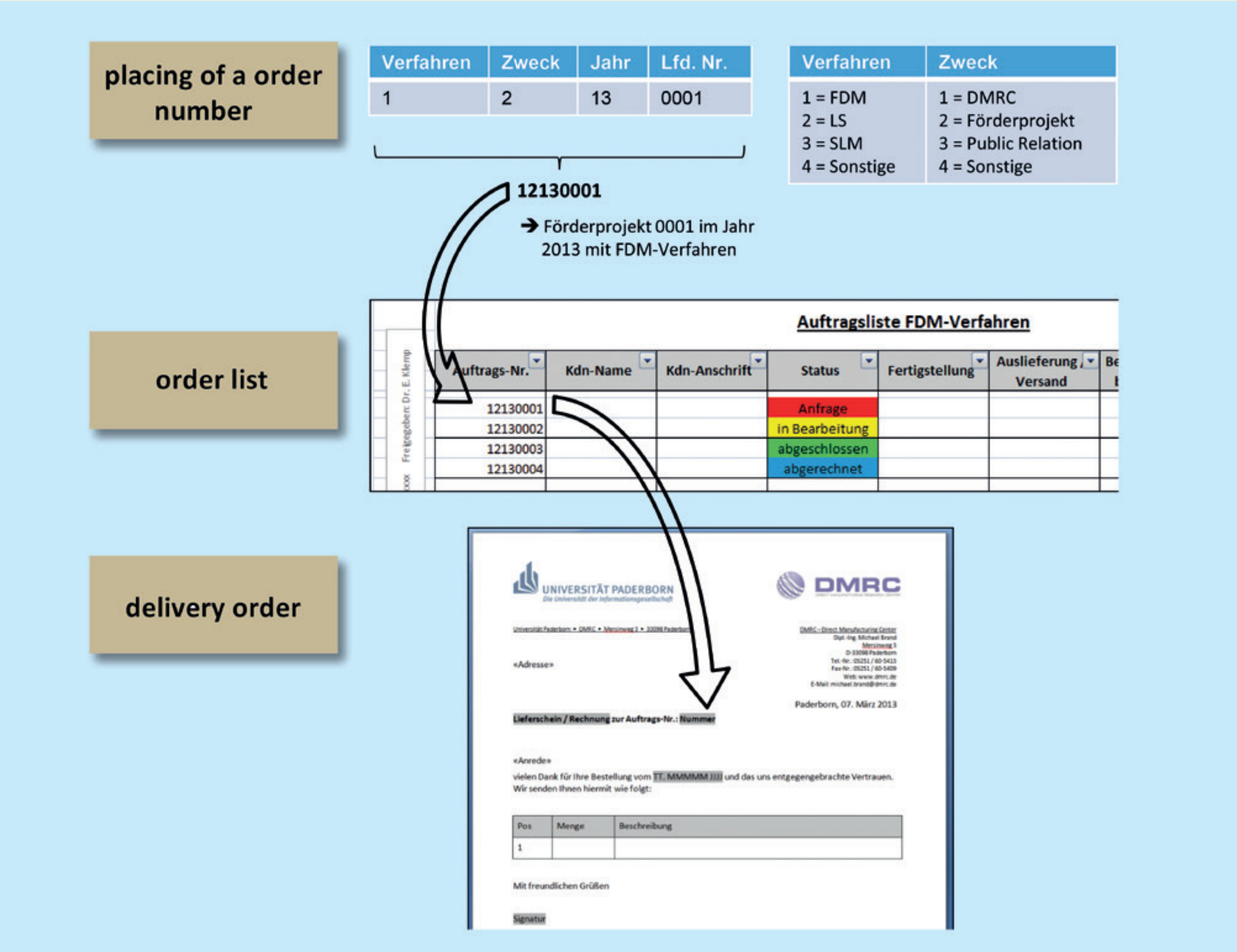


Fig 2: process traceability

The order list will be continuously updated during the whole process up to production. It is supposed to be a "living document". The completed order will be sent together with the invoice and delivery note to the customer. In case of queries the affected order with its order number can be effectively traced in DMRC to check the manufacturing process.

DMRC QM Manual

The aim of the QM manual is to establish a QM management system which will help develop and if possible improve the quality standards at DMRC. All measures taken will be documented in this QM manual.
This will describe the organizational and technical measures necessary to maintain the quality standards expected of DMRC as per DIN EN ISO 9001.
All changes and improvements effected in the year 2014 has been updated at the relevant places in the QM Manual.

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 time, the developed design rules apply only for boundary conditions that were considered within the DMDR project. 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 within the DMDR project. Standard elements 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 (Figure 1). Therefore the machines Eosint P395 (laser sintering), SLM 250HL (laser melting) and Fortus 400mc (fused deposition modeling) were used. For each machine common parameter settings 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 2).

Objectives

In general, design rules for additive manufacturing technologies, which can be used for training and teaching, need to be applicable for different boundary conditions. Thus the research "Direct Manufacturing Design Rules 2.0" project (DMDR 2.0) has the objective to extend the range of validity for the developed design rules.

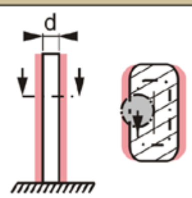
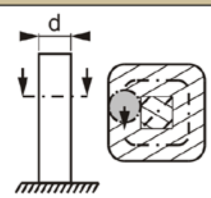
Group	Type	Attribute	Description: General / Process specific	Example: Not suitable for manufacturing	Example: Suitable for manufacturing	LS	LM	FDM
Basic Elements	Non-Curved	Thickness	Plates should be so thick that each layer can be structured of a contour with inscribed raster to minimize dimensional deviations and to avoid defects. *LS: d > 1,0 mm* *LM: d > 0,6 mm* *FDM: d > 1,5 mm*			X	X	X

Figure 1: Design rule, developed within the DMDR project.

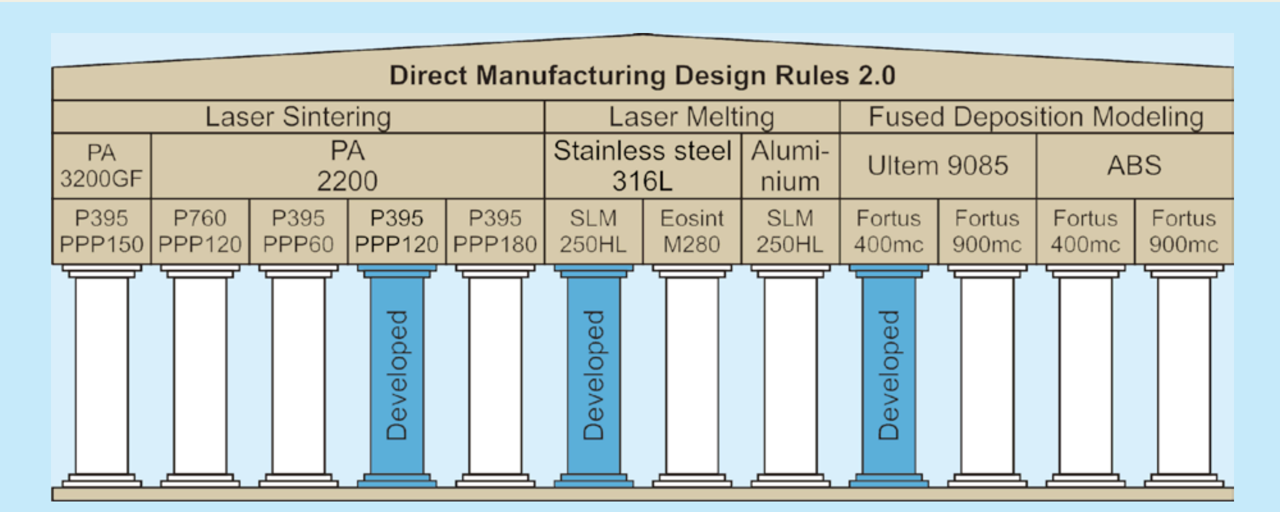


Figure 2: Range of validity for the developed design rules before (blue pillars) and after (white pillars) the DMDR 2.0 project.

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. As a result the validity range will be extended (Figure 2) 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 performed for laser sintering. The results clearly show that the general behavior and occurrence of geometrical deviations are independent from the considered boundary condition. Thus, in most cases the general descriptions of the prior developed design rules are applicable for different boundary conditions in laser sintering. 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. Together, both descriptions provide the information that is required to design parts that shall be manufactured with certain boundary conditions.

Advanced Additive Manufacturing Material and Part Properties-Reduced Refresh Rates & Cooling Process regarding Laser Sintering (AMP²)

Stefan Josupeit

This project treats two important challenges regarding the Laser Sintering Process. One focus is on an optimized polyamide 12 material (PA 2221), which allows a higher recycling rate of used powder and thereby reduces the material consumption. The impact on part and powder properties is investigated along a production oriented series of build and powder mixture cycles. Another focus is on the cooling process of the part cake, which strongly influences the part and powder properties but is less known yet. Therefore, the temperature history within the part cake is measured experimentally and correlated with part quality characteristics. In a second step, the cooling process is simulated as a basis for optimized process controls.

Reduced powder consumption using PA 2221 material

With the use of PA 2221 material it is possible to use very low refresh rates of about 30% compared to 50% with the standard nylon 12 material PA 2200.

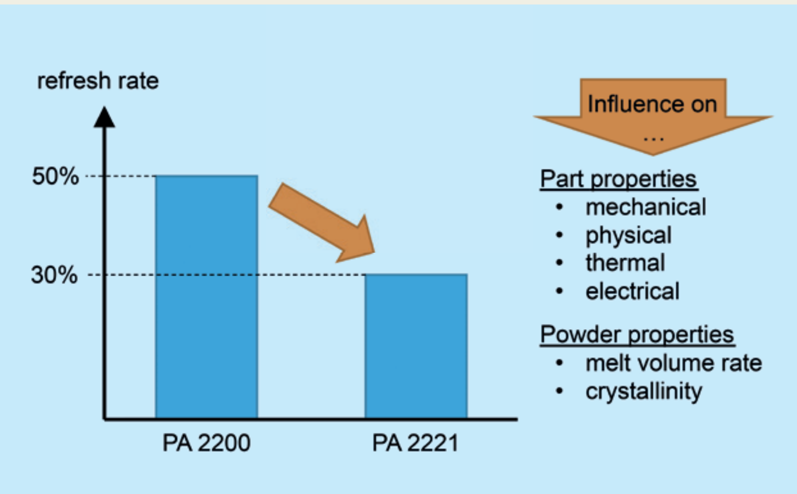


Figure 1: Reduction of the refresh rate and its influence on powder and part properties

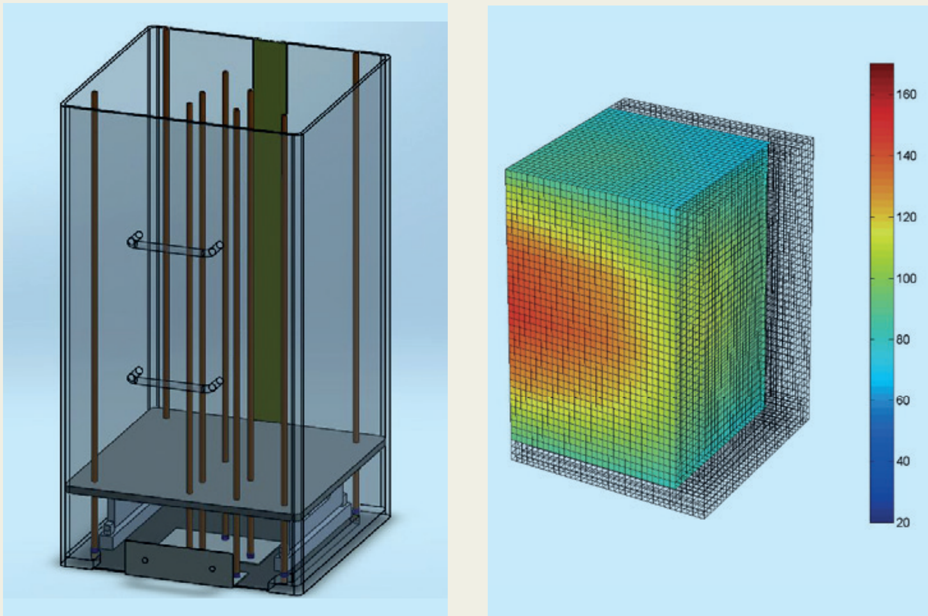
Maintaining similar part quality characteristics, the powder consumption and waste are thus reduced significantly. As a result, the cost efficiency of the laser sintering process can be increased.
The influence of the thermal loading on the powder age is analyzed with various methods, for example the melt volume rate or the crystallinity. Experiments are conducted along a test series with a rising number of build cycles using the refresh rate as well as the MVR value to adjust a used/virgin powder mixture ratio. Thereby, a representative ageing state for circulatory PA 2221 powder is achieved.

Determination of PA 2221 part properties

Since the ageing behavior of PA 2221 is known and characterized, experiments are performed to determine temperature-dependent material data, for example the mechanical, physical, thermal, electrical or impact part properties, which can be used for part design and FE analyses. These results will be compared to the standard material PA 2200. (Figure 1)

Temperature measurement within laser sintered part cakes

In previous investigations it has been shown that the position of a part within the part cake strongly influences its quality characteristics due to different temperature histories. Next to the part position, important job parameters like the part packing density or the build height influence the cooling rates. Nevertheless, the temperature distribution of the inner part cake during the build process (warm-up, build and cooling



(a) (b)

Figure 2: (a) Construction of the temperature measurement system
(b) Measured inner part cake temperature distribution during cooling (quarter view)

down phase) and its influence on part and powder properties is less known yet.

In a first step, a temperature measurement is installed into an EOSINT P395 laser sintering system. Therefore, the build frame and the lift mechanism of the machine is modified. More than 50 thermocouples are attached to tubes and measure the temperature of the inner part cake during the whole build process. In a second step, the influence of important job parameters like the build height and the used layer thickness is analyzed for part-free build jobs. The third step considers the influence of built parts on the temperature distribution and history. In addition, the different temperature histories are correlated with powder and part properties, for example the part crystallinity (and thereby shrinkage, warpage and mechanics) and the powder age (melt volume rate).

Simulation of the cooling process

The results of the temperature measurements are used to simulate the cooling process using the Finite Element Method (FEM). In this way, important thermal parameters of the bulk powder are analyzed. Different cooling down strategies can be tried out without the need of further experiments. An optimization of the cooling process, which is vital for better and more constant part qualities, may be developed in a follow-up project.

Costing Analysis for Additive Manufacturing (AM) during Product Lifecycle 2.0 (Project CoA²mPLy 2.0)

Christian Lindemann

In the project CoA²MPLy the cost structure of Additive Manufacturing (AM) has been analyzed and a costing framework considering the whole lifecycle costs is one result of CoA²MPLy. This allows a comparison between AM and traditional manufacturing concerning costs in each process in a parts lifecycle. During the research activities some problems regarding cost relevant parameters have been identified. Based on these outcomes and gathered knowledge there are three main objectives to address in the follow-up project CoA²MPLy 2.0:

(1) Enhancement of costing framework developed in CoA²MPLy

(2) Achievement of comparability between machines and technologies regarding costing aspects and particularly building rates - proposal for standardization

(3) Development of an expandable IT-System with a costing calculation module, an AM Database and a presentation of advantages of AM

Enhancement of the SLM costing framework

The costing framework developed in CoA²MPLy focuses Selective Laser Melting (SLM) with its specific characteristics in terms of necessary pre- and post-processing, the manufacturing process itself and the achievable benefits during product lifecycle compared to traditional manufacturing. Objective (1) comprises an adaption of the costing model to the Laser Sinter- ing (LS) process and to the Fused Deposition Modeling (FDM) as well to provide cost calculations for the three most used additive manufacturing processes (compare figure). This work will enhance the existing framework for costing analysis to be utilized by OEMs, additive manufacturing part suppliers and additive

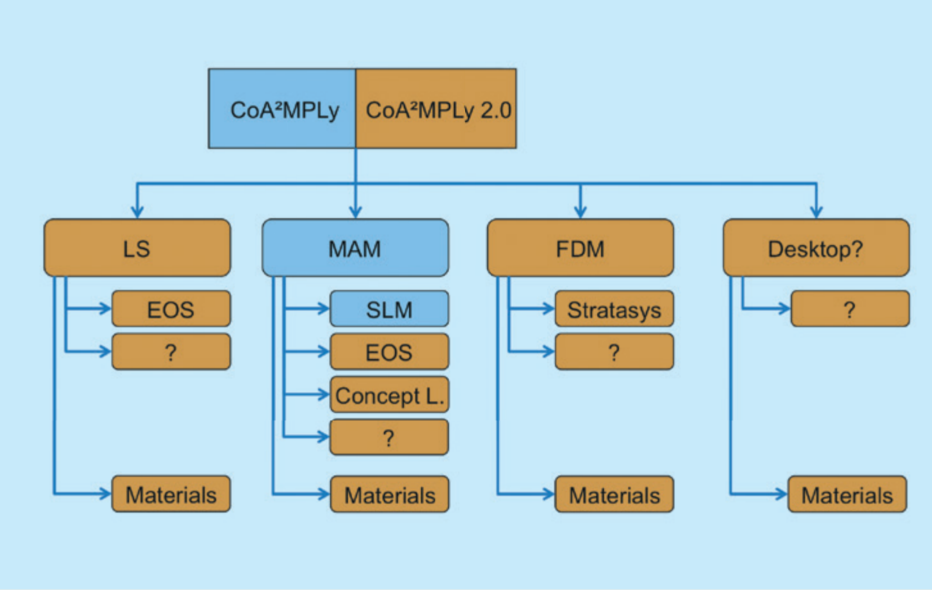


figure 1: enhancement of previous results

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 the machine manufacturers measure the building rate in different ways and specify these rates even in different units for instance cm/h or mm³/h. To achieve comparability and transparency for potential customers that are 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. Furthermore the effieciency of th use of ressources like energy and gas will be concidered.

Development of an IT System for costing calculation

During CoA²AMPLy the costing framework mentioned before is implemented as a Microsoft Excel tool. The capabilities of this software are limited particularly in terms of usability and complexity. Thus objective (3) is meant as development and implementation of an expandable IT-System concept. Simplifying and improving the use of the costing framework will be the starting module. 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. By reason of an interface to import STL/AMF files a more detailed calculation of expected costs will be possible. 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.

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 the possible end users to compare different technologies in regard of building speed and efficiency.

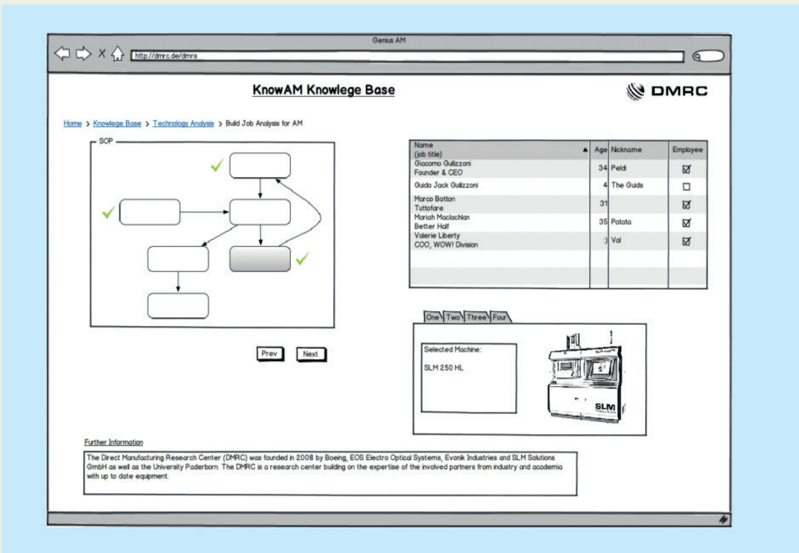


figure 2: Mock up of the IT System

Analysis of the FDM Part Quality Manufactured with ABS with the Focus on the Toy Industry

Matthias Fischer

Frederick Knoop

The aim of this project is to establish a database that is necessary for the direct manufacturing of parts via the Fused Deposition Modeling in the toy industry with the material ABS. For this, not only the strength properties and the influencing parameters on the strengths have to be worked out, but a knowledge of possible surface finishing methods is also needed in order to create a component that meets the given requirements. Another very important topic is the dimensional accuracy of the parts. A very high fitting accuracy is necessary in some applications. This research project is divided into three work packages. First the mechanical strengths are analyzed, then the surface characteristics in combination with the dimensional accuracy of FDM components manufactured with the material ABS are investigated experimentally.

Mechanical Strength Properties

First, the mechanical strength properties of ABS parts will be analyzed according to the ISO standards for plastic materials. The tests to be conducted are shown in Figure 1. For the purpose of these tests, test specimens will be built up with different slice heights due to variation of the tip size. Furthermore, the build orientation will be varied. First, components will be built up with the preset toolpath parameters and then these parameters will be changed in order to analyze the effect of the inner part structures of the fabricated parts on the resulting strength properties. Additionally, some tests will be conducted according to the standards of the toy industry in order to work out possible application fields.

Surface treatment methods

In this work package, the analysis of surface characteristics for ABS parts will be conducted with the aim of improving the decorative surface properties. In general, FDM-parts show rough and wavy surfaces with stair-stepping effects whenever the parts have sloped or rounded geometries. Important FDM process related parameters for the surface characteristics include: layer thickness, filament width, air gap and build orientation of the component. The post

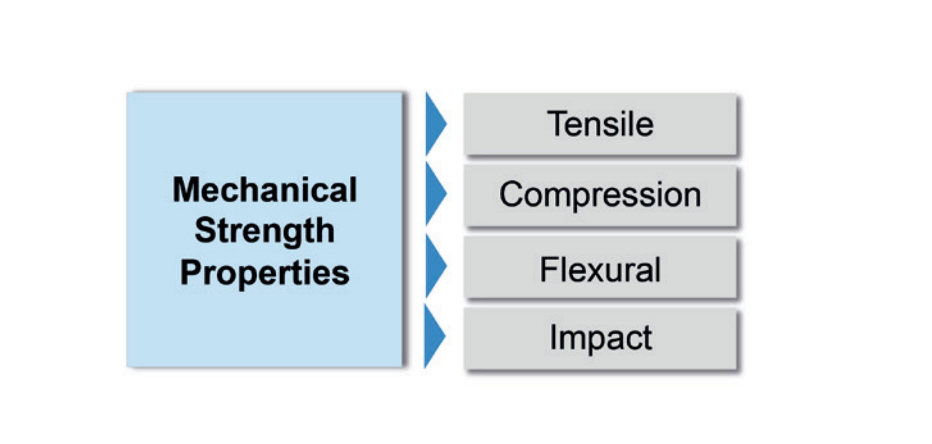


Figure 1: Mechanical properties

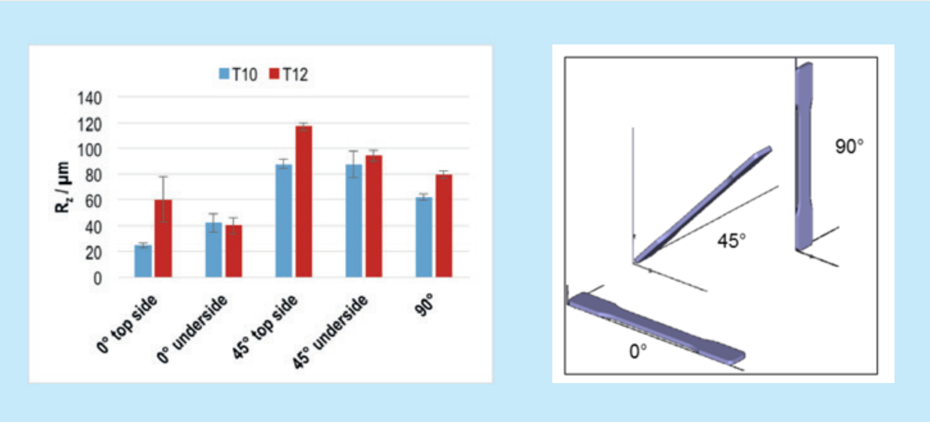


Figure 2: a) Average height of the profile of FDM parts; b) Tensile specimens in different building angles

treatment will be focused on mechanical methods such as vibratory grinding and abrasive blasting. For mass finishing, the process parameters granulate, geometry of the granulate, finishing time, and intensity will be analyzed. The influence of layer thickness, build orientation, and measurement direction on the surface roughness of untreated parts is shown in Figure 2.

Dimensional accuracy

Furthermore, the analysis of the dimensional accuracy of ABS parts will be conducted with regard to the surface smoothing method. To achieve this goal, standard elements were built with different process parameters (slice height, orientation and toolpath). The deviation from the nominal size is measured before and after a grinding treatment. Thus, the aim is to define a general guideline on how to achieve a required fitting accuracy in relation to the manufacturing process and the used surface smoothing method.

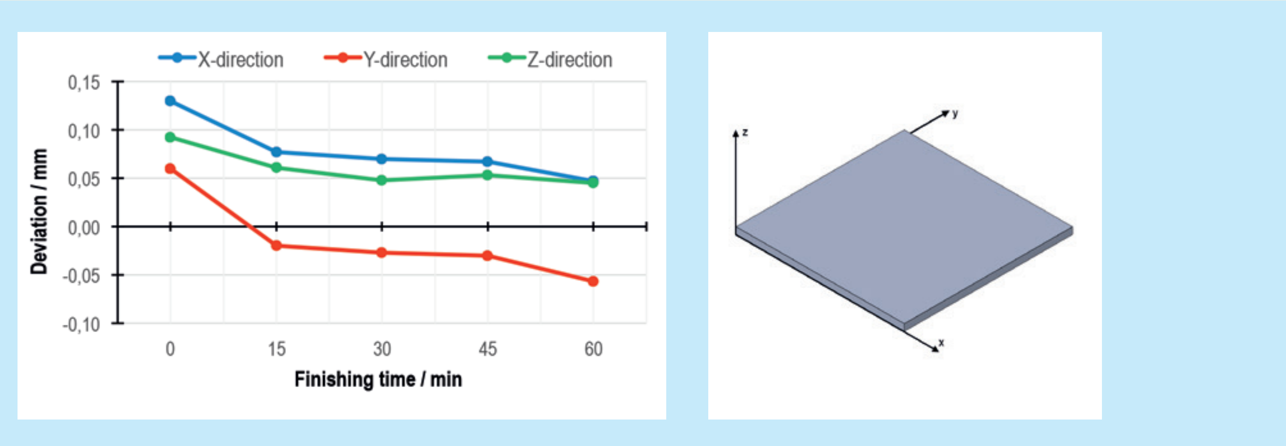


Figure 3: a) Dimensional accuracy of the standard element "plate" after grinding process; b) Standard element "plate" with the nominal size 50 x 50 x 2 mm (x/y/z).

Fatigue Life Manipulation

Wadim Reschetnik

Technical components are subjected to various stresses during operation. They are responsible for the limited service life of the components. Fatigue cracks are often observed far below strength limitations. The life time in components under fatigue loading is divided into crack initiation and fatigue crack propagation. Using crack growth retardation methods substantially higher fatigue life can be achieved. Figure 1 shows the effect of notches on the life time during crack growth period. The reason for the difference in life time 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.

Objectives

The main goal of this project is to extend the total life time of components. Using intrinsic advantages of additive manufacturing processes notched parts will be produced in order to manipulate the fatigue life, Figure 2. It is expected that due to changes in stress distribution caused by the notch the crack growth behavior will be influenced. By variations of the various notch forms, notch sizes and notch orientations basic knowledge about crack behavior in SLM processed components will be obtained.

Analysis

At the beginning preliminary studies regarding the simulation of unnotched and notched structures considering the period of crack initiation and fatigue crack propagation were performed. The effect of heat treatment on lifetime was studied by simulations of crack growth in solid components. In this case the software tool NASGRO was used for lifetime calculations. The results of the components' lifetime simulations show the absolute necessity of heat treatment. Depending on the maximum value of cyclic loading the residual lifetime can be increased by the factor 34 and

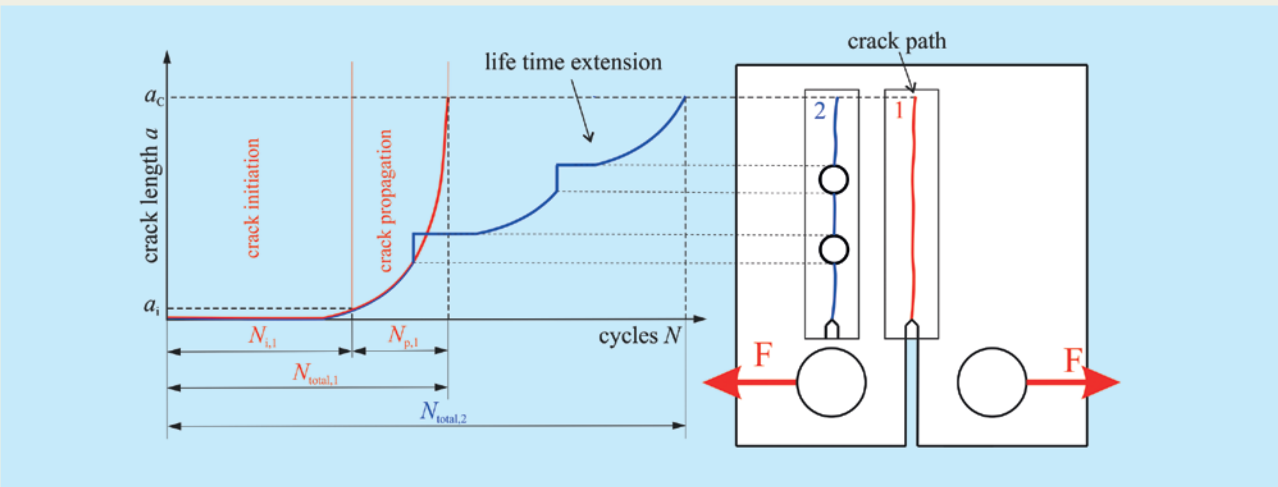


Figure 1: Schematic illustration of life time manipulation caused by notches

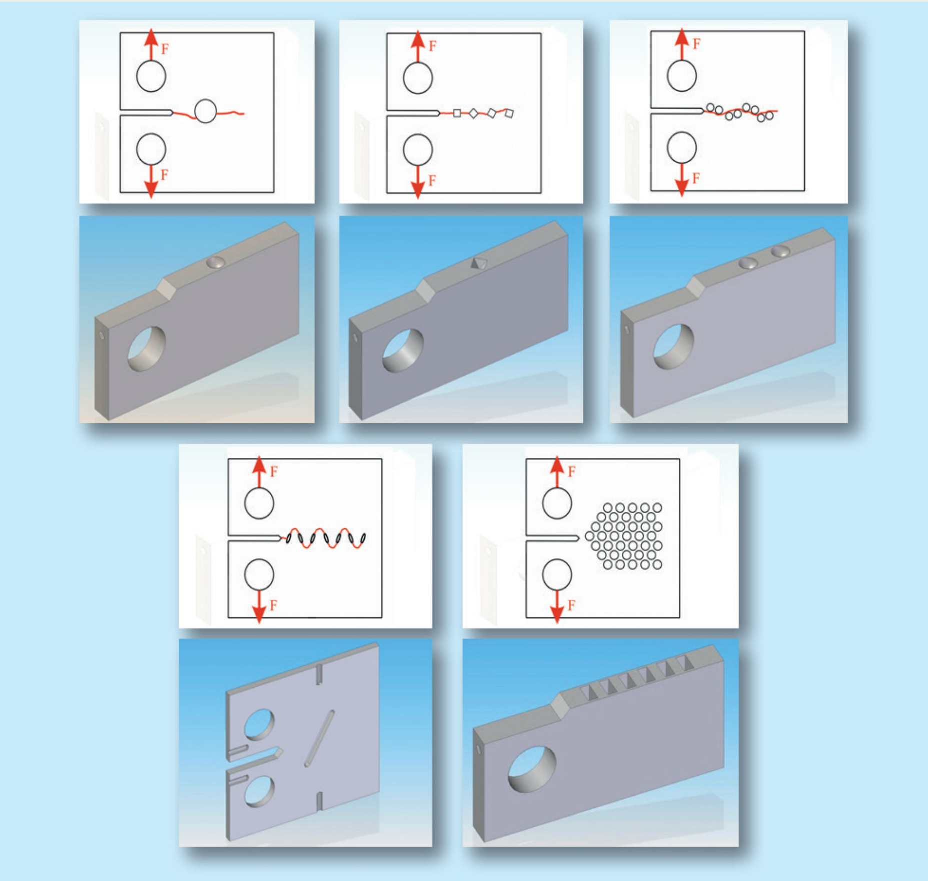


Figure 2: Schematic illustrations of notch form, notch position and notch orientation for life time manipulation

17 respectively. To perform the simulation of notched parts including crack initiation and fatigue crack propagation the software tool Franc/FAM was employed.

Approach

In the first step of experimental research, preliminary tests on modified CT-specimens containing one hole will be performed, Figure 2. In this step different parameter like hole size or hole position will be examined. Furthermore, the number of holes will be elevated to a row of holes, positioned inside the specimen. In the next step, samples with different notch positions will be produced in order to investigate life time manipulation due to crack deflection. After that, elongated holes with different orientations will be tested in order to investigate life time manipulation due to different crack deflection situations. In the last step, the number of rows will be heightened to an array of holes. The findings of this test series will be used to describe the crack growth performance in high-grade notched structures.

Innovative SLM Materials

Stefan Leuders

Through previous DMRC projects in the field of the Selective-Laser-Melting (SLM) process, very promising properties of materials and components manufactured by this production-technique have been shown by different research groups. As an example, tailored mechanical properties of components as well as high strength lattice structures could be mentioned. 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. This circumstance leaves one huge potential of the SLM process unconsidered: An in situ combination and processing of different materials in order to obtain innovative materials characteristics – maybe in contrast to each other when employing conventional production-routes.

In order to enable a systematic procedure for this project, it has been subdivided into the following work packages.

Work package 01: Specification & Screening

Within the first work package, a material-screening will be performed in order to define possible combinations of two or more materials to be investigated for the SLM process. In order to allow a non-biased screening, this work package is based on previous definition of desired properties, which should be achieved by the new material. Subsequently, the precise selection of the respective materials is carried out by a more detailed analysis taking into account for example physical properties, such as melting points or densities.

Work package 02: Parameter development

Since a transferability or adaption of existing exposure parameters cannot be assumed, these parameters will be fundamentally redeveloped for the composite material. Afterwards, regarding the targets adopted within work package 01, the verification of these required properties is the most important point in this work package. Depending on the target size, e.g. thermal conductivity, suitable measurement methods are applied in order to determine the degree of goal fulfilment. The microstructure of this composite will also be in the focus of these investigations, since the mechanical properties are often directly related to the evolution of the microstructure. Thus, applied analysis techniques will include optical microscopy as well as scanning electron microscopy. Furthermore, the influence of different mixing ratios of these two materials will be investigated. Here, in particular, the question arises to what extent do segregations or intermediate phases occur in relation to different densities or melting temperatures.

Work package 03: Mechanical properties

Since a detailed knowledge about the mechanical performance is a fundamental requirement for the use of a specific material, a comprehensive characterization of the mechanical properties will be carried out within work package 03. These studies include both quasi-static as well as cyclic tests, while

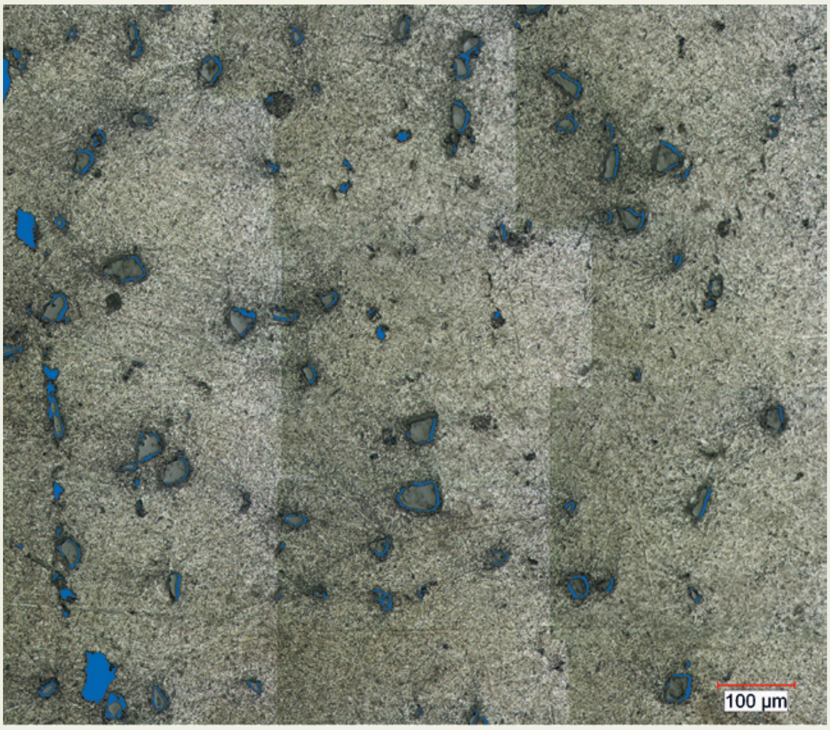


Figure 1 Micrograph of SLM-processed metal matrix composite consisting of aluminium alloy AlSi7Mg (94 wt%) + boron carbide (6 wt%). In this micrograph, the embedded boron carbide is coloured blue.

the emphasis is determined in consideration of the requirements from work package 01. In the light of complex interactions between material and laser, the focus of work package 03 is also on the impact of the process-related microstructure on the desired properties.

Work package 04: Concept development "locally adapted material combinations"

The work package 04 aims at developing a concept that enables for a local adaptation of mixing ratios. This concept is to identify ways and means to obtain graded material properties through adapted mixing ratios, combined with appropriate exposure parameters as well. The local variation of mixing ratios should be realized for both alongside the z-direction as well as within the x-y plane. Furthermore, through sensitivity analysis, it should be assessed to what extent different mixing ratios will require adjusted exposure parameters.

Work package 05: transfer analysis

In order to investigate a transferability of processing-routes on other Additive Manufacturing systems, the new material should also be processed on an EOS system. Afterwards, a rough comparison in terms of resulting microstructure and mechanical properties between these two different SLM systems will be carried out.

This research project is being processed by the department "Automotive Lightweight Construction".

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. With 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 evaluated. Main emphasis is on suitable math-

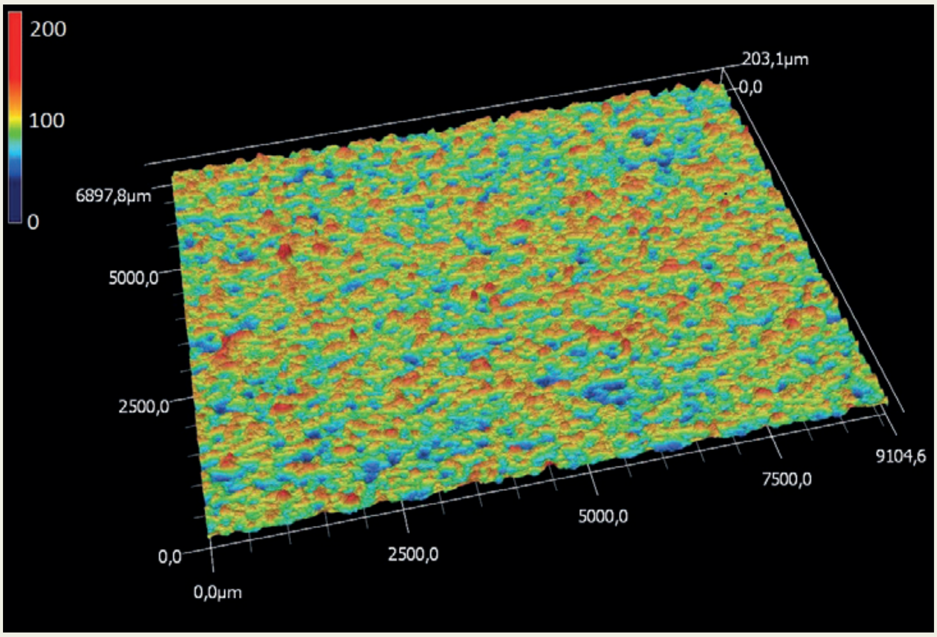


Figure 1: Surface topography of a laser sintered part surface. Adhered unmolten particles are obvious.

ematical 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, too.

Surface Finish according to Process Parameter

The post process is an important factor using the laser sintering process. After the unpacking process the powder has to be removed from the parts, which is performed by using a blasting cabin. In this part of the project the post process regarding the different post process parameter shall be investigated. The blasting time, the blasting distances as well as the blasting pressure are the most important parameters. Further on the blasting material shall be investigated as well. 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. Those should be specified as a function of defined properties, as a sensible parameter of surface roughness or a judgment of surface quality. The evaluation of these methods is done using the characterization method determined in the chapter „Surface Quality Characterization Method“.

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 exposed to light, humidity and temperature 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.

Research Strategies for Additive Manufacturing

Stefan Peter

Additive Manufacturing is a disruptive technology progressively permeating diverse markets. It is capable to trigger major upheavals reshaping supply chains and business models over the next decade. Many industries are seeking for opportunities how to capitalize on the benefits AM provides; new industries progressively draw their attention to AM's potential. As well, global research initiatives funded by different governments spark new impulses in the research landscape. Established and newly founded research centers, e.g. in the UK, the US or Germany are continuously striving to close research gaps and to transfer the research results into tangible outcomes for the industry. Therefore, demand-oriented research strategies are needed.

Additive Manufacturing Research Map

To deduce the need for research activity, the AM research landscape was analyzed. As a result, the AM Research Map was created (fig. 1-1), revealing the

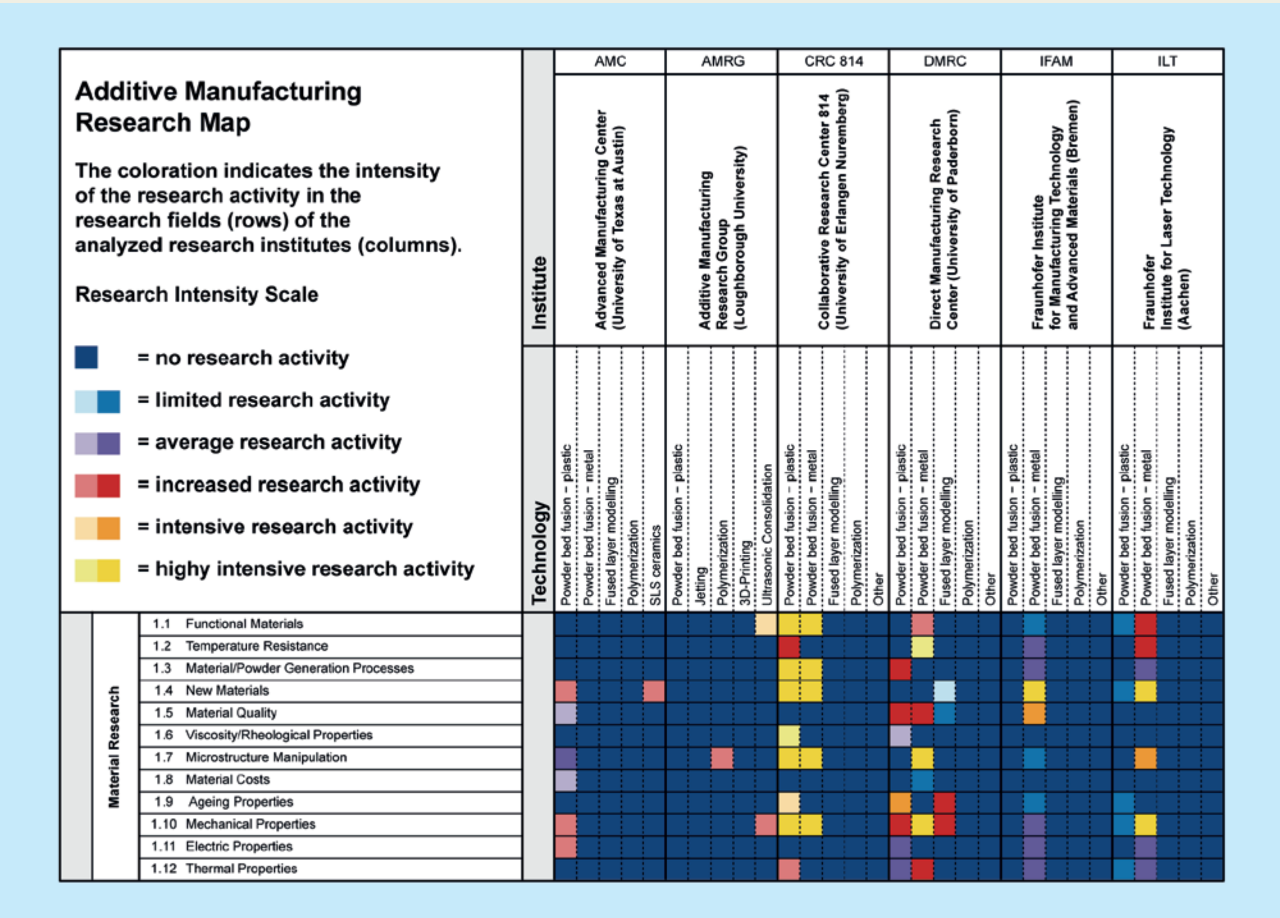


Figure 1-1: Excerpt from the Research Map, indicating the research intensity in different research fields (rows) for selected institutes/technologies (columns)

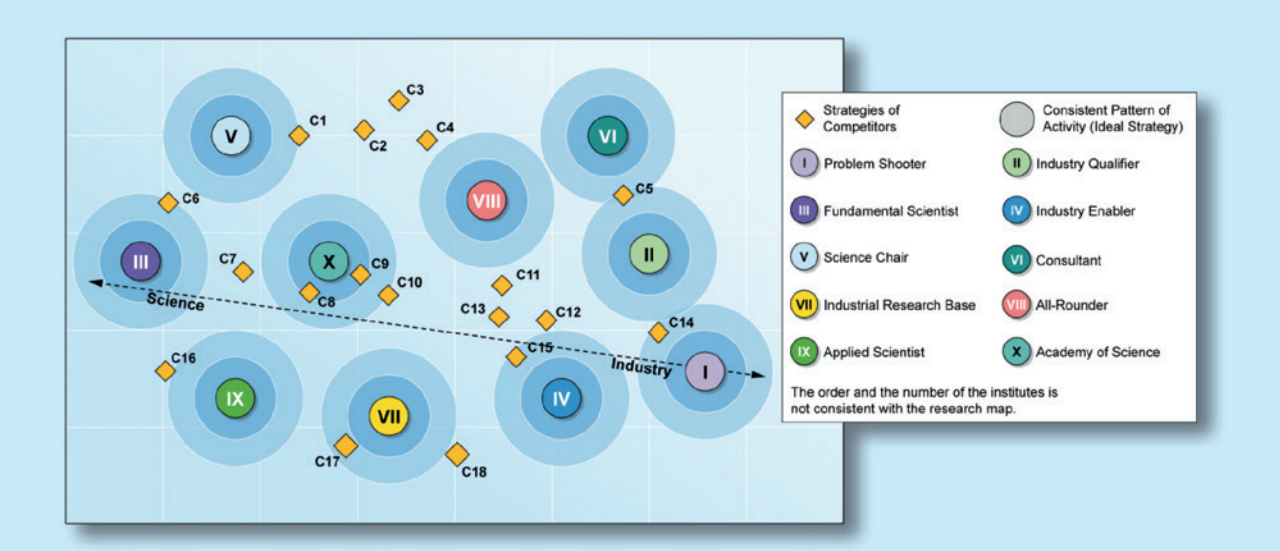


Figure 1-2: Strategy Map: Visualization of developed strategy variants and the current strategies in the research landscapecating the research intensity in different research fields (rows) for selected institutes/technologies (columns)

research intensity of the analyzed research institutes.

For instance, just a few institutes focus on cross-technological research fields, e.g. the development of design rules; the research intensity is medium; others, e.g. material research, are intensively investigated. An outstanding research intensity is prevalent in e.g. mechanical properties, new materials, material quality, microstructure manipulation. Research fields with a rather low research intensity are e.g. supply chain optimization and process automatization. Concurrently, conclusions emerge for technology-specific research intensity. The highest and lowest research activity distributed over all research fields are indicated for Powder Bed Fusion Metal and Polymerization Technologies, respectively.

Additive Manufacturing Strategy Map

To identify crucial levers for future research strategies, white spots need to be revealed. Therefore the research activity and intensity were contrasted with the future relevance of the research fields. Process automatization and design rules were determined as white spots and should be considered as levers in future strategies. Research fields such as new materials are important as well. Here however, the research intensity is already high. Based on the white spots, success factors enabling the levers were deduced. Hence, AM research could significantly benefit from e.g. a stronger interconnection of institutes within the research landscape and a closer integration of companies along the value chain.

These aspects were taken into consideration to develop consistent strategies. The result are ten consistent strategy variants, ranging from a Fundamental Scientist to a Problem Shooter. Contrasting the developed strategies with the strategies the institutes currently pursue, a Strategy Map is resulting (fig.1-2). All deduced conclusions are considered for the development of a coherent strategy for the DMRC.

Strategy Lab

For regular strategy controlling and updating a Strategy Lab was developed. By combining internal and external perspectives, the Strategy Lab ensures a comprehensive view on the institute's current situation. This includes its position within the research landscape and crucial success factors. Contrasting these to the institute's goals and measures reveals required changes in the strategic focus. In a regular review meeting, this focus will be discussed and consequential measures and research topics can be deduced. Thus, it can be ensured that a strategy is aligned with actual and important influences on the institutes business.

Development of an Additive Manufacturing Potential Check System (DynAMiCS)

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 industrial revolution, which is present in the subtext of our media. As of today, the DMRC has been working on propelling the technology from Rapid Prototyping to Direct Manufacturing for more than five years. The DMRC's competences enables 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 systematic technology-diffusion concept. In the course of the project we endeavor to explore the resentments against AM which hinder its broad acceptance and an answer to the question: Is AM different in its diffusion process?

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

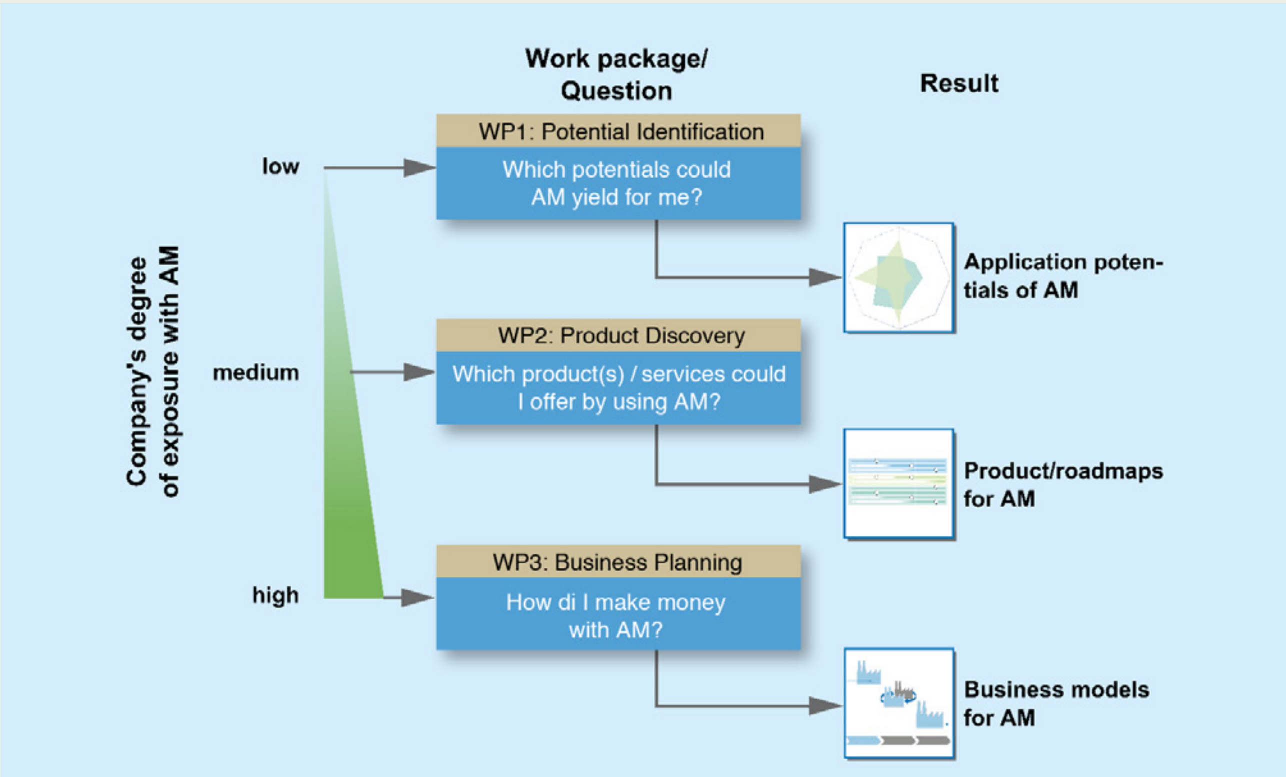


Figure 1: Logic behind the project

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 (see exemplarily figure 2). 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 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.

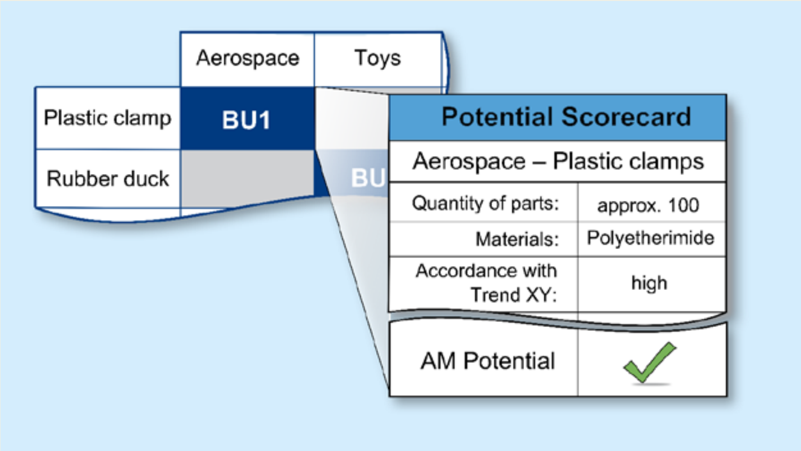


Figure 2: Criteria-based selection of market segment and product category combinations.

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.

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 gather a lot of 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 out of it. However, all of these tests have been performed on thermoplastic polymers, especially polyamide 12. Polyamide 12 is a material with a great amount of technical applications, yet it only presents a fraction of the possibilities polymers can offer. 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 an entirely new field 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 as yet no in-depth knowledge about the material's processability and properties of parts manufactured using it. It is therefore an ideal study subject for this project.

Goals

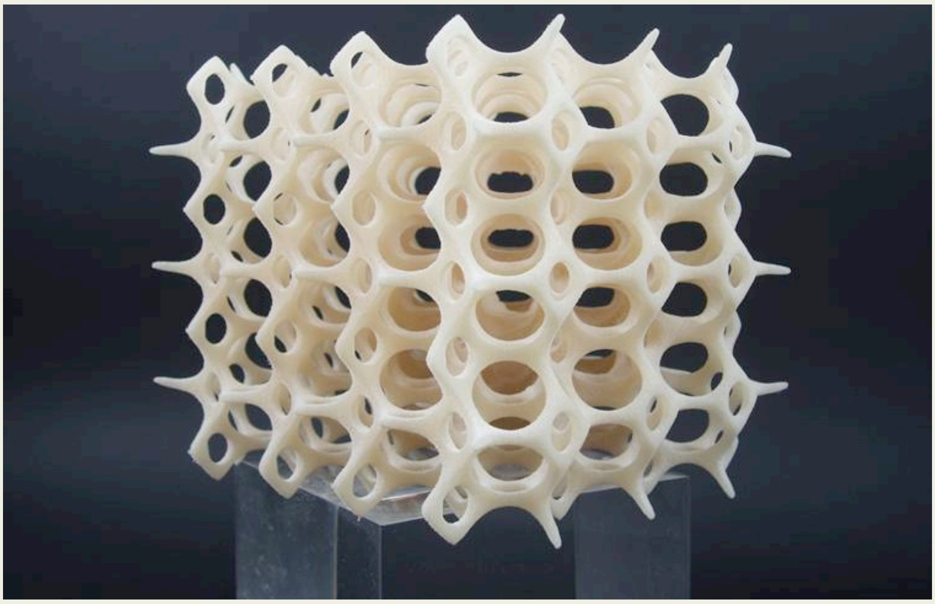
The goal of this project is to gather a wide range of knowledge about the new material. The two main fields for this knowledge are process and material data. First of all, a lot of process data has to be collected in order to be fully control the process. Experience with process limits is needed to achieve 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 how to make optimal use of the qualities of the material.

Parameter Variation

The first part of the project will consist of varying process parameters in order to develop a better understanding of the process and its limits. The most important parameters to be varied 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.

Powder Ageing

Powder ageing is an important factor in every polymer Laser Sintering process. As preliminary tests have shown, if PrimePart ST 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 known. There is also no known test which can easily determine the thermal loading of the powder without building actual parts. The examination of powder ageing will therefore play an important role in this project. First tests will consist of artificially ageing powder in an oven. These samples will then be compared to virgin (untreated) powder using a variety



Quelle: EOS)

of methods in order to find a possible test to tell apart old from new powder. If such a test is found, the experiments will be verified using powder aged in the actual Laser Sintering process. Further tests will then be carried out in order to quantify the powder ageing and to determine the impact on the part quality that is to be expected with powder of a certain age.

Elastic Part Properties

After gaining a first understanding of the processability of the material, part properties are going to be 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 of this part of the project is comparing parts built with similar parameters on different machines. In an initial phase, relevant possible tests will be 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. Once a study subject is determined, it has to be made sure that the design is suitable to be manufactured by Laser Sintering with PrimePart ST, otherwise, it will be modified accordingly. Once the part is produced, it will be 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). This will help to show advantages and disadvantages of the new material.

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

Alexander Taube

Markus Wiesner

Motivation

Different steel alloy moulds used for the production of polymer parts were characterized for their mechanical properties and their corrosion tendency. The steel alloys are used to form injection moulds with cooling channels by laser sintering. As the channels cannot be polished after the sintering process the reactive surface which is in contact to the cooling electrolyte is due to the roughness much larger and incompletely molten powder particles adhere on the surface.

The cooling electrolyte consists of biocides, inhibitors and chlorides and differs in its temperature. It can be assumed that at high temperatures (90°C) the oxygen solubility is decreased which leads to lower corrosion rates than for lower temperatures (25-40°C). In addition to the oxygen solubility the crystallinity of the oxide film might be higher at elevated temperatures.

Within this project the laser melting standard alloy MS1 (X3NiCoMoTi 18-9-5, high Ni-concentrations), a laser melting alloy Orvar and conventionally moulded H13 (ca. 5%Cr + Mo, medium Cr-concentrations) as well as a laser melting alloy Corrax (X3CrNiMoAl 12-9, high Ni- and Cr-concentrations) will be compared.

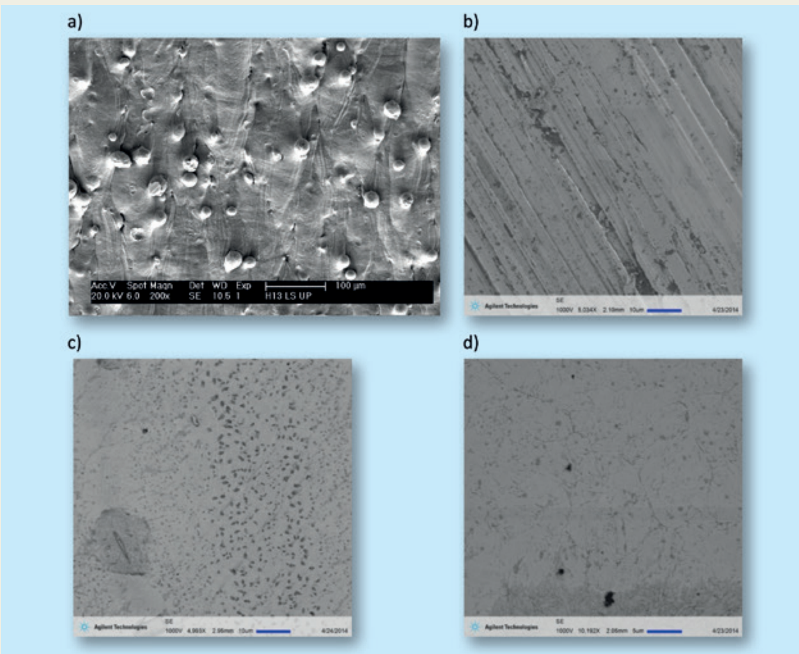


Figure 1: a) SEM image of Orvar unpolished with the incompletely molten powder particles, b) SEM image of H13 unpolished with roll marks, c) SEM image of Orvar polished and etched with pittings, d) SEM image of H13 polished and etched with grain boundaries

Experimental

In the first quarter of the project time the investigation of Orvar and H13 was in the point of view.

The samples were delivered by DMRC (Orvar) and LEGO (H13). All samples were solvent cleaned with tetrahydrofurane (p.A., Merck KGaA, Darmstadt), isopropyl alcohol (p.A., Merck KGaA, Darmstadt) and ethanol abs. (p.A., Merck KGaA, Darmstadt) each for 10 min in an ultrasonic bath (Ultrasonic Cleaner, 45 kHz, 120 W, VWR International GmbH, Darmstadt). To figure out the influence of polishing the samples were grinded and polished until a polishing grain size of 1µm before they were rinsed with water, cleaned with Ethanol (p.a., Merck KGaA, Darmstadt), dried in an air steam and finally etched in Nital-solution (3 vol.-% HNO_3 (65 %, p.a., Merck KGaA, Darmstadt) and 97 vol.-% EtOH (p.a., Merck KGaA, Darmstadt)) for 40 s, cleaned with Ethanol (p.a., Merck KGaA, Darmstadt) and dried in an air steam.

Results

On figure 1a) the incompletely molten powder particles after the laser sintering could be clearly seen. The assumption was that these spheres are preferential for the corrosive attack.

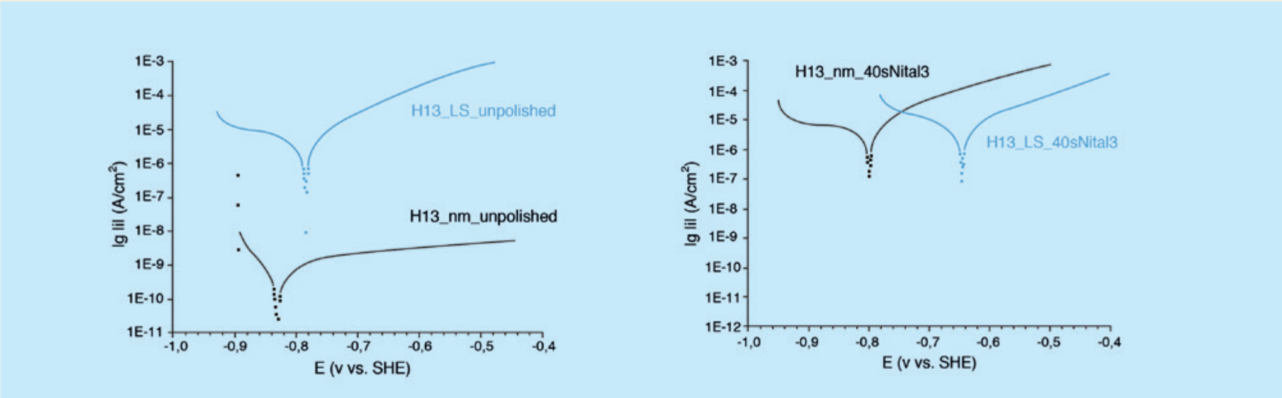


Figure 2: a) current density vs. potential curve of the unpolished samples Orvar (H13 LS) and H13 (H13 nm), b) current density vs. potential curve after polishing and etching of the samples Orvar (H13 LS) and H13 (H13 nm)

Figure 1b) showed the surface of the conventionally moulded alloy with still having roll marks on the surface. It could be assumed that the indentations were preferential for the corrosive attack.

Figure 1c) showed the Orvar surface after polishing and etching with nital3-solution. The spheres were not visible anymore but instead holes appeared what led to the assumption that some alloying elements were dissolved. On the polished and etched H13 sample on figure 1d) the grain boundaries were clearly visible. Different from the Orvar sample no dissolution of alloying elements could be detected.

The Raman spectroscopy (not shown here) gave the evidence that the samples consisted of Fe_2O_3, Fe_3O_4 and mixed Cr-Fe-oxides before the electrochemical investigations. Afterwards additionally FeOOH and Cr_2O_3 were detectable.

By means of current density vs. potential curves (see figure 2) it could be shown that the Orvar samples, polished as well as unpolished, showed a much higher exchange current density than the unpolished H13 sample. After polishing and etching the exchange current density of the H13 sample is nearly as high as the Orvar sample.

SEM images (not shown here) after the electrochemical investigations showed that contrary to the assumptions done before neither the spheres on the Orvar samples nor the indentations on the H13 samples are preferential for the corrosive attack.

Conclusion

An enrichment of Cr could be observed in the near-surface region of the samples. However the investigated samples showed no passivation behavior in the used electrolyte with 5.6 mol/L NaCl. It could be shown that neither the spheres which adhere on the surface after laser sintering nor the indentations between the roll marks after conventional moulding were preferential for a corrosive attack.

Additive Manufactured Function Integrated Damping Structures (AMFIDS)

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 additional needed installation space. Further, 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.

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 to the production. 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 will be developed and manufactured first. The test technology will be able to create free and forced vibration under bending and 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. First 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. The goal of the 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 doesn't 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.

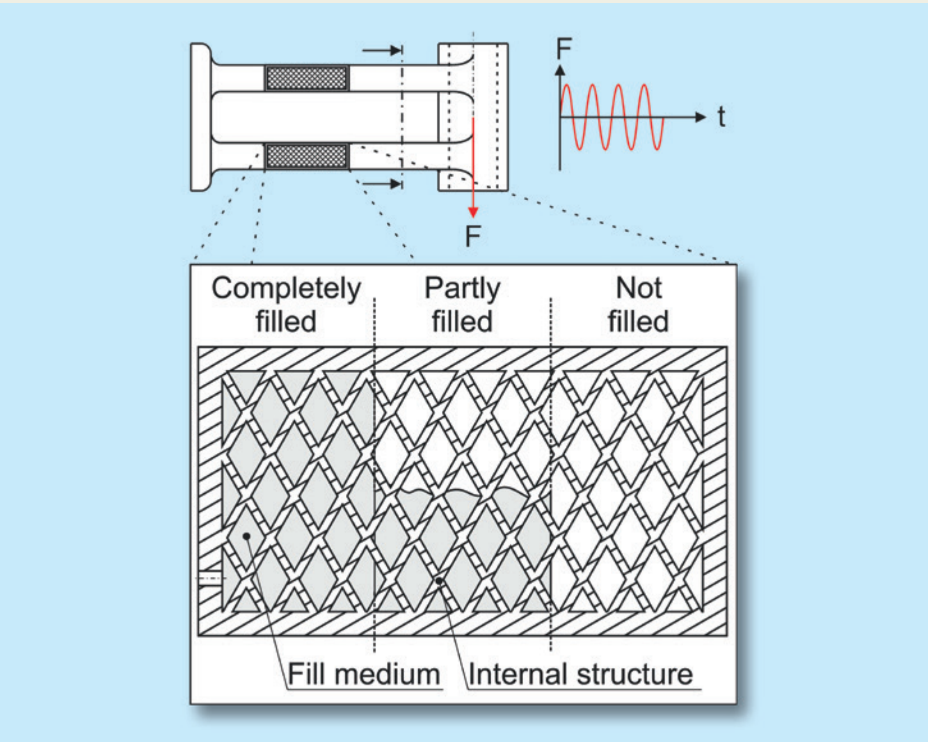


Figure 1: Integration of damping functions into existing structures

Dimensional Tolerances for Additive Manufacturing (DTAM)

Tobias Lieneke

During their design phase, technical parts are virtually created with their nominal shape that meets its ideal shape perfectly. Such a nominal shape does only exist theoretically. Generally, parts have geometrical deviations after their physical manufacturing. Nevertheless, each technical part is made for different functions. In order to fulfil these functions, parts have to be in contact and assembled with other parts. Thereby, the functionality of technical parts in terms of its assembling ability is significantly influenced by the interaction of various geometric deviations. Dimensional, form and position deviations determine if technical parts can be assembled with other parts. Because geometrical deviations are unavoidable during physical manufacturing, limitations need to be given for geometrical deviations. This is typically done with tolerances that have to be kept with the physical manufacturing of technical parts.

Challenges

Although additive manufacturing provides great design freedoms and benefits, its industrial relevance is still limited. One reason therefore is that parts need to meet high quality requirements if they are manufactured in terms of direct manufacturing. They have to fulfill all their requirements and functions. Consequently, geometrical part shapes have to fulfil its requirements, too. These are determined by the tolerances.

For additive manufacturing processes, 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.

Aim

The project "Dimensional tolerances for additive manufacturing" has two different aims:

- Aim 1: Dimensional tolerances shall be developed that can be stated if additive manufacturing is workshop-commonly used. A workshop-commonly usage describes the application of often used standard parameters, materials and machine settings.

- Aim 2: It shall be examined, how dimensional deviations and tolerances can be reduced. Therefore, relevant process parameters and manufacturing influences shall be identified first. Next, optimized settings shall be examined for process parameters and manufacturing influences that can be used to reduce dimensional deviations and dimensional tolerances.

Proceeding

The proceeding within the project "Dimensional tolerances for additive manufacturing" follows two different ways. The first way strives to fulfill aim 1; dimensional tolerances shall be developed that can be stated if additive manufacturing is workshop-commonly used. The second way strives to fulfill aim 2; dimensional deviations shall be reduced due to optimized settings for process parameters and manufacturing influences.
Within the first step of the project,

two methods will be developed for the further proceeding. The first method describes a proceeding for the examination of dimensional deviations that can be stated if additive manufacturing is workshop-commonly used. The second method describes a proceeding for the reduction of dimensional deviations due to the identification and optimization of process parameters and manufacturing influences.

Within the second step, experimental tests will be performed. Dimensional deviations will be examined that occur if additive manufacturing is workshop-commonly used. Parallel process parameters and manufacturing influences will be identified and optimized in order to reduce dimensional deviations.

Within the third step, dimensional tolerances are derived from the measured dimensional deviations. These tolerances provide the borders within which the dimensional deviations should lie if additive manufacturing is workshop-commonly used. Furthermore, measures will be derived that can be used to reduce dimensional deviations. Finally, the results will be summarized and interpreted.

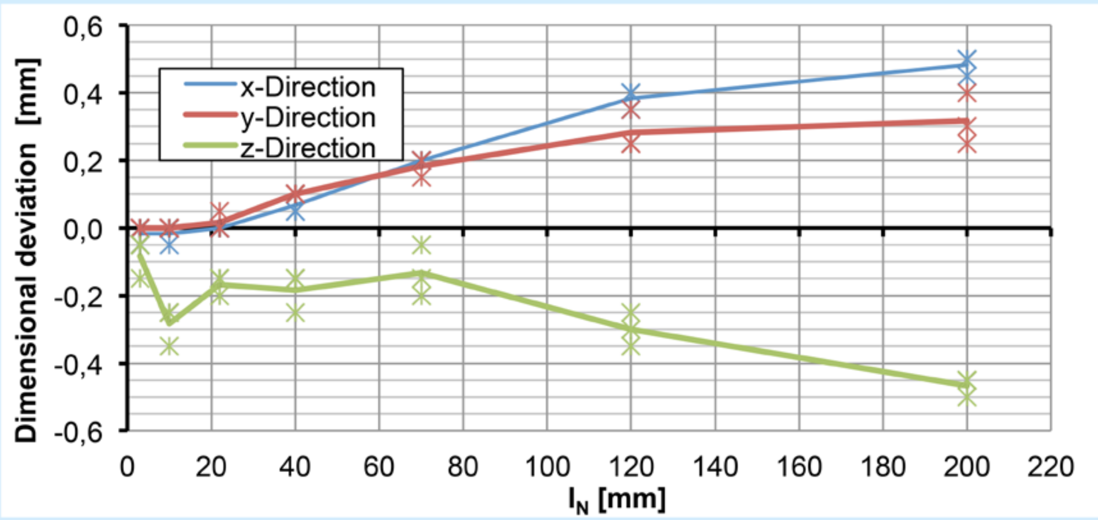


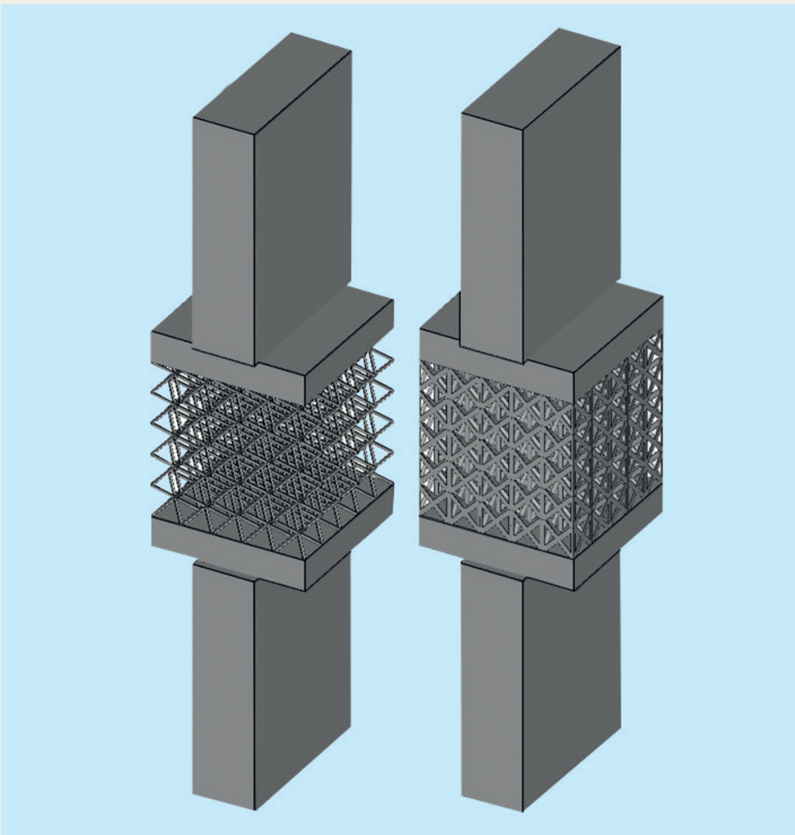
Figure 3: Dimensional deviation versus the nominal length l_N

Robust Simulation of Complex Loaded Cellular Structures

Alexander Taube

Currently, one of the main challenges in industry 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 use 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.

Figure 1: Samples with a body-centered base cell (left) and face-centered base cell with additional struts in loading direction (right)



Objectives

The establishment of a finite element analysis (FEA) model for complex loaded cellular light-weight structures is the aim of the present project. Based on the findings of a preliminary linear-elastic simulation the examinations will be extended to linear-plastic deformation behavior including diverse material conditions by applying 316L stainless steel (ductile) and Ti-6Al-4V alloy (brittle). The main goal will be to achieve a solution for the simulation of different deformation effects depending on the cell geometry. This aspect is very important for reducing time-consuming experiments in order to establish the applications for energy absorbing light weight structures.

Furthermore, plastic cellular structures will be manufactured by Laser Sintering (LS) in order to verify the developed FEA model for a fundamentally different kind of material.

Preliminary Analysis

For characterizing the fundamental behavior of cellular structures the first 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. Figure 1 shows two samples with different base-cell designs. Based on theoretical analysis the body-centered base cell is bending dominated and the face-centered base cell is stretch domi-

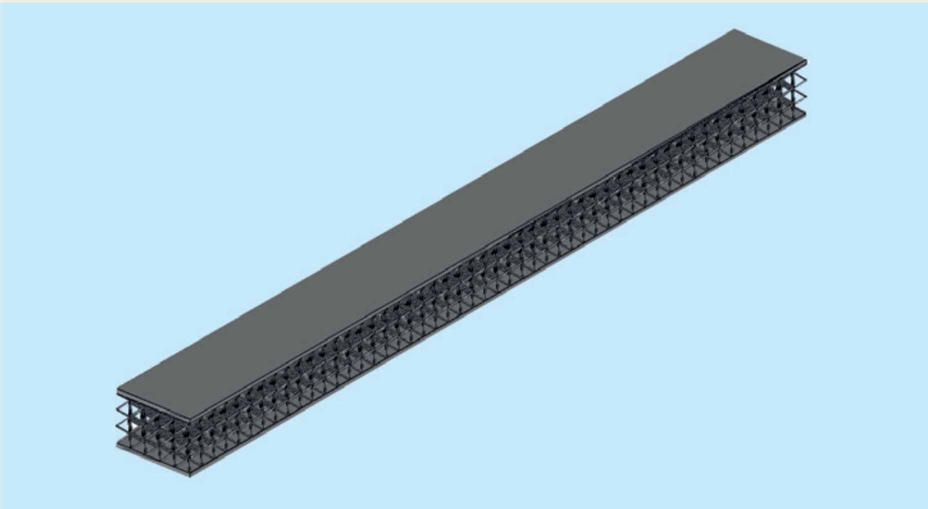


Figure 2: Design of a sample on basis of party load adapted sandwich structures

nated based on theoretical analysis. 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 a 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 to 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 needed.

In the first work package of the current project the literature was screened for existing approaches for designing cellular structures. Different cell geometries were evaluated on basis of FEA with respect to several aspects, such as the spatial stiffness and the stress distribution of the base cells, as these certainly have a high impact on the resulting mechanical performance. In a next step the base cells will be examined by mechanical testing. The focus will be on the behavior under both uniaxial and bending load, whereby the latter will be contemplated for sandwich structures as shown in Figure 2.

Approach

The main activities to reach a robust FEA model include the following aspects. At first the base cells have to be analyzed by using FEA simulation. Thereby the elastic-plastic behavior must be implemented in the FE model. Because of different microstructural conditions of the material after post-treatments diverse FE models will be extended in order to cover this aspects. After that 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.

Future RepAIR and Maintenance for Aerospace Industry

Christian Lindemann

Gereon Deppe

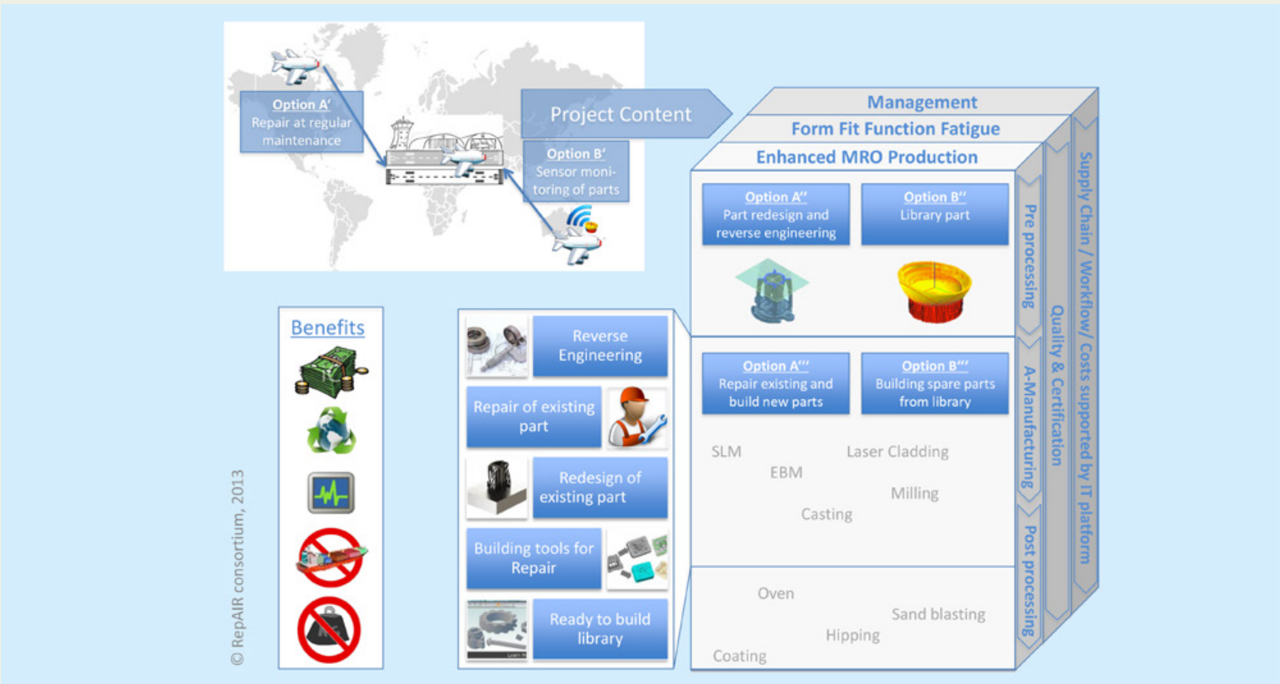
Marco Plaß

The goal of this research project with twelve partners from all over Europe and from the US is the onsite maintenance and repair of aircraft 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 on-time maintenance without having the need of sophisticated supply chains. 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 energy-intensive produced 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.

Figure 1: The RepAIR Concept



Additive Manufacturing in MRO

European maintenance service providers have to deal with an enormous financial pressure. 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. Based on the effort of the producers to reduce quantity and variety of components, multiple functions will inevitably be merged in complex components, whose maintenance could be taken over by technological leading MRO providers. For cost optimized work, one has to decide specifically if each component has to be replaced or could be reworked or recreated. If the costs for the production and the overhaul of complex components were considerably reduced, the decision would automatically be postponed from 'buy' to 'make'.

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

The analysis of the aerospace industry and its processes led to the specification and architecture of the RepAIR IT Management Platform that supports the repair workflows. Four visionary scenarios describe the short- and long-term developments to show where sustainable business models can evolve. An AM classification system for aerospace parts has been set-up to facilitate the decision which repair technology should be applied. To foster the research of integrated part health management a test rig has been designed and installed to collect information of part behavior and failures. To repair defect parts with AM, a clamping device has been designed that enables the high-batch repair of one of the selected sample parts. To guarantee a high quality repair an in-situ control system is being developed for the SLM process. This is also an important issue for the certification of aerospace parts where an approach has been defined for the AM technology. Furthermore, the software design for a Laser Cladding machine is evolving and an early demonstrator could already be built.

Collaboration partners

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)

it's OWL 3P: Prevention of Product Piracy

Ulrich Jahnke

In a fast moving age manufacturers of innovative products and products of exceptional quality are often victims of product piracy. Imitators enter the market just copying extensively developed products and reducing the deserved turnover of the original creators. To fight this current threat conscious behavior and reliable protection measures are required. But at first the companies itself have to change the way of dealing with the protection of products.
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.

Changing the way of thinking

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 as well 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 approach for the protection of products.
The Direct Manufacturing Research Center (DMRC) is leading a work-package focusing on possible contributions of Additive Manufacturing to prevent product piracy. At the projects beginning the specific characteristics and possibilities of AM have been analyzed to show the potentials of preventive protection by the use of this innovative technology. During the runtime of "it's OWL 3P" "traditional" protection measures have been adapted to be applicable by AM and new measure have already been developed. A very important step for the use of AM is the identification of suitable part candidates that are technologically manufacturable and crucial for the function of a product to achieve protective effects. An iterative process is focused in the project for the selection of parts with a high functionality worth to be protected on the one hand and for the proof of being manufacturable on the other hand.

Potentials of AM to prevent product piracy

Considering the measures developed during "it's OWL 3P" in the early stages of product development process 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.
Main aim of the DMRCs work-package is the development of a catalog listing the possible protection measures (strategic, product-related, tagging etc.) to be applied. Some sample parts demonstrating a small set of the measures realizable by AM are shown in figure 1.

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.

figure 1: Sample parts showing protection measures by AM ("local modification of density", "de-standadization", "use of complex geometries", "form fitting" and "increased efficiency")

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

As an external project there are four companies participating. The project is funded by the ESA and led by the DMRC started in November 2013. Due to the short distances between the partners frequent meetings and thus an effective interaction can easily be realized.

The project partner "Invent GmbH" works on structural parts for satellites made from composites or metal 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

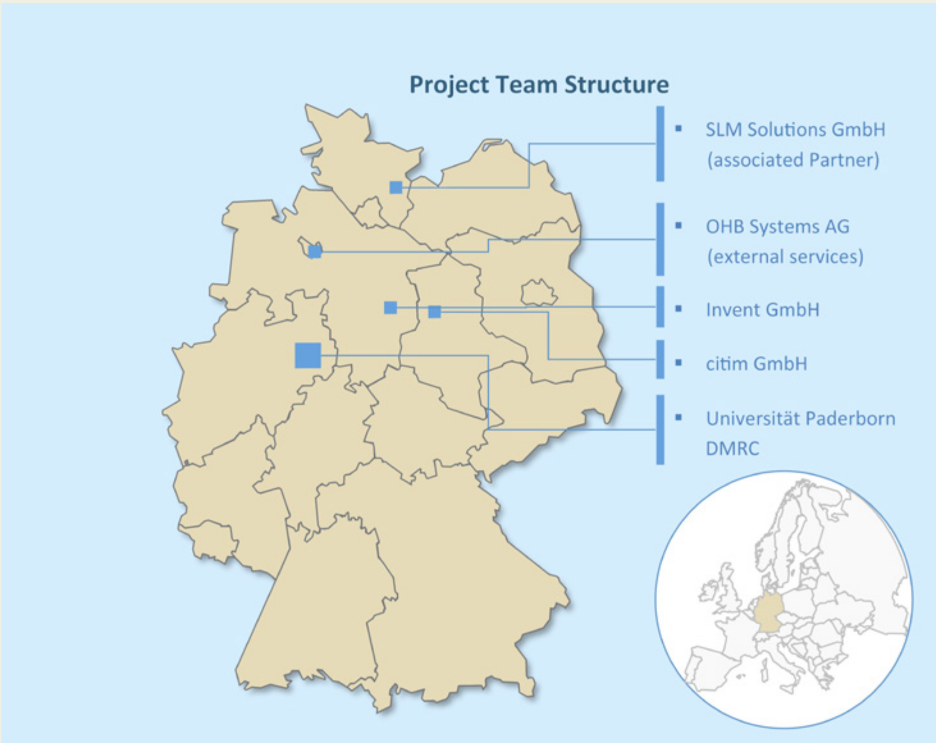


Figure 2: Geographical structure of the project team

in the experience in additive manufacturing, as known from the work in the DRMC and with citim.

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 ranked according to two types:

- 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 will be examined in detail. These parts will be built in the Selective Laser Melting (SLM) process either with or without redesign especially for AM. The resulting improvements gained by changing the manufacturing process with or without a redesign on costs and weight will be figured out.

Selection of part candidates for Additive Manufacturing

The developed trade-off methodology helps finding appropriate AM part candidates for an economic use of the technology. The methodology is divided in three main phases: information phase, assessment phase and decision phase. This shall help to minimize the effort of dealing with numerous part candidates, which are not capable for AM. Detailed part information for an appropriate redesign will only be collected for the most promising parts. This helps to reduce the effort spent in gathering part requirements for the later redesign.

Additive Manufacturing 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 will be developed. This will help to ensure a certification for space use.

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

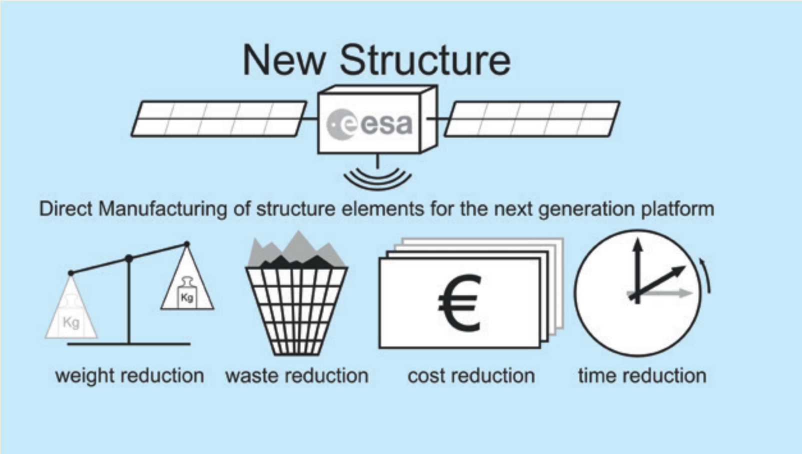


Figure 1: New Structure objectives in a nutshell

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

Mehmet Esat Aydinöz

One of the main advantages of selective laser melting is the producibility of complex geometries and highly customized parts. SLM allows to design metallic parts without any restrictions imposed by traditional manufacturing techniques such as casting or forging. Turbine blades, for instance, can be manufactured with complex internal structures for aerospace industry. The goal of this research-project is to understand the process-microstructure-mechanical property relationships of Ni-based superalloys processed by SLM. The properties of the component are largely determined by the parameters of the SLM process and so far, even with optimized parameters, complete density cannot be obtained. Defects such as pores are particularly deteriorating material properties under cyclic loading. To improve the mechanical properties of SLM-parts different post-processing methods come into focus. At this point, Hot Isostatic Pressing (HIP) shows very promising results. Today, HIP is used to remove porosity from a wide range of nickel based alloy for aircraft engines and structural components. For effective compression, the workpiece should only show closed porosity to avoid pressure equalization inside the pores that will prevent the pores from closing. If open pores are present, it has to be encapsulated.

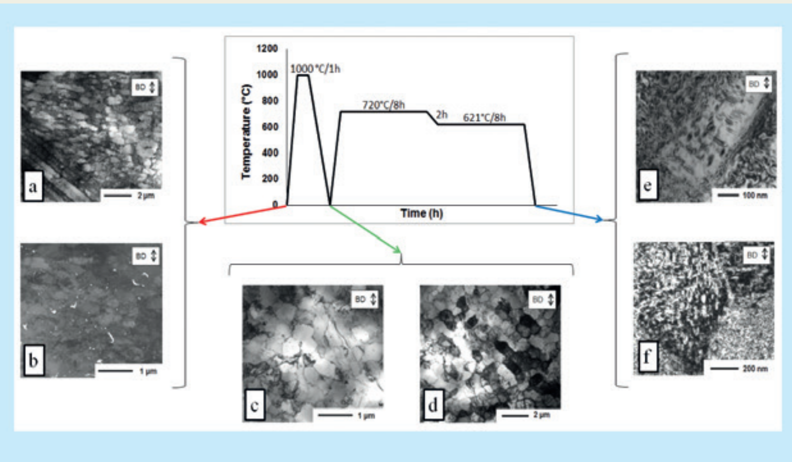


Figure 1 Heat-treatment procedure for IN 718 specimens amd TEM bright field images in the conditions as-built (a),(b); solution annealed (c),(d) and heat-treated (e),(f)

Microstructural analyses and heat-treatment on additively manufactured Inconel 718 specimens

Microstructural Analyses: Nickel based superalloys develop their desired properties through the heat-treatment process. They are considered as solid solution or precipitation strengthened alloys. In the most demanding applications, such as in the hot area of gas turbine engines, a pricipitation strengthened alloy is required. In order to do this, samples of this alloy were processed, heat treated and tested in the as-built, solution annealed, hot isostatic pressed and heat-treated conditions. During the reported period mechanical testing was focused on tensile loading of Inconel 718 specimens.

In order to understand the reason for different tensile strengths of specimens, the microstructure evolution was characterized by means of transmission electron microscopy (TEM). The obtained results are shown in Figure 1. In this case, γ-precipitations which are responsible for the hardening were detected after heat treatment (Fig.1e, 1f). Additionally, TEM images (Fig 1c,1d) show the devolopment of sub-micron cell structures after solution annealing (1000°C/1h). In further experiments, it will be of high interest to show the influences of different microstructural features such as precipitation, sub-micron cell structures etc. on the fatigue life prediction of the material. Besides, dislocation arrangement with cell structures (Fig 1a) and minor precipitation (Fig 1b) in the as-built condition were also detected.

Tensile tests with different specimen conditions

Mechanical Testing: Figure 2 highlights the role of heat treatments on the mechanical behavior of Inconel 718 specimens.
The results can be summarized as follows:

- Tensile stress is significantly increased by ageing.
- Hardness is reduced by HIP processing and solution annealing as compared to the base material.
- Elongation to failure is increased by HIP processing and solution annealing.

Influence of hot isostatic pressing (HIP) on porosity

The results of densification experiments without encapsulation show that the compaction of pores inside the specimen has been successful. The pores near the surface marked in Fig. 3d are still open and visible after densification by HIP. Therefore, functional encapsulation is necessary.

Tasks for the next period

The results obtained by TEM analyses showed that the microstructure is changed after heat treatment. Therefore, one of the main activities during the next period will be the influence of aged condition on the fatigue behavior of IN 718 specimens. In order to understand the development of hysteresis and fatigue life prediction of the material, the microstructure evolution will be analysed before and after fatigue experiments. Furthermore, the fatigue behavior under elevated temperature with different specimens conditions will be examined, as this could be a more relevant case for later application.

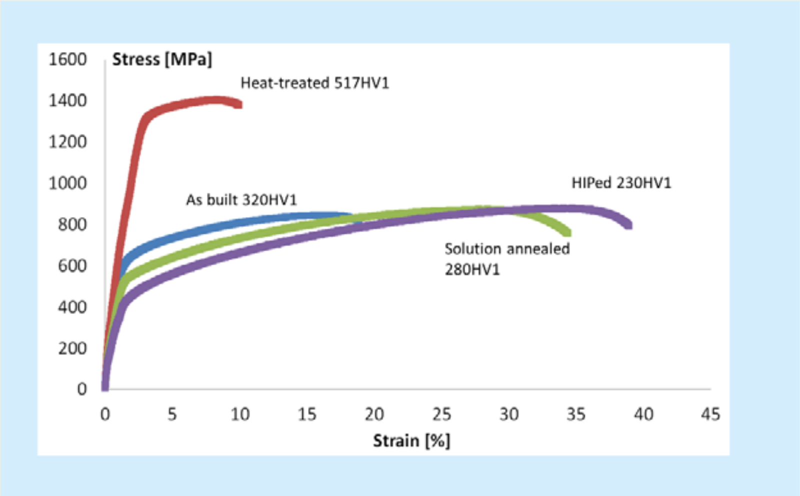


Figure 2: Stress-strain curves and hardness values of different specimens conditions at ambient temperature

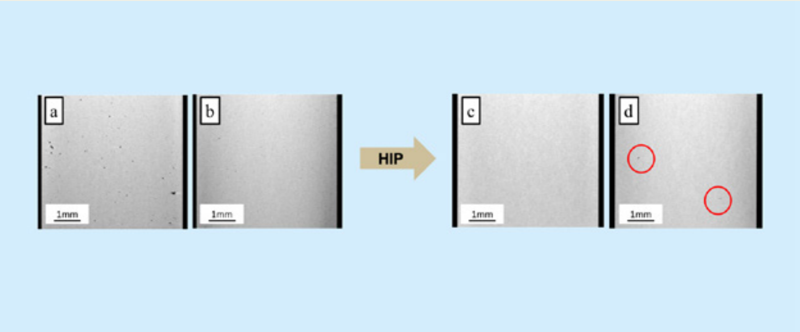


Figure 3: Sectional view parallel to the building direction at different depths of the sample directly after manufacturing (a),(b) and after HIP without encapsulation (c),(d).

4 Involved Chairs and Institutes

KTP

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University of Paderborn
Design and Drive Technology
KAt

PVT

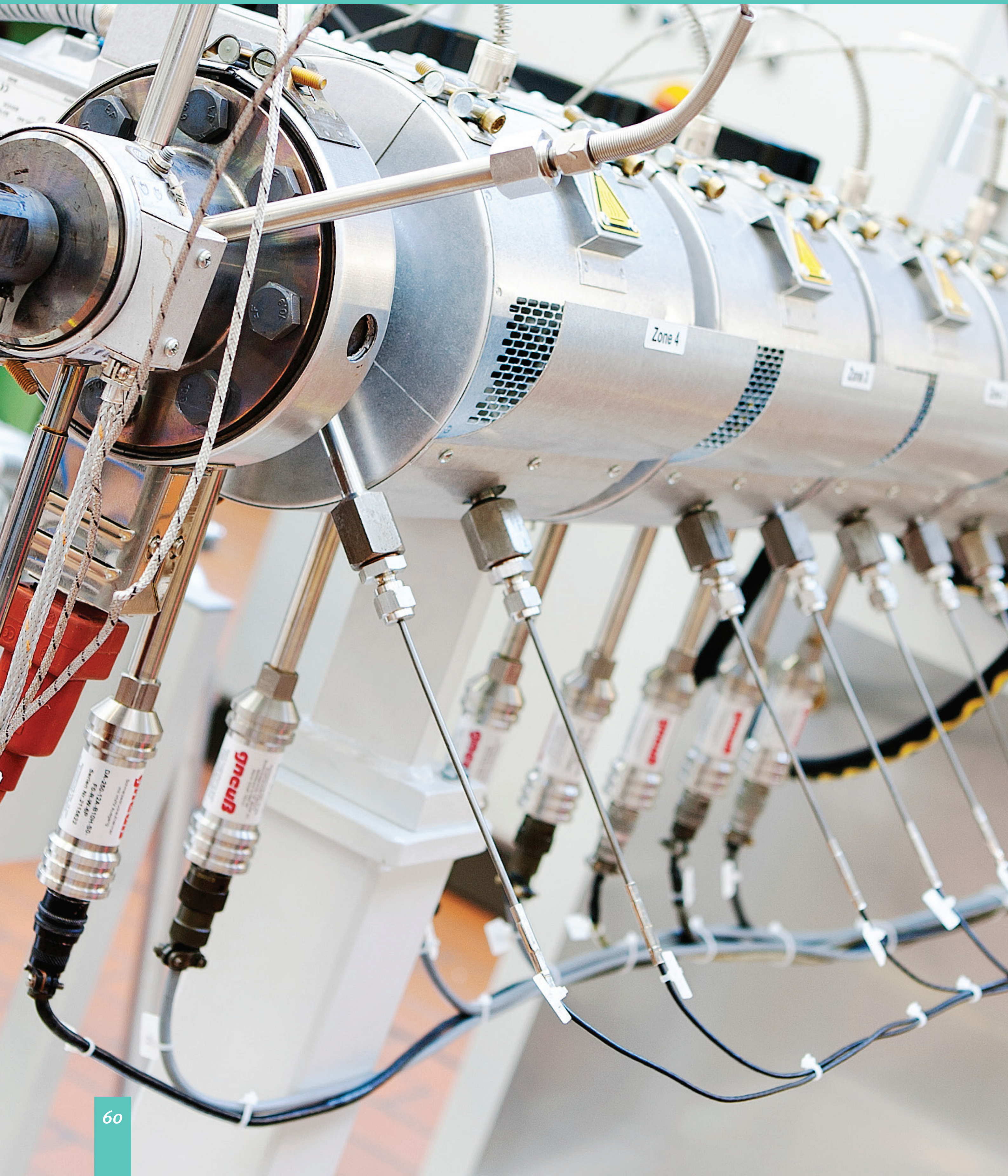
FAM

HEINZ NIXDORF INSTITUTE
University of Paderborn

LWK
Lehrstuhl
für Werkstoffkunde

c.l.k.

TMC
Technische und Makromolekulare Chemie


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.

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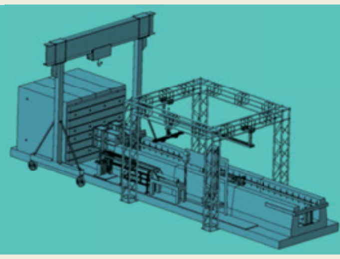
Komponentencrashanlage des Lehrstuhls



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

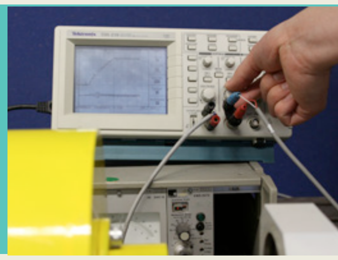
Research Activities
Due to exhaustible raw materials and demands on climate protection, the reduction of vehicle masses in order to reduce fuel consumption is of critical importance. Therefore, main focus of the group "Automotive Lightweight Construction" is on innovative solutions for the automotive 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)

Institute of Applied Mechanics FAM

Teaching and training

During the lectures of the institute for applied mechanics, basic knowledge and procedures to assess stress conditions and the course of movements of components as well as of machines is imparted. 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 are characterized by the imparting of basic knowledge concerning technical mechanics (static, strength theory, dynamics) while during the advanced study period basic research and practically oriented knowledge is consolidated especially with respect to strength optimized and fracture save design, methods of structure analysis, the Finite-Element Method, computer supported product optimization and biomechanics.

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 development of the existing Finite-Element-Method standard software and its efficient use in various applications. In this connection the applied tools are stress and deformation analysis 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 motor activity” 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 prosthesis 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.

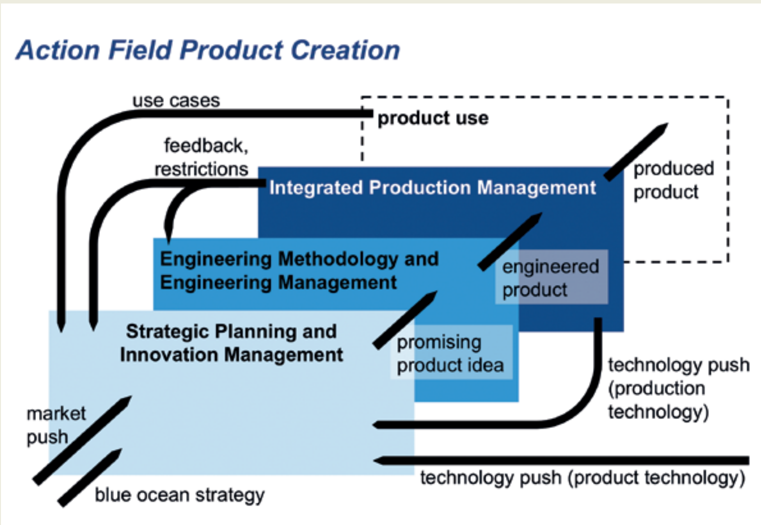
HEINZ NIXDORF INSTITUTE
University of Paderborn

Chair for Product Creation

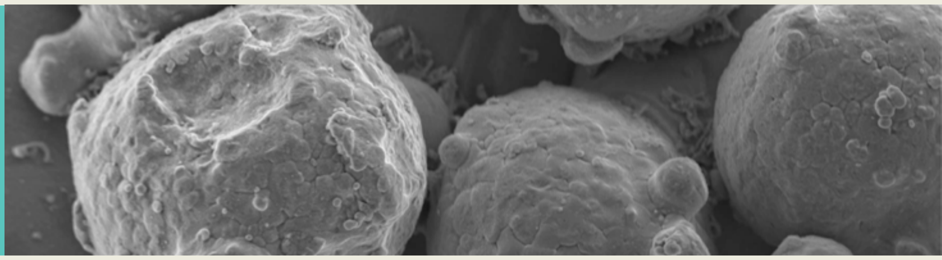
The chair's field of action spans from planning business strategy to the produced product (figure 1). Within strategy planning and innovation management, promising product ideas are generated by systematically forecasting markets, technologies and business periphery. In addition, strategic business segments 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

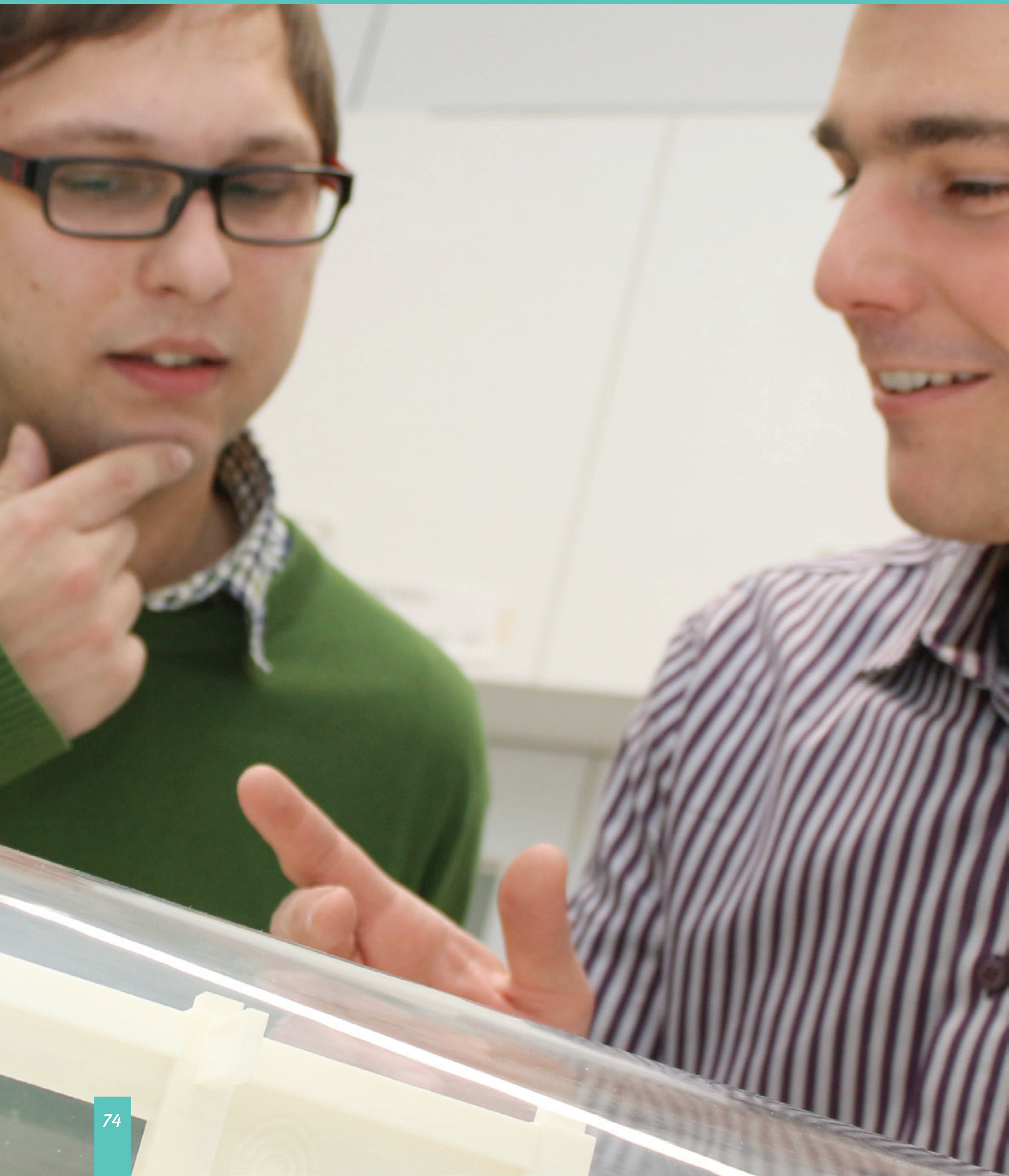
As the majority of innovations is based on the development of new materials or on enhancements of materials already used, the field of materials science is one of the key activities of today´s research in academia and industry. Under the impact of the increasingly scarce resources the efficient use of 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

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 technologies 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 implementation of information systems.
- Evaluation of research results and quality management in the product development with focus on usability of software solutions.

In collaborative research projects the C.I.K. bridges the gap between science, industry and user. This is emphasized by close connections with manufacturing and service companies including small and medium sized enterprises as well as large industry. The focus on problems 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 oriented provision of information is studied with respect to pragmatic aspects. In this regard, the use of business process management methods and semantic technologies is a major priority in current projects.

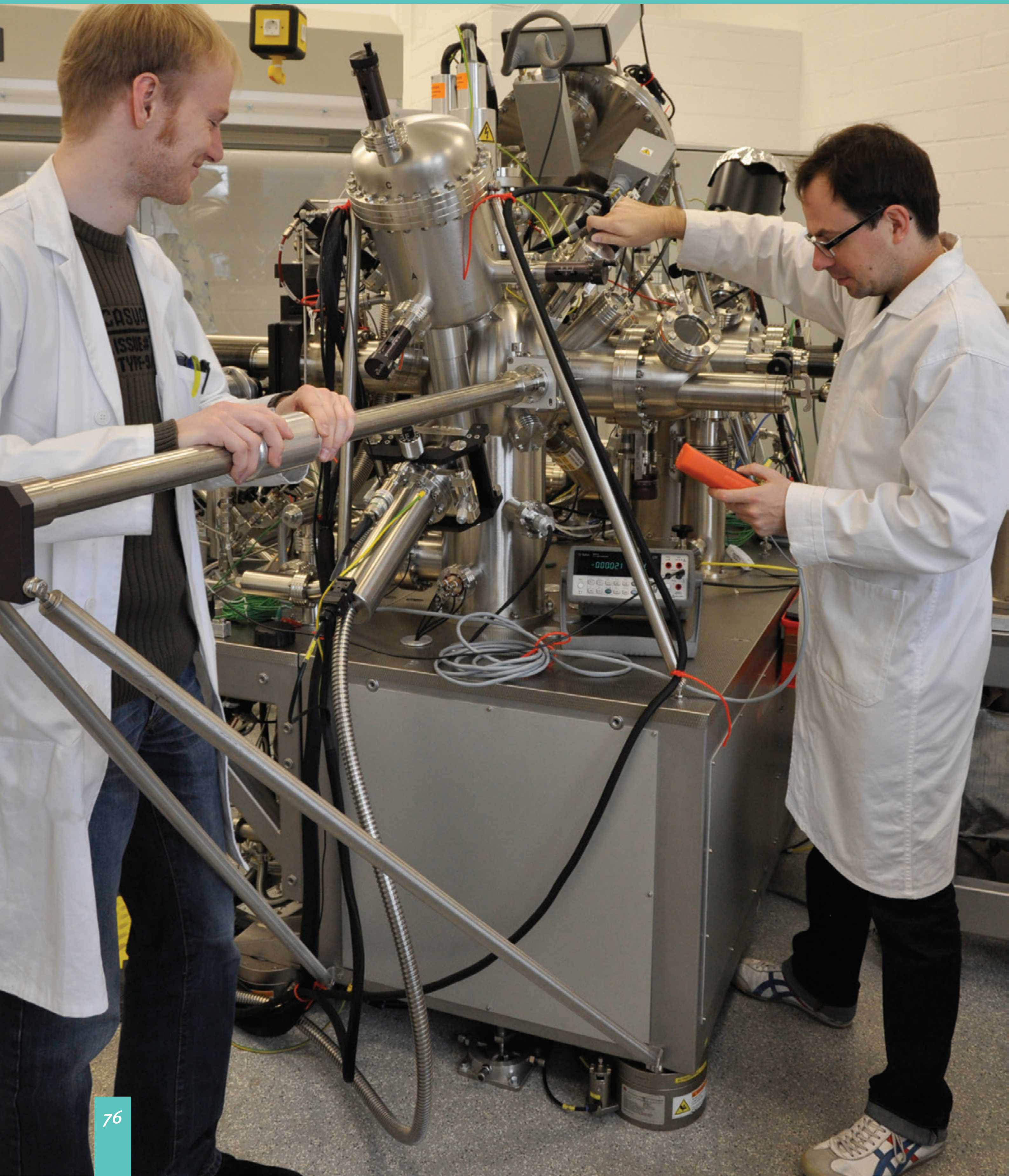
The projects of the C.I.K. cover a broad spectrum of relevant topics in the field of Design and Planning. Specific goals are given by the collection of experiences, the integration of expert knowledge into product and process models, the identification and utilization of hidden knowledge as well as IT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

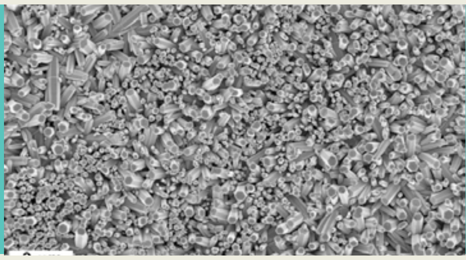
The research group C.I.K. is one of the leading German institutes for research on civil safety and security. Within numerous projects the research group is building the bridge between civil rescue organisations, additional end user groups and other project partners. The experience in industry research 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 foundation for our ideas, systems and technologies in the context of emergency planning, coordination support, training and decision support.

Today thirteen research assistants and about twenty 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.

The TMC teaches students studying chemistry, chemical engineering and mechanical engineering in the fields of Technical Chemistry, Interface Chemistry, Interface Analysis, Electrochemistry and Functional Materials.

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6 Publications

Publications and Conference Proceedings 2014

Development of a Basic Model to Simulate the Laser Sintering Cooling Process
S. Josupeit, H.-J. Schmid
Proceedings of the 5th International Conference on Additive Technologies (iCAT), pp. 222-227
Vienna, October 16-17, 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
EuroPM 2014
Salzburg, September 21-24, 2014

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, 45B (2014), pp. 1181-1185
published August 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

Simulation of the Surface Topography on Laser Sintered Polymer Parts
P. Delfs, A. Herale, Z. Li, H. 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

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
Austin, August 4-6, 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

A Method to Characterize the Quality of a Polymer Laser Sintering Process
S. Rüsenberg, S. Josupeit, H.-J. Schmid
Hindawi Publishing Corporation, Advances in Mechanical Engineering, Volume 2014, Article ID 185374
published July 16, 2014

On the mechanical performance of structures manufactured by selective laser melting: Damage initiation and propagation
S. Leuders, T. Tröster, A. Riemer, H. A. Richard, T. Niendorf
Additive Manufacturing with Powder Metallurgy Conference
Orlando, May 18-20, 2014

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

Optimization of SLM structures with respect to crack growth and lifetime
W. Reschetnik, A. Riemer, H. A. Richard
American Society for Precision Engineeri,ng 2014 Spring Topical Meeting: Dimensional Accuracy and Surface Finish in Additive Manufacturing
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
American Society for Precision Engineering 2014 Spring Topical Meeting: Dimensional Accuracy and Surface Finish in Additive Manufacturing
Berkeley, April 13-16, 2014

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

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 (2014) 7, pp. 857-861
published March 28, 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

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, 20 (2014), pp. 15-25
published March 20, 2014

Design for Additive Manufacturing – Element transitions and aggregated structures
G.O. Adam, D. Zimmer
CIRP Journal of Manufacturing Science and Technology, Volume 7, Issue 1, pp. 20-28, 2014

Presentations 2014

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

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

Vertrauen in Additive Fertigungsverfahren – mit dem richtigen Ansatz zum richtigen Produkt
E. Klemp
D-Druck Potenziale, Chancen und Herausforderungen VTH Verband Technischer Handel e.V.,
Neumünster, October, 22nd

Fatigue Crack Growth in TiAl6V4 and 316L Manufactured by Selective Laser Melting – Influencing Factors and Measures for Lifetime Optimisation
A. Riemer, W. Reschetnik, H.A. Richard
ESA workshop on additive manufacturing for space application
Noordwijk, October 28-29, 2014

On Design for Additive Manufacturing: Systematic Investigation of Minimum Feature Sizes and Geometrical Accuracies
G. Adam, D. Zimmer
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Additive Fertigungsverfahren - Chance oder Risiko
U. Jahnke
Solutions OWL: Keine Chance für Nachahmer: Prävention gegen Produktpiraterie
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DMRC: Additive Manufacturing
E. Klemp
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E. Klemp
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E. Klemp
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Die Bedeutung für die Konstruktion Erwartungen – Chancen – Risiken
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Evolving Technology - Additive Manufacturing
U. Jahnke, C. Lindemann
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FE-gestützte Optimierung und Konstruktion von Strukturbauteilen unter Anwendung von Additive Manufacturing
T. Reiher
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Exploring the influence of an Additive Manufacturing integration on future MRO processes in aeronautics
G. Deppe
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G. Adam
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Impact of plasticity on the deformation behavior and loading capacity of non-stochastic cellular structures
F. Brenne, T. Niendorf, M. Schaper
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Fatigue behavior of NI-base superalloy processed by SLM
M.E. Aydinöz
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High performance metals manufactured by selective laser melting
W. Reschetnik
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Economic Aspects in Additive Manufacturing
C. Lindemann, U. Jahnke
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Material Properties of Additive Manufactured Polymer Parts
M. Fischer, S. Josupeit
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Design for additive manufacturing: From the idea to the design
G. Adam
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Onsite maintenance and repair of aircraft by integrated direct digital manufacturing of spare parts
C. Lindemann
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Frankfurt/ Germany, 15th November

Exploring The Capabilities And Costs Of Additive Manufacturing Technologies For Production
C. Lindemann
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London/ GB, 19th November

Impact and Influence Factors of Additive Manufacturing on Product Lifecycle Costs
C. Lindemann, U. Jahnke, M. Moi, R. Koch
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An event-driven software architecture for process analysis in Additive Manufacturing
M. Moi, C. Lindemann, U. Jahnke, R. Koch
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Potentials of Additive Manufacturing to Prevent Product Piracy
U. Jahnke, C. Lindemann, M. Moi, R. Koch
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A material-based Quality Concept for Polymer Laser Sintering
S. Josupeit, S. Rüsenberg, H.-J. Schmid
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Some Investigations Regarding the Surface Treatment of Ultem*9085 Parts Manufactured with Fused Deposition Modeling
M. Fischer, V. Schöppner
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Verhalten von lasergeschmolzenen Bauteilen aus der Titan-Aluminium-Legierung TiAl6V4 unter zyklischer Beanspruchung
A. Riemer, S. Leuders, H. A. Richard, T. Tröster
Materials Testing; Carl Hanser Verlag
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A. Bagsik. V. Schöppner, E. Klemp
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Fracture mechanical investigations on Selective Laser Melting materials
A. Riemer, H. A. Richard, E. Klemp
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A. Riemer, H. A. Richard
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On the mechanical behaviour of titanium alloy TiAl6V4 manufactured by selective laser melting
S. Leuders, M. Thöne, A. Riemer, T. Niendorf, T. Tröster, H.A. Richard, H.J. Maier
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T. Niendorf, F. Brenne
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Im freien Fall - Bionik-Projekt „Fly Sense“
M. Bähr, H. Frey, E. Klemp, L. Schmidt
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Tensile and Flexural Properties of Fused Deposition Modeling Parts manufactured with Ultem9085
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A. Bagsik, V. Schöppner, E. Klemp
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C. Lindemann; U. Jahnke; M. Moi; R. Koch
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Controlling the Quality of Laser Sintered Parts Along the Process Chain
S. Rüsenberg, R. Weiffen, F. Knoop, M. Gessler, H. Pfisterer, H.-J. Schmid
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A. Riemer, S. Leuders, T. Tröster, H.A. Richard
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Influence of heat-treatment on Selective Laser Melting products – e.g. Ti6Al4V
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S. Rüsenberg, H.-J. Schmid
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E. Klemp, M. Wall
Digital Engineering Magazin 4/12

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J. Gausemeier, N. Echterhoff, M. Kokoschka, M. Wall
Study Part 2

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J. Gausemeier, N. Echterhoff, M. Kokoschka, M. Wall
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T. Tröster, T. Marten, D. Thomas, H. Block, C. Lauter, M. Thöne
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2011

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Porosity as a Key to Increase Material Properties of Laser Sintered Parts
S. Rüsenberg, L. Schmid, H. Hosse, H.-J. Schmid
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Direct Manufacturing Design Rules Advanced Research in Virtual and Rapid
D. Zimmer, G. Adam
5th International Conference on Advanced Research in Virtual and Rapid Prototyping
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Powder Aging upon Laser Sintering-Characterization and Consequences
H.-J. Schmid, S.Rüsenberg, Z. Sun
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Mechanical and Physical Properties-A Way to assess quality of Laser Sintered Parts
S. Rüsenberg, L. Schmidt, H.-J. Schmid
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J. Gausemeier, N. Echterhoff, M. Kokoschka, M. Wall

Mechanical Properties of Fused Deposition Modeling Parts Manufactured with Ultem*9085
A. Bagsik, V. Schöppner
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Klein, stark und wendig
E. Klemp, A. Trächter, C. Loh
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Konstruktionsregeln für additive Fertigung in Forschung und Lehre
D. Zimmer, G. Adam
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FDM Part Quality Manufactured with Ultem*9085
A. Bagsik, V. Schöppner, E. Klemp
14th International Scientific Conference on Polymeric Materials
Halle/ Germany, 15th -17th 2010

7 Equipment

DMRC

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

Universal testing system, HB 250, Zwick GmbH

Optical Analysis

Particle size analyser, Mastersizer 2000, Malvern Instruments Ltd.

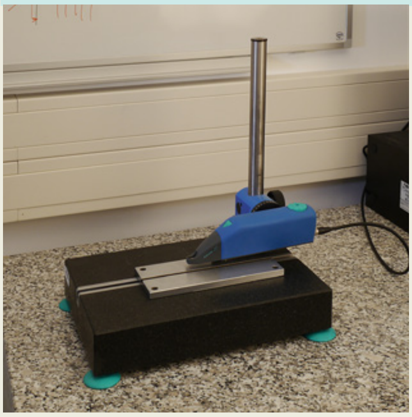
Scanning Electron Microscope (SEM), Phenom SEM, Phenom World

Optical Analysis

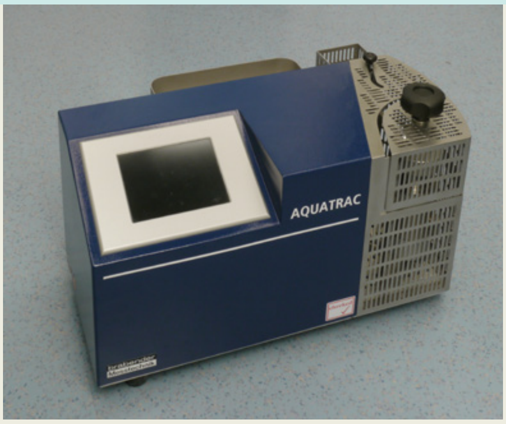
3D scanning device, kolibriMulti, FhG IOF

3D Measuring Macroscope, VR-3100, Keyence

Physical Analysis



Mechanical profilometer, Hommel Etamic T8000, Jenoptik AG



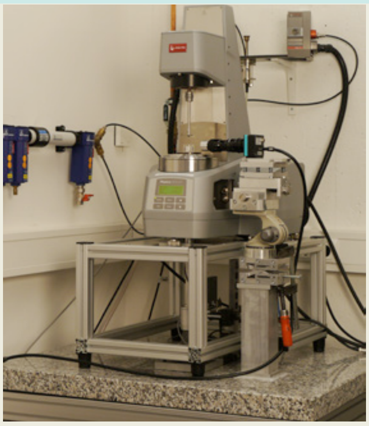
Moisture measurement device, AQUATRAC, Brabender Messtechnik GmbH

Precision balance, CPA 224s, Satorius AG

Equipment

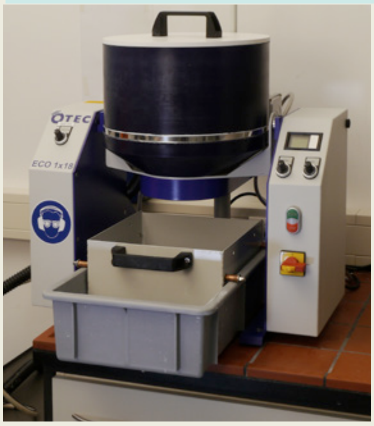
Physical Analysis

Broadbrand dielectric spectrometer, Novocontrol GmbH

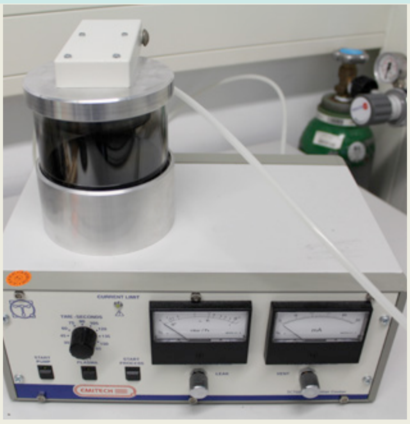


Rheometer, Physica MCR 501, Anton Paar GmbH

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

KTP

Mechanical Analysis

Pendulum impact tester, HIT5.5P, Zwick Roell

Optical Analysis

Thin Cutting device, Polycut, Reichert Jung

Digital microscope, VHX- 600, Key-ence

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

Melt Index Tester, Mflow BMF-001, Zwick/Roell

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

Joining Laboratory

Hot plate welding machine, K2150, Bielomatik Leuze GmbH

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

LWK

Mechanical Analysis

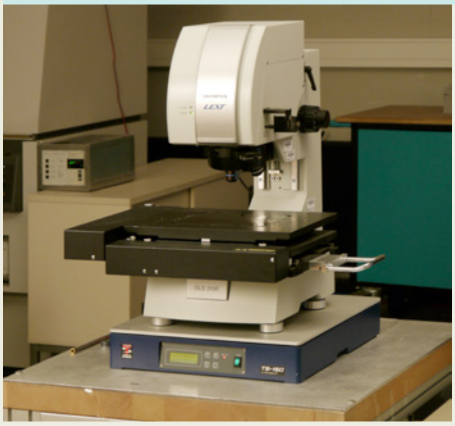
Servo-hydraulical testing system, MTS Systems

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

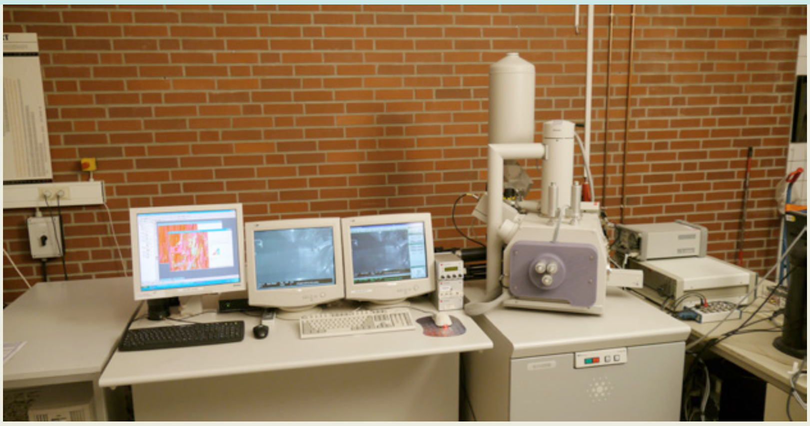
Servo-hydraulical testing system, MTS Landmark, MTS Systems

Testing system, Electro-Force 3550, Bose

Optical Analysis



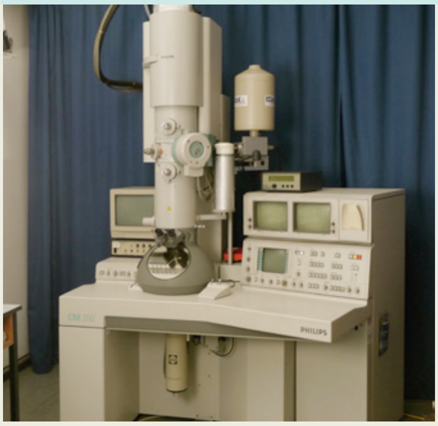
Confocal laser scanning microscope, OLS3100, Olympus



Scanning electron microscope, XL 40 ESM TMP, Philips

Equipment

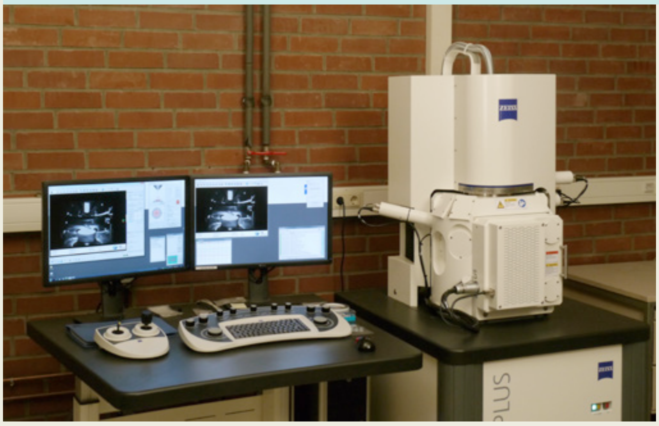
Optical Analysis



Transmission electron microscope, CM200STEM, Philips

X-Ray diffractometer, X‘pert Pro, Philips

Optical Analysis



Field Emission SEM, Ultra Plus, Zeiss

How to find us...

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33098 Paderborn

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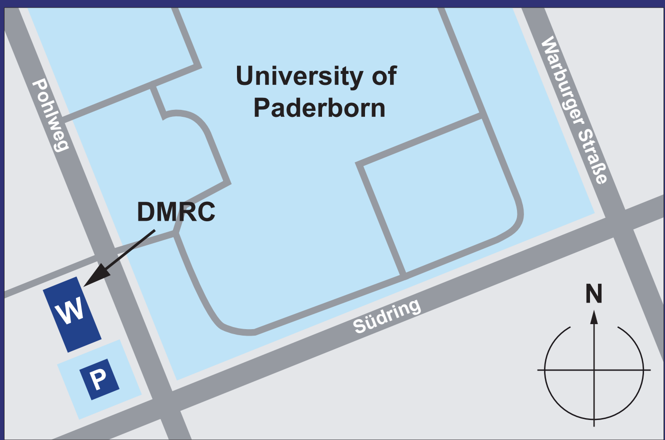

www.DMRC.de