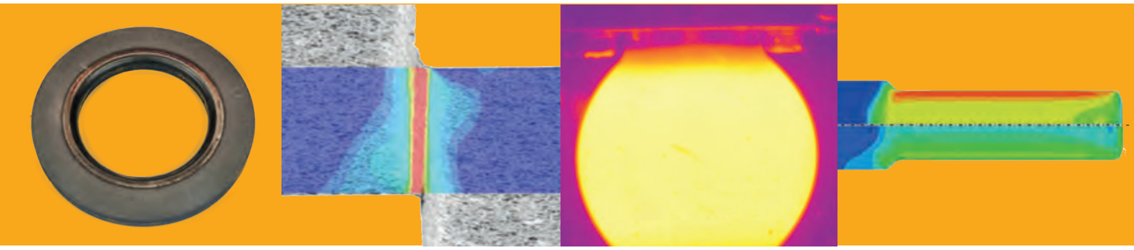

50 Jahre IUL
Dortmunder Umformtechnik

Activity Report 21

technische universität
dortmund

Institute of
Forming Technology and
Lightweight Components

Activity Report

21

technische universität
dortmund

Imprint

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Preface

Dear readers,

In last years's preface we expressed the hope of being able to return to a pre-epidemic normalcy in the foreseeable future. Now we are challenged by reality to still take patience - a virtue that is by no means foreign to the academic world: researchers demonstrate a high degree of endurance in their academic training and persistency is also usually required in everyday research life. Patience, however, is not just passive lingering, but also manifests itself in patient acting. Thus, the IUL will continue to work patiently to be a reliable contact for students and partners of the institute by transparently communicating all Corona measures to be taken and by prudently and flexibly using all liberties and options that are possible in the pandemic situation. The priority in 2022 will be to guarantee teaching and support for students in an optimal quality and to continue the research work at the institute at an excellent level. Read more about the results achieved in the research chapter of this activity report.

The pandemic undoubtedly causes terrible human and social dramas. It is challenging and difficult for all university members. However, as a striking caesura in terms of everyday university life, it also offers the opportunity to question established routines and to dare to do something new. For example, we are now quite naturally using new working concepts and the digitization of teaching and administration forcedly proceeds faster than ever imagined. It is also motivating to see that the high level of commitment is rewarded. This summer, Matthias Kleiner received the first engineering honorary doctorate "Dr.-Ing. E.h." from Leuphana University Lüneburg for his outstanding contributions to engineering research and science management.

We received very positive feedback from students for our expertise in digital and hybrid seminar and lecture concepts. Thanks to digital concepts implemented at short notice, major events such as the "International Conference on High Speed Forming 2021 (ICHSF)" or Dortmund's "8th Colloquium on Tube and Profile Forming (DORP)" could still take place. Both events were particularly well received by the participants. Some stays of visiting researchers could also be realized in 2021 and, thus, we could even personally cultivate our international network. Articles about the events and research stays can be found in the corresponding chapters of this report.

Of course, all of this has only been possible thanks to the extraordinary commitment of the IUL staff and we would like to express our sincere thanks.

Specials thanks are also given to all persons and institutions supporting the IUL. Let us look forward together with confidence to the year 2022, which will be a special one for the IUL as it celebrates 50 years of „Dortmunder Umformtechnik“ (Metal forming in Dortmund).

50 Jahre IUL
Dortmunder Umformtechnik

We would like to take the institute’s 50th anniversary as an opportunity to duly celebrate the extremely successful history of metal forming in Dortmund on two consecutive days. In September 2022 international guests from the research community will present current impulses and innovations in metal forming within the scope of a scientific colloquium. There will also be an anniversary ceremony bringing together the IUL‘s alumni and friends to have a look at the exciting past and future of metal forming in Dortmund.

By the way: the anniversary year and its celebration were our motivation to relaunch the IUL website. Welcome to the new **www.iul.eu**!

A. Erman Tekkaya

Matthias Kleiner

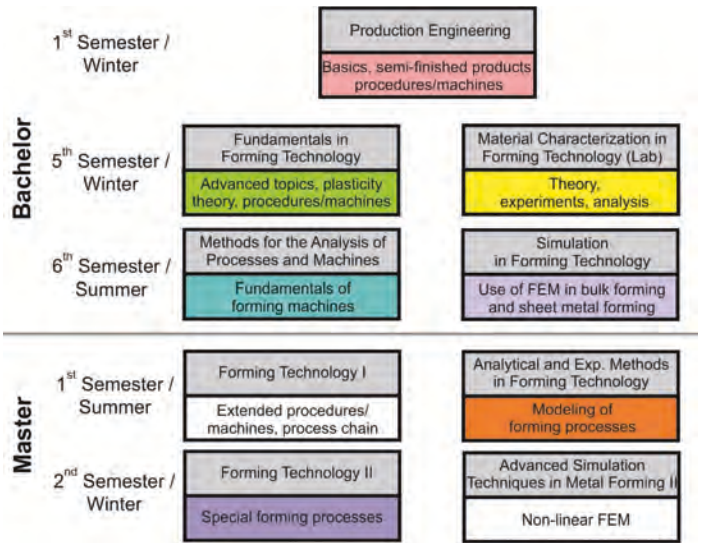
Education

01

1 Education

1.1 Offered Courses

The Institute of Forming Technology and Lightweight Components offers lectures and laboratories in the following bachelor and master programs: logistics, industrial engineering, and mechanical engineering. In addition, students of computer science, physics, and those studying to become teachers attend the courses offered by the institute as part of their minor subject. The students acquire knowledge in the field of forming technology that is necessary in order to succeed in the industrial working environment or to enter an academic career. Since the winter semester 2019/2020, the following lectures were offered:



Structure of lectures for the study program mechanical engineering with a specialization in production engineering

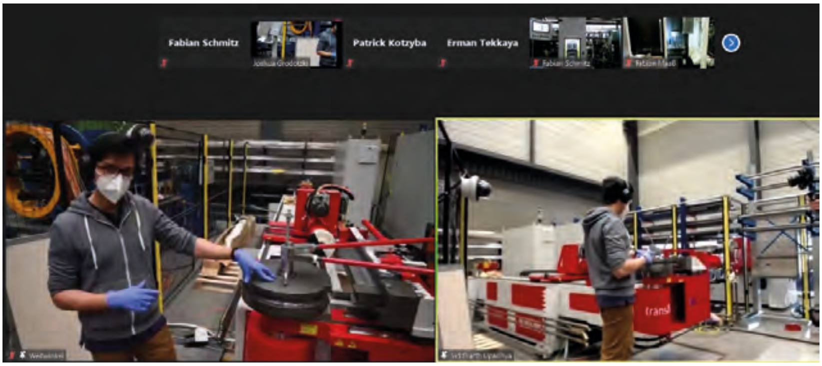
Other courses offered by the institute in 2021 were:

- Manufacturing of semi-finished products with the aim to set material properties
- Lecture series on forming technology
- Laboratory work A as part of the Master's Program in Mechanical Engineering

- Laboratory work B as part of the Bachelor's Program in Industrial Engineering

The following courses are offered in English as part of the international master's program "Master of Science in Manufacturing Technology" (MMT):

- Forming Technology I – Bulk Forming
- Forming Technology II – Sheet Metal Forming
- Advanced Simulation Techniques in Metal Forming
- Additive Manufacturing
- Aluminum – Basic Metallurgy, Properties, Processing, and Applications
- Laboratory Work – Material Characterization in Forming Technology



Digital experimental hall visit at IUL

Due to the pandemic, lectures had to be given digitally for the most part throughout 2021. Also the experimental hall visit of the winter semester 2020/21 was held via live stream for the first time. IUL staff members conducted experiments in material characterization, rotary draw bending, incremental sheet metal forming, and adiabatic shear cutting and commented in detail on what they showed. The 100 participating students were able to ask questions and comment at any point by using a video conference software. Thanks to the gradual relaxation of the corona measures, more on-campus courses could be offered in the winter semester 2021/22.

In 2021, the following guest lecturers have contributed to the course offer at the IUL:

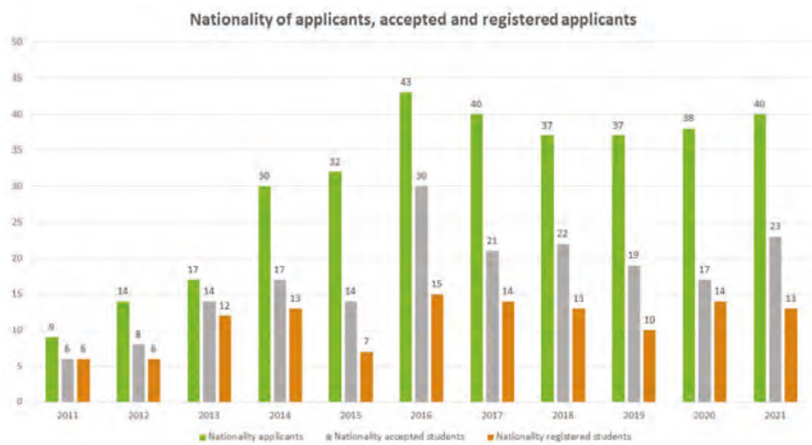
- Prof. J. Hirsch, Aluminium Consulting, Königswinter, Germany
- Prof. J. Sehrt, Ruhr-Universität Bochum
- Dr. G. Georgiadis, Excelix Ltd.
- Dr. K.-F. Karhausen, Speira GmbH
- Dr. J. Ostrowski, Quaker Houghton
- Dr. S. Gies, Danieli Germany GmbH
- Dr. L. Kwiatkowski, OTTO FUCHS KG
- A. Roßbach, SMS Group GmbH

For further information, please visit: **www.iul.eu/en/teaching.**

1.2 Master of Science in Manufacturing Technology (MMT)

Coordination
Prof. Dr.-Ing. A. Erman Tekkaya
Frigga Göckede B. B. A.
Kerstin Barton M. A.
Siddhant Goyal M. Sc.

The English-taught, four-semester study program 'Master of Science in Manufacturing Technology', which started in 2011, was again of much interest to international students regarding the start of studies in winter semester 2021/22. 57 carefully selected and excellent students out of around 800 applicants from 40 nations have been admitted to the MMT program. 28 of them started their studies at the Faculty of Mechanical Engineering, including five female students. This means that the class of 2021/22 has an above-average share of women. Within the scope of the cooperation with the Turkish-German University in Istanbul, organized by the German Academic Exchange Service (German: DAAD), one student from Turkey started his MMT studies.



Diversity of nationalities of applicants, accepted and registered applicants

In order to further increase the diversity of the MMT program, the coordination team analyzed the countries of origin of the students and, on this basis, took steps to inform more students from other countries about the study program. In this context, newsletters were send out, webinars were offered and ads were published. In addition, a marketing strategy has been developed that will be implemented gradually and will also make more extensive use of social media such as Instagram and LinkedIn to attract prospective students.

After a successful test run, a type of "half-time analysis" will be offered for each cohort after two semesters in the future, where students can give feedback on the first half of their MMT studies and receive the necessary information for the upcoming two semesters, especially on laboratory, project, and master's thesis. The regular, personal feedback from the students will be evaluated and passed on to the chairs to optimize teaching and study conditions. Furthermore, in cooperation with Department 4 and the examination administration, the MMT examination regulations were revised and adapted to the new Higher Education Act.

The ongoing pandemic has once again had a major impact on the start of the 2021/22 academic year. As official authorities and institutions in some countries are still not operating in normal mode, not all admitted applicants were able to travel to Dortmund for the start of the winter semester. As a result, the participating chairs agreed upon continuing the teaching of the MMT program in the winter semester 2021/22 in digital form.

In order to give the students beginning their studies digitally from their home countries the best possible start at the Faculty of Mechanical Engineering, the MMT coordination team has organized a virtual Welcome Week with various activities for the new batch of students. To kick off the event, Professor Tekkaya as head of the study program welcomed the new students via video conference. The students also had the opportunity to make first contact with each other. The following day, the MMT coordination team organized a workshop on living and studying in Dortmund. The German higher education system was explained to the students and useful advice and practical tips were given. In the Q&A session that followed, the new MMT students had the opportunity to ask questions about studying and living in Germany. A lively exchange between the students and the MMT coordination team took place via video and chat. On day three of the Welcome Week, the students were given the opportunity to network with each other and expand their intercultural skills through teamwork in a digital scavenger hunt.

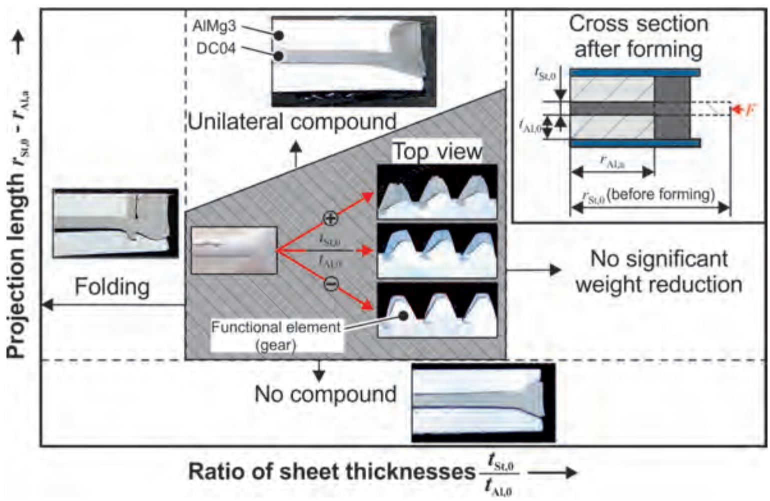
Together with the International Office, an information video was produced and published on the channels of the International Office as well as on the MMT homepage. Thanks to the help of some enrolled and former MMT students, prospective international students can gain an insight into the specific requirements and characteristics of the MMT degree program through the video.

Für weitere Informationen: **www.mmt.mb.tu-dortmund.de**

1.3 Doctoral Theses

Wernicke, Sebastian	Incremental Sheet-Bulk Metal Forming of Load-Adapted Functional Components
Original title	Inkrementelle Blechmassivumformung belastungsangepasster Funktionsbauteile
Series	Dortmunder Umformtechnik, Volume 112
Publisher	Shaker Verlag, 2021
Oral exam	February 2, 2021
Advisor	Prof. Dr.-Ing. A. E. Tekkaya
Co-examiner	Prof. Dr.-Ing. P. Steinmann (FAU)

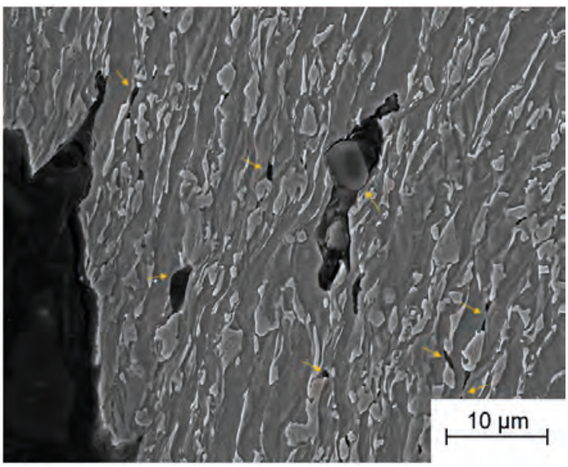
Incremental sheet-bulk metal forming (iSBMF) presents an innovative approach for the resource-efficient manufacture of load-adapted functional components. This work investigates the usability of the kinematic flexibility of iSBMF processes to influence the forming history yielding to a targeted adjustment of the product properties. An analyzation of the process-dependent forming history occurs based on finite element modeling of the thickening and the subsequent gear forming processes. The development and investigation of a process strategy for the hybridization of functional components enabled the achievement of a more distinct grading of the product properties. Beyond the improved grading of product properties, the hybridization also substantially reduces the maximum forming force which is required to enhance the tool life.



Compound depending on projection length and ratio of sheet thickness at iSBMF of hybridized functional components

Heibel, Sebastian	Damage and Failure Behavior of High-Strength Multiphase Steels
Original title	Schädigung und Versagensverhalten hochfester Mehrphasenstähle
Series	Dortmunder Umformtechnik, Volume 114
Publisher	Shaker Verlag, 2021
Oral exam	March 25, 2021
Advisor	Prof. Dr.-Ing. A. E. Tekkaya
Co-examiner	Prof. Dr.-Ing. S. Münstermann (RWTH Aachen University)

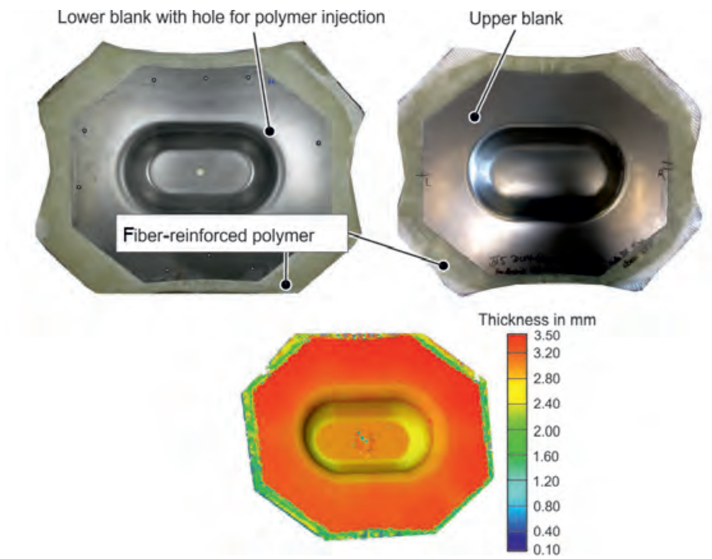
The higher strength of multiphase steels is accompanied by a lower ductility. In particular, the heterogeneous microstructure of dual-phase steels tends to damage evolution and influences the plastic deformation capacity. In contrast, complex-phase steels show that a homogeneous microstructure leads to high damage tolerance and high locally bearable strains. It is shown that a consideration of the microstructural damage effects in the sense of a reduction of the load bearing cross section is not necessary in sheet metal forming simulations on a macroscopic scale. To improve the failure assessment, the application of model fracture curves of inversely calibrated damage models or fracture criteria is suitable. Based on material fracture curves the true thickness strain at fracture is qualified as a suitable measure for the determination of the plastic deformation behavior and, thus, damage tolerance. Together with the true uniform strain as a measure, the assessment of the ductility and the ductile damage and failure behavior is possible.



Example for damage evolution of DP600 on a shear cut edge

Mennecart, Thomas	In-Situ Hybridization of Fiber-Metal Laminates
Original title	In-situ-Hybridisierung von Faser-Metall Laminaten
Series	Dortmunder Umformtechnik, Volume 115
Publisher	Shaker Verlag, 2022
Oral exam	December 6, 2021
Advisor	Prof. Dr.-Ing. A. E. Tekkaya
Co-examiner	Prof. Dr.-Ing. N. Ben Khalifa (Leuphana University Lüneburg)

While the autoclave method is standard to produce fiber-metal laminates, there are at the same time numerous research activities for the mass production of these. In these research-based processes a formed blank or pre-consolidated fibers are necessary. Additionally, there are a lot of challenges in forming and producing fiber metal laminates with these processes. This PhD thesis deals with the development of a new process to produce fiber-metal laminates without using pre-formed or pre-consolidated parts. The parts are produced in just one main process step. The influence of the fibers on the formability of sheets is analyzed. The process and the fiber-metal laminate optimized tool have been developed and parts could be formed successfully. A process understanding could be realized. Further knowledge was obtained by different investigations for an additional design of a process window.



Parts produced with the in-situ hybridization with thickness distribution

Education

01

Research

02

2 Research

With their research, the employees (36 scientists, 11 technical and administrative staff members and more than 50 student assistants) at the Institute of Forming Technology and Lightweight Components make an important contribution to a climate-friendly design of production engineering. In this context, they develop entirely new methods such as the extrusion of sheet metal from metal chips and the configuration of outstanding properties of products via new control concepts. To achieve this, the employees investigate testing processes and simulation methods until they are ready to use. The extrusion of profiles from metal chips already saves 47% of the energy and 55% of the CO_2 emissions compared to the production from secondary aluminum. The extensive experience of the IUL team was also incorporated in a collaboration with the Dortmund Economic Development Agency in 2021: The study concentrating on strengthening Westphalia as a location for innovation and business has social significance beyond the boundaries of the discipline. Another matter close to the heart of the institute's management is the active organization of joint research projects with national and international partners from research and industry.

The participation in the two "Collaborative Research Centers" TRR 188 and TRR 73 (both as local spokesperson) as well as in the two "Priority Programs" SPP 2013 and SPP 2183, which were both extended this year, express these intensive networking efforts. In addition to the three departments "Bulk Metal Forming", "Profile and Sheet Metal Forming", and "Non-Conventional Processes", the institute structure shown in the diagram consists of the three inter-divisional units "Research Center for Industrial Metal Processing" (ReCIMP), "Research Group on Additive Technology" (ReGAT), and "Research Group Applied Mechanics". In the following, the department-specific research objects and research projects are described in detail.

Institute structure

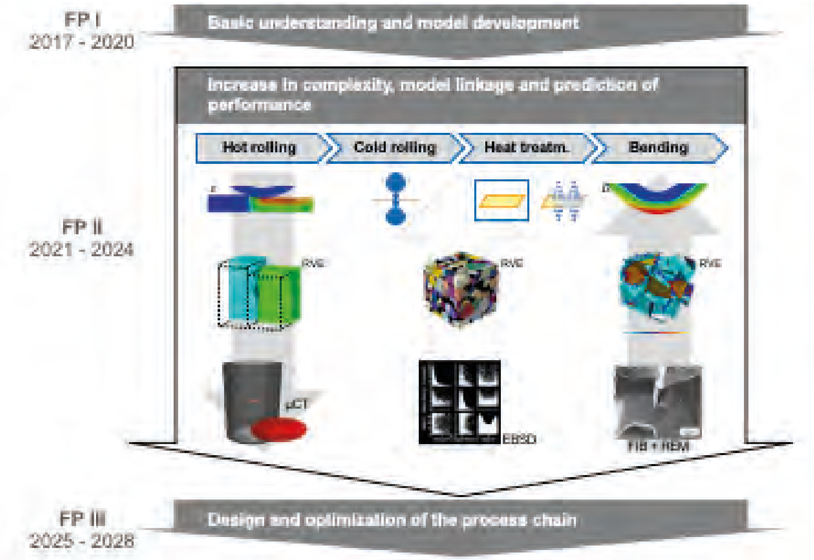
2.1 Research Groups and Centers

2.1.1 Collaborative Research Center Transregio 188 – Damage Controlled Forming Processes

Funding	German Research Foundation (DFG)
Project-ID	CRC 188/2-2021
Deputy Spokesperson and Spokesperson for Dortmund	Prof. Dr.-Ing. A. Erman Tekkaya

In January 2021, the second funding period of the Collaborative Research Center jointly initiated by RWTH Aachen University and TU Dortmund University began. Since 2017, the DFG has been funding research on material damage that occurs during forming. The research hypothesis of the CRC/Transregio 188 is that the damage caused by the forming process significantly influences the performance of the components and that the performance can be increased by adjusting the damage in a controlled manner. Accordingly, the overall goal of TRR 188 is to understand the mechanisms of material damage during forming to be able to quantitatively predict the evolution of damage and to selectively adjust damage states with regard to component performance. The guiding principle of TRR 188 "Damage is not a failure" means that the ductile damage in forming technology is not only a measure of the distance to the failure limit ("formability"), but it also has a decisive influence on the performance in the application ("usability"). If the damage evolution is taken into account in the component and process design, formed parts with customized and guaranteed performance can be realized.

The results of the first funding period prove the feasibility of this vision. It was demonstrated for the first time that the amount of material damage accumulated in the forming process influences the performance of the products even before the occurrence of a failure event and, thus, represents a non-negligible variable for the component properties. The sole influence of the damage on the performance could be shown by a targeted parameter isolation. On the other hand, it could be shown by selected bulk and sheet metal forming processes that the damage level in a component with the same material and the same starting and target geometry can be controlled by the targeted choice of the process design and that an increasing degree of forming does not necessarily lead to higher damage. Efficient characterization methods have been developed and refined to quantify the damage and the mechanisms at work. This made it possible, among other things, to determine the activation energies for the identified damage mechanisms and to develop initial measures for a material design with improved damage tolerance. For the prediction of the damage first modeling approaches from the micro to the macro scale were developed and validated based on experimental data.



Development perspective second funding period

Scientists from manufacturing technology and materials science, mechanics and measurement, and testing technology were involved in working on the complex, interdisciplinary research questions. Cross-project working groups on the central cross-cutting topics of "efficient damage characterization", "performance", "validation", and "damage definition" promoted professional exchange and team building. In addition, TRR 188 received important impulses and suggestions for the research work from an industrial advisory board that includes material and semi-finished product manufacturers, technicians from sheet metal and bulk forming, component users, and companies from the fields of software and measurement technology. Some research approaches are now being further developed in transfer projects with a view to their later application in industrial practice. At the same time, TRR 188 offers the scientific staff involved excellent opportunities for further qualification. In addition to the completion of many student theses and several dissertations, it is particularly noteworthy that three junior scientists have received a call to a professorship.

The fundamental results and findings of the first funding period will be applied to more complex component geometries and process sequences in the second funding period, which has now begun. They will be developed further with regard to application-oriented demonstrators. As an additional aspect, temperature-assisted forming or heat treatment will be taken into account. The established consideration of two process chains and the associated standard material concepts will be continued as well as the division of the projects into the three areas “A: Technology”, “B: Characterization”, and “C: Modeling”. The working groups will also be continued in a slightly modified form, as will the scientific service project. The latter prepares the developed damage models for finite element simulations in commercial programs and provides software tools for process simulation and parameter identification.

More complex components require process chains consisting of other and of several forming steps, so that in project area A the damage evolution under load paths, in which not only the hydrostatic but also the deviatoric stress component changes strongly, is investigated. In addition, microstructure evolution must be considered in the hot forming as well as in intermediate and subsequent heat treatment steps. As shown in project area B, this has an additional influence on damage evolution and, thus, on the performance of the components. Besides, the interaction of ductile and cyclic damage mechanisms will be comprehensively investigated in project area B in order to be able to describe the relationship between initial ductile damage and the resulting component performance as accurately as possible, even in the case of fatigue loading of the formed component. In project area C, the damage models developed in the first funding period are being further developed in order to be able to simulate process chains holistically and optimize them with regard to component performance. This results in the following goals for the second funding period:

- Deepening the understanding of damage, its mechanisms, and the mechanism interaction
- Increasing the complexity through new forming processes, consideration of the temperature influence (characterization, hot forming, heat treatment) and multi-scale modeling
- Strengthening the link between processes, acting mechanisms, and resulting material properties
- Separation of the effects of strain hardening, residual stress, microstructure evolution, and damage for complex components and elevated temperatures
- Quantification of performance as a function of damage and microstructure effects

In Dortmund the projects are being carried out by the Institute of Forming Technology and Lightweight Components (IUL), the Institute of Mechanics (IM), and the Department of Materials Test Engineering (WPT) from the Faculty of Mechanical Engineering and by the Chair of Structural Mechanics (BM) from the Faculty of Architecture and Civil Engineering. At RWTH Aachen University (the spokesman university) the project leaders come from the Institute of Metal Forming (IBF), the Steel Institute (IEHK), and the Institute for Physical Metallurgy and Materials Physics (IMM) from the Faculty of Georesources and Materials Engineering as well as the Laboratory for Machine Tools and Production Engineering (WZL) from the Faculty of Mechanical Engineering and the Central Facility for Electron Microscopy (GFE). The Institute for Applied Materials – Materials and Biomechanics (IAM-WBM) from the Faculty of Mechanical Engineering at KIT Karlsruhe and the non-university institute Max-Planck-Institut für Eisenforschung GmbH (MPIE) in Düsseldorf are also involved in TRR 188.

2.1.2 ReCIMP – Research Center for Industrial Metal Processing

Head Dr.-Ing. Sebastian Wernicke

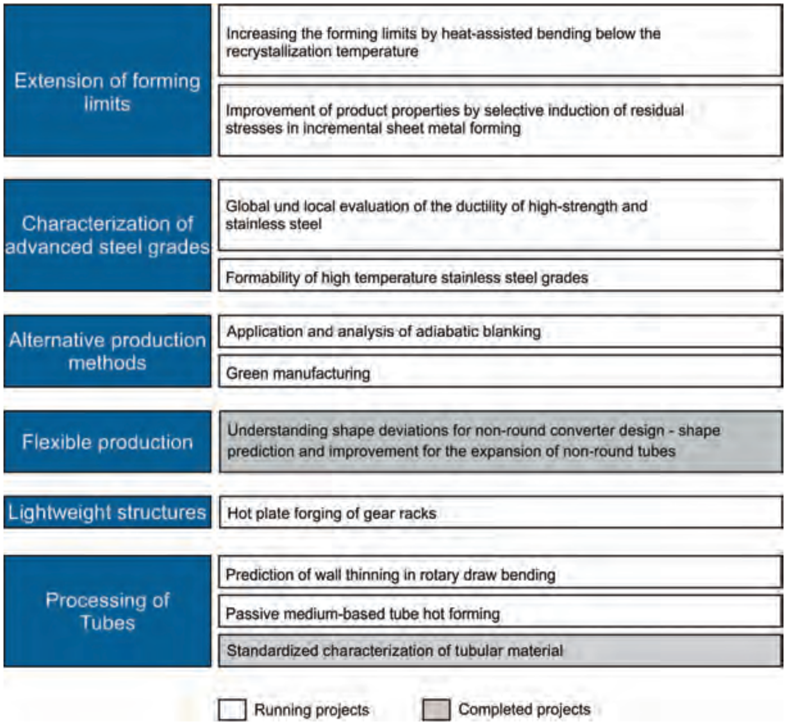
The cooperation with the international automotive supplier Faurecia, which has been established for eight years now, was successfully continued in 2021. In the Research Center for Industrial Metal Processing (ReCIMP) the IUL cooperates with Faurecia's divisions Automotive Seating and Clean Mobility in a number of projects in the field of innovative metal forming processes. The superordinate objective of each project is to improve and deepen the basic knowledge of the processes and process chains under investigation. In addition, there is a focus on the identification and investigation of new scientific research directions in the field of manufacturing technology. Cooperation with other industrial companies and research institutions to build up a competence network is a welcome side effect.

Structurally, the individual ReCIMP projects are assigned to the following six priority areas:

- Extension of forming limits
- Characterization of advanced steel grades
- Alternative production methods
- Flexible production
- Lightweight structures
- Processing of tubes

The project work is performed by scientists from the various IUL departments on a subject-specific basis. The Advisory Board of ReCIMP regularly discusses the progress of the individual projects as well as the overall strategy of the research center. The figure on the following page gives an overview of the projects carried out in 2021.

The researchers are supported by a large number of student assistants and students who prepare projects or final theses in the projects. Since the establishment of the research center far more than 65 students have been involved in ReCIMP projects; for several current research assistants of the IUL, a thesis in ReCIMP was the first step into a scientific career. In 2021 alone, five project, bachelor, and master theses were written within the scope of the research center. The cooperation is particularly effective when ReCIMP research topics lead to fundamental questions and research fields for externally funded projects – as it has happened several times in the past years.



Research topics worked on in 2021

In the field of characterizing modern steel grades, the investigations on the evaluation of global and local ductility where continued in 2021. Depending on the manufacturing process chain, one of the two properties is more important than the other. However, there are also cases in which a balanced relationship between global and local formability is of interest. The evaluation of the formability ensues based on forming limit curves and fracture forming limit diagrams. The investigation in the project "Formability Limits of Advanced High Strength Steels" focuses on a more time-efficient and economical determination of the required parameters with the aid of analytical approaches. These parameters are determined for various steel grades for applications in the areas of "seating technology" and "exhaust tract" (see chapter 2.3.14).

Powered by the raising political effort towards the reduction of $C0_2$ emissions ReCIMP continued its project on "Green Manufacturing" which started in 2020. This project aims at the determination and reduction of CO_2 emissions in metal forming process chains. After the identification of political and industrial efforts as well as developments, exemplary hot forming process chains in metal forming were broken down into the sub-processes and their respective emissions. Based on this breakdown, different CO_2 saving potentials are revealed. Moreover, an analytical approach is developed for all sub-processes and enables the prediction of CO_2 emissions already at the stage of product and process design. Current investigations focus on the saving of raw material and heat recovery (see chapter 2.4.11). Beside sheet materials, ReCIMP also considers the forming of tubular materials. Emphasis is on non-round tubes as their impact increases, for example in exhaust systems, due to limitations in the assembly space. Within the project "Shape Prediction and Improvement for Canning of Non-Round Tubes" a numerical model of the forming processes is developed and validated. This model allows the calculation of geometrical deviations due to the filling (canning) of a ceramic monolith into the formed tubes as well as the load-distribution between the tube and the sensitive monolith (see chapter 2.3.11).

The projects on "Formability of High Temperature Stainless Steel Grades" (see chapter 2.4.10) and "Prediction of Wall Thinning during Rotary Draw Bending of Tubes" (see chapter 2.3.12) consider the challenges in metal forming when substituting austenitic by ferritic stainless steel grades. This substitution enables a significant decrease of CO_2 emissions in material acquisition, but leads to challenges in respect to formability. In 2021, the project on "Increasing the Forming Limits by Heat-Assisted Bending below the Recrystallization Temperature" started as well. This project tends to avoid cracks at the cutting edge when bending blanked sheet metal. Such cracks appear especially when bending high-strength material and must be avoided in safety components like car seats (see chapter 2.3.13). In addition, also the project "Hot Plate Forging of Load-Adapted Gear Racks" focuses on a forming strategy at elevated temperatures. This technology facilitates a further reduction of material and, thus, of weight at the manufacture of seats. The emphasis is on a reduction of the thermo-mechanical tool load and an optimization of the workpiece contour (see chapter 2.4.12).

2.1.3 ReGAT – Research Group on Additive Technology

Contact Dr.-Ing. Dipl.-Wirt.-Ing. Ramona Hölker-Jäger
Stephan Rosenthal, M. Sc.

Increasing product complexity, competing production technologies and materials, shorter periods of product development and product live times as well as increasing importance of resource and energy efficient production methods motivate the working group “Research Group on Additive Technology“ ReGAT), which works on the combination of metal forming and additive manufacturing, to do research on and develop hybrid materials, products, processes, and process integration. Current research deals with the development of additively manufactured semi-finished products for further processing as well as the use of additive manufacturing processes for tool production or as part of the forming production chain.

Two different additive manufacturing machines for processing metal powder exist at the IUL for doing research in this field (see Figure 1):

- 5-axis-milling machine with integrated unit for laser-powder-deposition (DMG Mori Lasertec 65 3D Hybrid) and
- Powder bed-based machine for selective laser melting (SLM) (DMG Mori Lasertec 30 SLM).

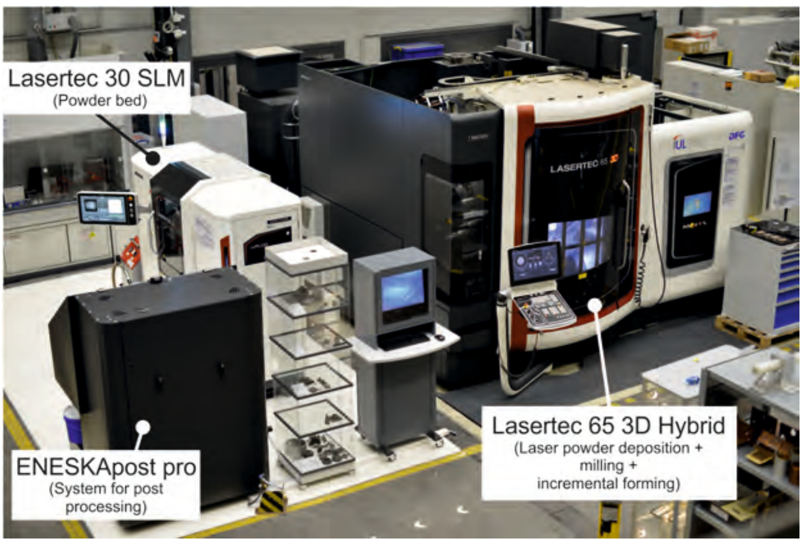


Figure 1: Machines for additive manufacturing based on metal powder at the IUL

In addition, three fused deposition molding (FDM) devices for processing of polymers are available.

The 5-axis-milling machine with integrated unit for laser-powder-deposition, which combines additive manufacturing and milling-post-processing, has been extended by the option of incremental sheet metal forming within a research project funded by the DFG (385276922). Therefore, it is possible to apply three different manufacturing processes (forming, additive manufacturing, subtractive manufacturing) in one setup with the aim of producing custom-designed parts. Besides the processing of stainless steel and tool steel, the generation of hybrid materials by mixing different metal powders is possible.

Current research projects, applying the Lasertec 65 3D Hybrid machine, deal with new tool concepts for metal forming. Project 417202720 funded by the DFG deals with the functionalization of additively manufactured press hardening tools by means of roller burnishing. The manufacturing of the dies by direct-energy-deposition (DED) allows a surface-near positioning of the cool-

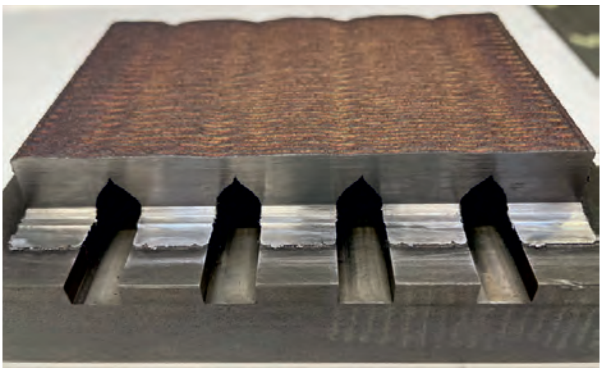


Figure 2: Subtractive (machined) and additively manufactured cooling channel in drop shape

ing channels and the roughness resulting from the DED can be levelled by subsequent roller-burnishing. It could be proven that the roughness can be reduced by 35%-75% using roller burnishing, depending on the process parameters (e.g. material, roller pressure). In this case, compressive residual stresses, which increase with higher burnishing pressures, are generated. When designing the cooling channels, which can be geometrically more complex against channels which are manufactured only in a machining manner, it is necessary to achieve a compromise between the additive manufacturability and the surface fraction, which effectively contributes to the heat balance on the tool surface. To manufacture the cooling channels, open cooling channel structures are milled into a solid material and then sealed using

DED (see Figure 2, cooling channel in drop shape).

In another fundamental research project using the Lasertec 65 3D Hybrid strategies are developed to reduce the stair step effect in tools made of laminated sheet metal (426515407). This is done by means of a combination of additive manufacturing and post-processing employing surface roller burnishing. This means that even complex tools can be manufactured quickly and cost-effectively.

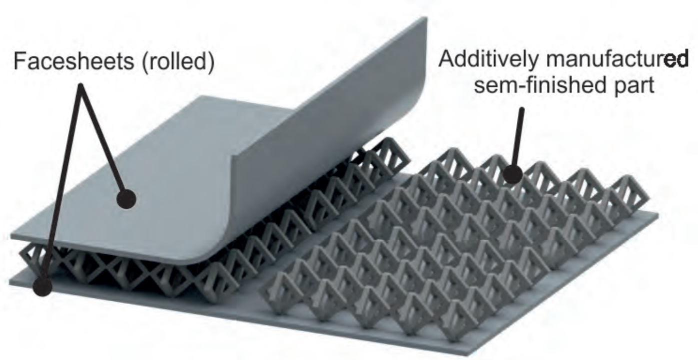


Figure 3: Additively manufactured sandwich sheet

The machine working in the powder bed using Selective Laser Melting (SLM) enables the production of highly functional metallic components with filigree geometry details. In the renewal application currently approved by the DFG (317137194), the design of semi-finished sandwich sheets manufactured using the powder bed process with core structures optimized for forming operations is examined (see figure 3). By a subsequent forming operation of the semi-finished products, the productivity of the process chain can be increased by up to 360%, depending on the complexity of the component. The size limitations of additive manufacturing machines can be overcome and a high degree of lightweight construction and functional integration can be achieved in the core structure.

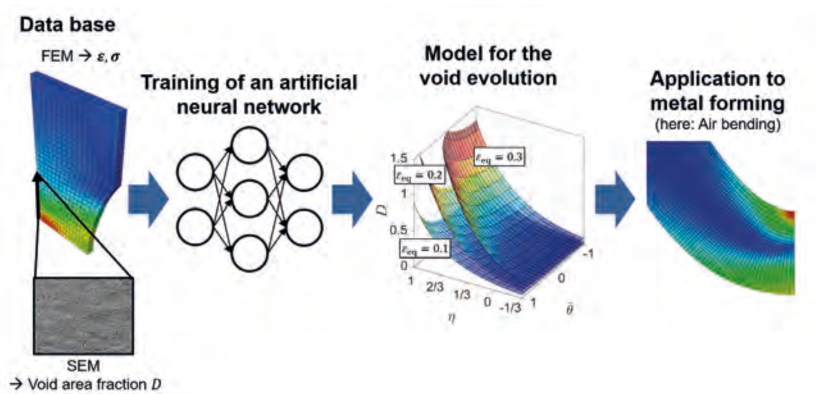
To expand the post-processing options for additively manufactured components (e.g. milling, grinding, cutting, polishing), a new system with integrated extraction and use of post-processing tools was procured at the end of the year 2020 and put into operation in 2021. It ensures safe and efficient working conditions in the additive manufacturing environment.

2.1.4 Research Group Applied Mechanics

Contact Dr.-Ing. Till Clausmeyer

The Research Group Applied Mechanics concentrates on the competences of the Institute of Forming Technology and Lightweight Components in the fields of analytical approaches, material characterization, material modeling, and simulation for forming applications. The researchers working in these fields discuss these topics and jointly develop new mechanical and microstructural characterization methods at IUL. The development and application of the aforementioned methods is conducted for the forming technologies available at IUL: bulk, sheet and profile forming as well as non-conventional forming methods. The purchases of a Weiler Condor VS2 turning machine and a 3D profilometer VR-5200 (company Keyence) strengthen the competences of the research group in the manufacturing of specimens and surface measurements.

The methods supported by the research group play an important role regarding the grants acquired by IUL in 2021: a DFG project to control product properties in hot forming, an EFRE project to develop a biaxial testig device, and an AiF project concerned with modeling the microstructure during hot extrusion. The AiF project aims at developing new methods of parameter identification. The researchers present their results to the public in journal articles and presentations at conferences. The colleagues receive valuable feeback from scientists e.g. involved in the "The International Academy for Production Engineering". Felix Kolpak presented a new material testing method at the "CIRP General Assembly". Flow curves with true stains larger than 1 are determined



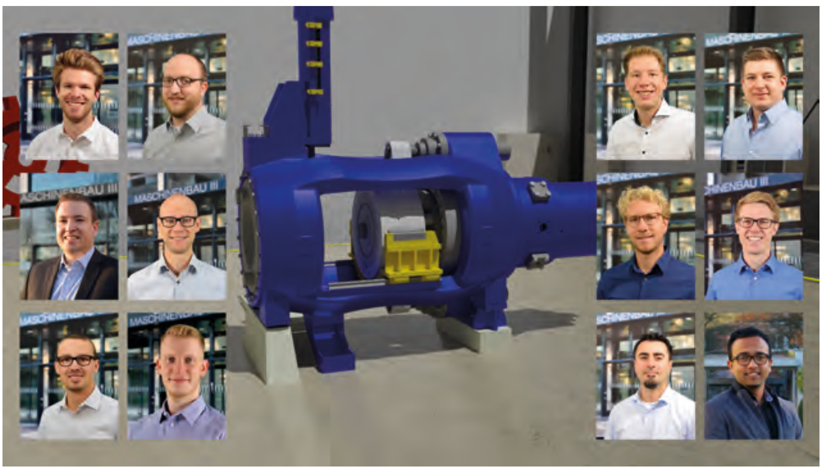
Principal sketch: Prediction of void area fraction with artificial neuronal networks in bending by a special evaluation of a cold forward extrusion test. The method is also suited to obtain flow curves for subsequent deformation.

Further journal articles cover a newly developed software package for parameter identification with explicit consideration of extensive field data such as strains and distributions of the void volume fraction. The software is particularly suited for application in damage. The collaboration with the Institute of Mechanics of TU Dortmund University (IUL authors: Schowtjak, Clausmeyer, Tekkaya) provided the software package ADAPT as Open Source Code. The IUL authors Alexander Schowtjak, Jan Gerlach, Till Clausmeyer, and A. Erman Tekkaya predicted the void area fraction in bending operations faster and more accurately with artificial neural networks than with constitutive models. The research was performed jointly with colleagues of Prof. Kaan Inal's Computational Mechanics Research Group (CMRG) at University of Waterloo in Canada.

2.2 Department of Bulk Metal Forming

Head André Schulze M. Sc.

The focus of the department of bulk metal forming is on the investigation of the processes hot extrusion and cold forging. Fundamental issues as well as innovative processes and process variants are investigated. Fundamentally, the influence of anisotropic hardening and the influence of forming-induced damage on the performance of extruded components are considered. Methods and models are developed for the prediction of damage evolution during cold forging and microstructure evolution during hot extrusion.
The process development aims at lightweight-oriented process designs and resource conservation. The processes of composite cold forging and draw-forging enable lightweight and load-adapted components to be realized. In hot extrusion, the grading of mechanical properties over the profile cross section and the direct recycling of aluminum chips into sheets and their further processing by forming operations are investigated. A process for continuous extrusion is designed and analyzed using a model material.

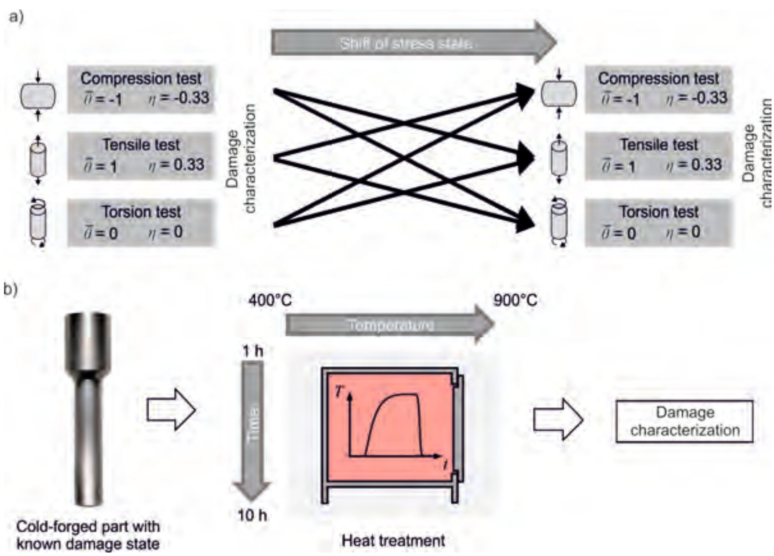


Members of the department of bulk metal forming in front of the virtual hot extrusion press

2.2.1 Influencing the Evolution of Damage in Cold Extrusion

Funding	German Research Foundation (DFG)
Project	CRC/TRR 188 • Subproject A02
Contact	Robin Gitschel M. Sc.

During metal forming, voids inside the material develop and grow on a microscopic level. These voids are referred to as ductile damage and influence the performance of manufactured components during service life. In the first funding period of the project, it was demonstrated that damage-controlled cold forging processes can produce components with increased product performance. For this purpose, the hydrostatic stress state was specifically varied during the forming process. The aim of the second funding period is to extend this proof to the influence of a change in the deviatoric stress state and the influence of heat treatments between forming steps or after forming. These influences will first be investigated in basic experiments before application-oriented cold-forged parts are examined, which are produced in several stages using the forming processes backward can extrusion, forward hollow extrusion, ironing, upsetting and, if necessary, with additional heat treatment (see figure).

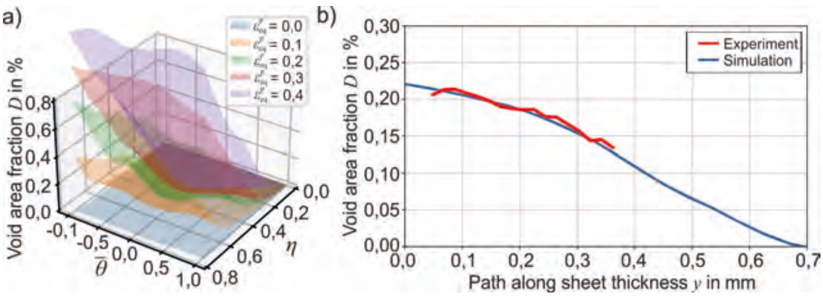


a) Experiments to determine the effect of load path changes and b) of heat treatments on damage

2.2.2 Model Integration for Process Simulation

Funding	German Research Foundation (DFG)
Project	CRC/TRR 188 • Subproject S01
Contact	Jan Gerlach M. Sc.

The CRC/TRR 188 aims at understanding and predicting the mechanisms of damage in order to optimally design forming processes. With regard to the product properties, an accurate prediction of the void fractions is essential. To this end, a model was developed that predicts the damage evolution based on experimental data rather than on assumptions, as it is common in constitutive material models. The experimental data used are measurements of void area fractions by scanning electron microscopy. Accompanying FE simulations are used to calculate the stress and strain states. Artificial neural networks are used to predict the damage evolution. For this purpose, the damage evolution is defined as a function of the loading state in terms of the plastic equivalent strain, the triaxiality, and the normalized lode parameter. The so-called damage locus represents the void fraction as a function of the loading state (see Figure a). The application for air bending provides qualitatively and quantitatively good results (see Figure b).



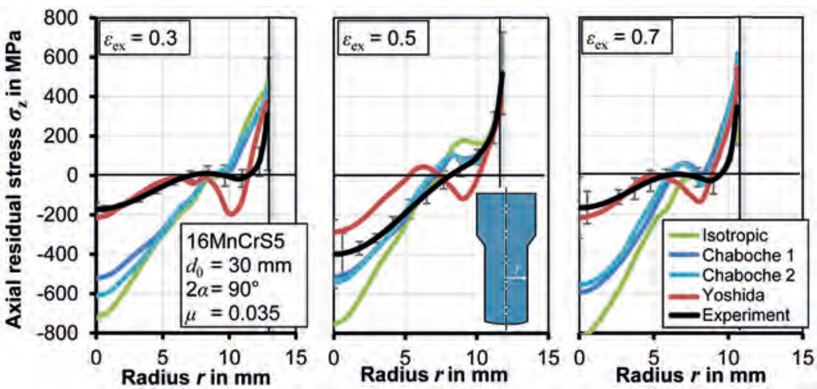
a) Damage locus, b) Validation in terms of air bending

2.2.3 Influence of the Multiaxial Bauschinger Effect in Cold Forging

Funding	German Research Foundation (DFG)
Project	418815343
Contact	Felix Kolpak M. Sc.

In the field of cold forging, multi-staged forming operations are applied frequently to produce complex parts for applications under high loads. In these processes local material regions are oftentimes deformed multiple times, which leads to the manifestation of anisotropic work-hardening phenomena. Therefore, the conventional assumption of isotropic hardening leads to errors in the prediction accuracy of forming simulations, which could not be quantified up to now.

Experimental methods were developed that allow the characterization of anisotropic hardening phenomena up to large strains of ε = 1.6. The methods were applied successfully to three different steels and one aluminum alloy. The utilization of a modified Yoshida-Uemori work hardening model enabled the consideration of all relevant anisotropic hardening phenomena in numerical simulations over the complete relevant strain regime. Consequently, the prediction accuracy of cold forging simulations with regard to process forces and resulting component properties could be increased considerably (see figure).

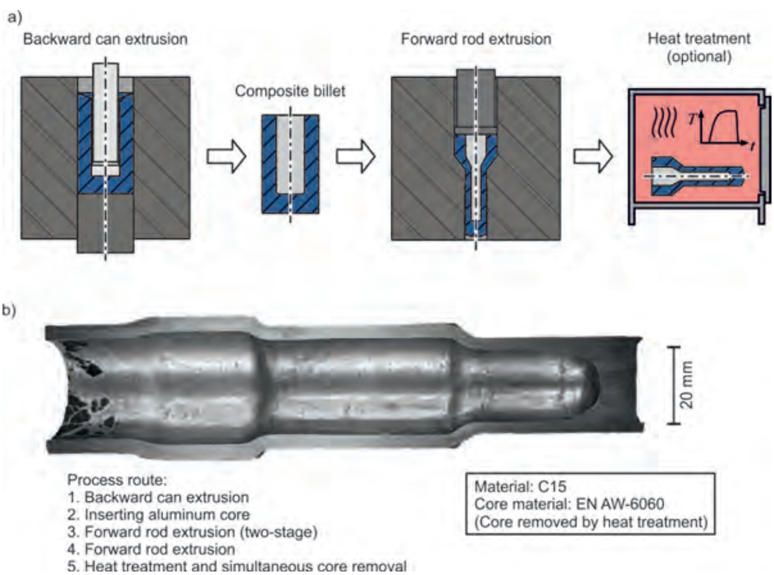


Numerically determined residual stress distribution in cold-extruded parts and comparison with experiments

2.2.4 Composite Cold Forging of Cold-Forged Semi-Finished Parts

Funding	German Research Foundation (DFG)
Project	270149504
Contact	Robin Gitschel M. Sc.
Status	Completed

Composite cold forging enables the production of material composites by cold forging. In this process, backward can extrusion is used to produce semi-finished product geometries. In a subsequent process step, a core material is inserted into the semi-finished can. Subsequently, this composite billet is formed by forward rod extrusion to join both materials and produce a hybrid shaft (Figure a). By combining materials with different physical properties, the lightweight potential can be increased or additional functions can be integrated. Through experimental as well as numerical investigations, general design guidelines for the successful manufacture of composite shafts were derived. Since heat treatment often takes place between or after forming in cold forging, heat treatment concepts for steel-aluminum composite shafts were investigated. For long dwell times above the melting temperature of the core material, the core can be removed by melting so that heat-treated hollow shafts can be produced (Figure b).

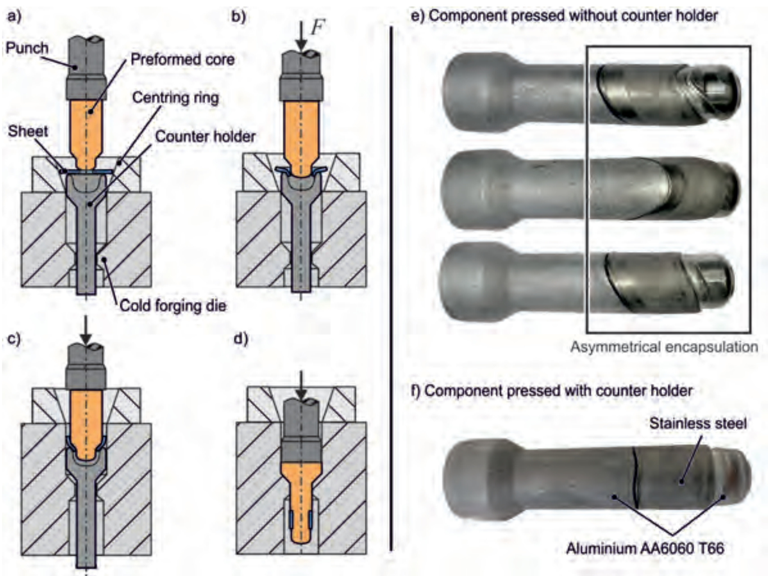


a) Process route for composite cold forging, b) Hollow demonstration part

2.2.5 Process for Manufacturing Composite Components by a Combination of Deep Drawing and Cold Forging

Funding	German Research Foundation (DFG)
Project	289596321
Contact	Johannes Gebhard M. Sc.

Draw-forging is the combination of deep drawing and full-forward rod extrusion in one process step. This allows the production of composite components with a lightweight core and a steel encapsulation, combining the benefits of different materials. In the second phase of the research project, the product spectrum is extended by increasing the maximum drawing ratio through intermediate annealing and deep drawing in multiple steps. To encapsulate specific sections, another process route is investigated, where a pierced sheet is expanded, deep-drawn over the corresponding section, and extruded together with the core. Slight local changes in friction as well as geometric inaccuracies of the blank or the eccentricity of the die set lead to unstable expansion and prevent the process from being successful. With a new contoured counter holder, the process (see Figure a-d) can be stabilized and the repeatability can be significantly increased. Figure f shows a component with a free tip and partial encapsulation.

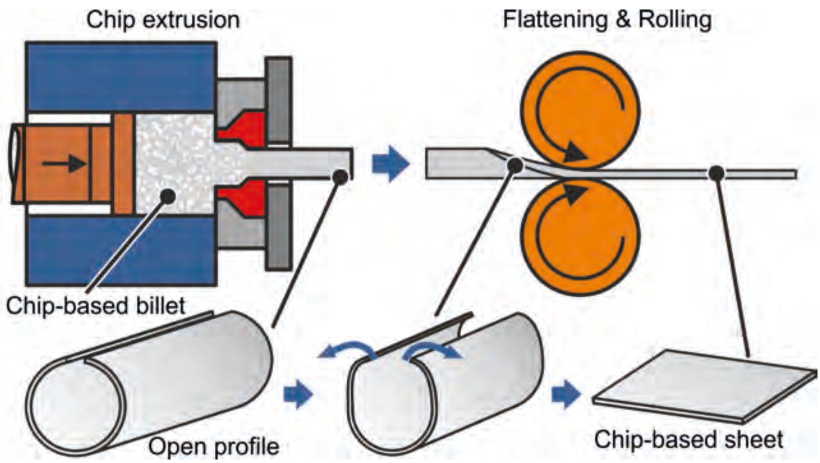


a-d) Process with counter holder, e) Asymmetrically and f) Symmetrically encapsulated component

2.2.6 Production of Sheets by Hot Extrusion of Aluminum Chips

Funding	German Research Foundation (DFG)
Project	437426733
Contact	André Schulze M. Sc.

The direct processing of aluminum chips into semi-finished and final products is an energy- and resource-saving recycling method compared to the conventional remelting process route. The aim of the research project is to produce sheets from aluminum chips and to investigate their ability for further forming processes. Chip-based sheets are realized by a new process chain consisting of hot extrusion of aluminum chips to a cylindrical open profile, flattening and subsequent rolling. The properties of the hot extruded chip-based sheets are examined by tensile tests and microstructural investigations. The results show comparable mechanical and microstructural properties to sheets made from conventional cast billets. Further forming of the chip-based sheets is analyzed by producing bent components and deep-drawn cups. No significant differences are found between the bent components or the deep-drawn cups made from chips and those made from cast material in terms of their suitability for further plastic forming operations.

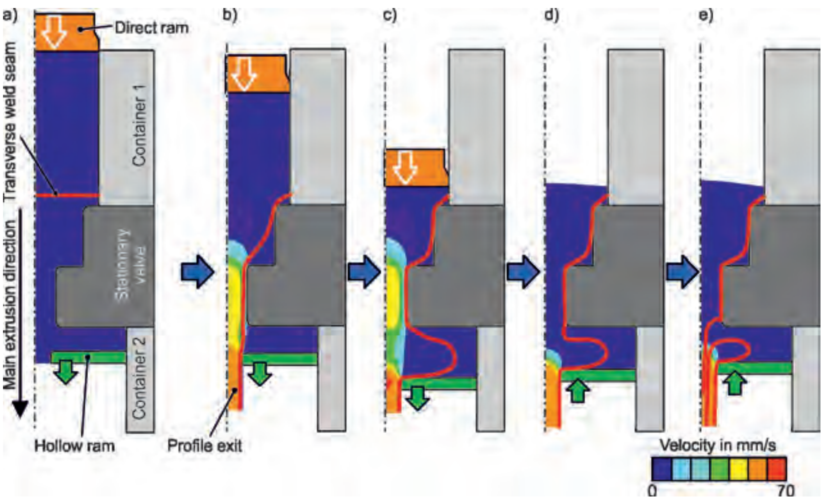


Process chain for the production of chip-based sheets

2.2.7 Analysis of a New Process for Continuous Hot Extrusion Utilizing the Theory of Similarity

Funding German Research Foundation (DFG)
Project 437724884
Contact Johannes Gebhard M. Sc.

Continuous hot extrusion is the combination of direct and indirect hot extrusion, which enables an uninterrupted profile exit at a constant velocity throughout all stages of the process. The two processes are combined with a valve, which allows the material to flow towards the main extrusion direction and prevents it from flowing in the opposite direction. During the dead-cycle times, the material in the second container can be consumed by indirect extrusion and the profile output is maintained. As there is currently no machine for continuous hot extrusion, the process is modeled using numerical methods and scaled experiments with a model material. The valve can be designed stationary or movable and has an individual influence on the material flow in each case. The movable valve is comparable to a porthole die and causes additional longitudinal weld seams. A stationary valve causes strong mixing of the transverse weld seam. The figure shows the position of the transverse weld seam for one press cycle, including the direct phase (see Figure a–c) and the indirect phase (see Figure d-e).

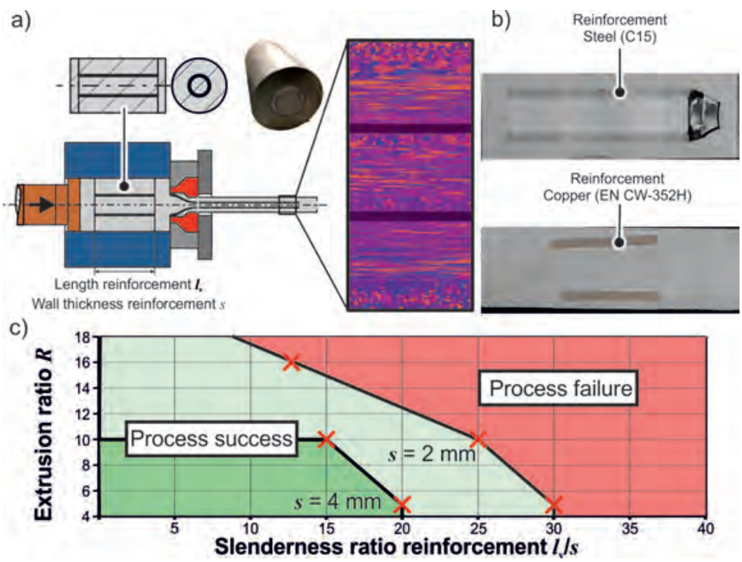


Cycle of continuous hot extrusion, a-c) Direct extrusion, d-e) Indirect extrusion phase

2.2.8 Production of Flange-Shaped Components by Cold Forging of Composite Hot Extruded Semi-Finished Products

Funding	German Research Foundation (DFG)
Project	404239924
Contact	Patrick Kotzyba M. Sc.
Status	Completed

The aim of the project was the development of a process route consisting of composite extrusion with tubular reinforcing elements and subsequent lateral extrusion to produce flange-shaped components. While the extrusion process (see Figure a) was carried out at the IUL, the Institute for Metal Forming Technology (IFU) at the University of Stuttgart took over the further processing of the semi-finished products by means of lateral extrusion. Initially, hybrid profiles were extruded from the combination of AA6060 as matrix material and AA7075 as reinforcing element. Here, the maximum diameter of the reinforcing element is limited by the shear zone during extrusion. In the case of steel and copper reinforcing elements, the length of the reinforcing elements has an influence on the success of the process. If this length exceeds a critical value, the reinforcing element experiences high tensile stresses, resulting in failure of the tube. The diameters of the tubes must not exceed the diameter of the die for these two materials.

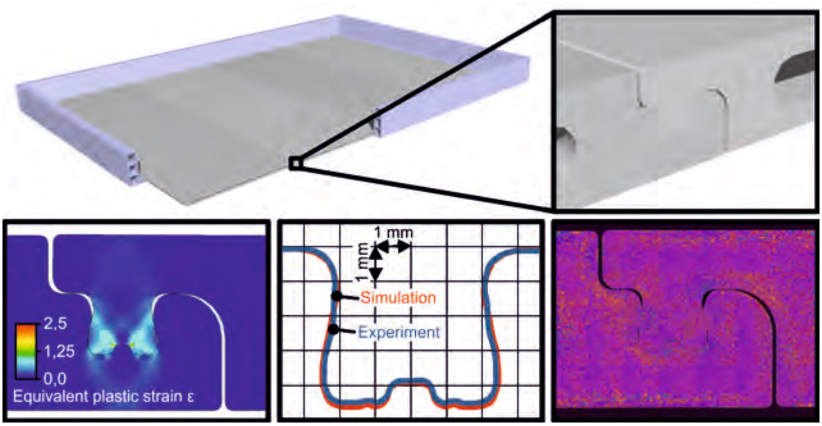


a) Process sequence, b) Profile cross section with steel and copper as reinforcements, c) Process window aluminum - steel

2.2.9 Longitudinal Mechanical Joining of Extruded Aluminum Profiles with Increased Tightness Requirements

Funding	AiF/Stifterverband Metalle
Project	21048 N
Contact	Florian Kneuper M. Sc.

In cooperation with the Laboratory for Material and Joining Technology (LWF) at Paderborn University, this project investigates the development and implementation of a novel extrusion concept to produce profiles with increased sealing requirements for battery trays. By means of a simulation-based profile geometry development, three profile geometries are determined that show a good joint formation (including a large undercut) as well as high forces under typical load cases such as shear tensile and bending loads. In the joining process the profiles are joined by forming within one press stroke. Initial joining tests show only minor geometric deviations in the joint formation compared to the simulation (see figure). By varying the extrusion parameters and using a suitable (local) cooling strategy, the strength of the profiles is to be graded to improve the properties of the joint. The resulting tightness will then be investigated for the manufactured profile composite systems.

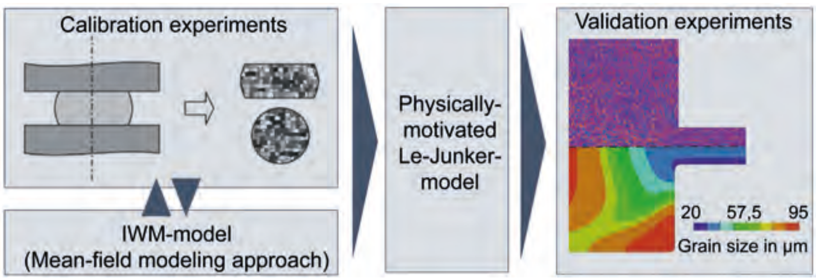


Longitudinal joining: equivalent plastic strain, contour comparison, and microstructure image

2.2.10 Development of an Efficient Physical-Based Modeling Approach for the Prediction of Microstructure in Extrusion Processes

Funding	AiF/Stifterverband Metalle
Project	21682 N
Contact	Jan Gerlach M. Sc.

During hot extrusion the large plastic deformation together with recovery and recrystallization processes influence the grain structure and, thus, the mechanical properties of the profile. Therefore, the microstructure evolution has to be depicted as well in order to predict the product properties. This motivates the project objective, which is to develop a practical approach to predict the grain structure by means of numerical simulation. For this purpose, the physically-motivated Le-Junker model is used due to its fast runtime behavior. The model includes both microstructure-dependent and temperature-dependent model parameters and is calibrated using experimentally determined data from compression tests as well as numerically generated data from a physically-based model developed by Fraunhofer IWM in Freiburg, Germany (see figure). Finally, the Le-Junker model is validated by experimentally determined microstructure data from hot extrusion processes.

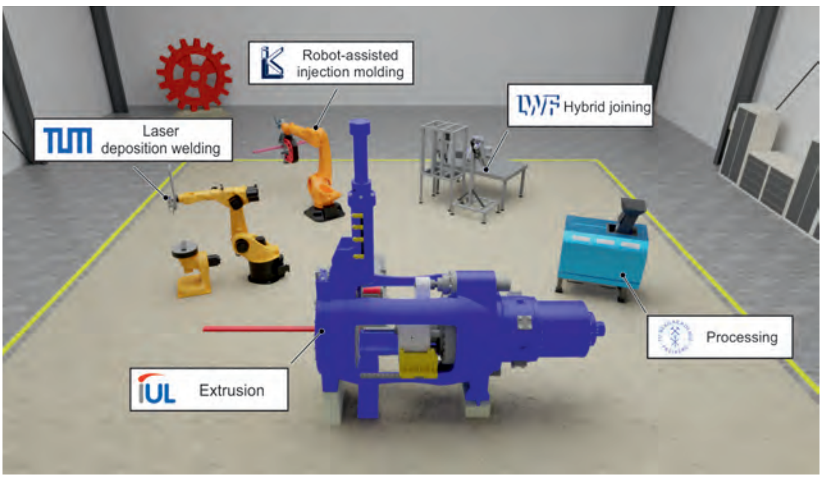


Schematic workflow of the model development

2.2.11 Joint Project: Concepts for the Resource-Efficient and Safe Production of Lightweight Structures (KORESIL)

Funding	BMBF/PTKA
Project	02P20Z004
Contact	Joshua Grodotzki M. Sc.

The joint project KORESIL, which started in spring 2021, combines the expertise of the IUL with that of the Institute of Lightweight Structures and Plastics (ILK, TU Dresden), the Institute of Machine Tools and Industrial Management (iwb, TU Munich), the Laboratory of Materials and Joining Technology (LWF, Paderborn University), and the Institute of Processing Machinery (IAM, TU Bergakademie Freiberg) to analyze a closed process cycle. Starting in Dortmund, where a battery box profile is extruded from chips, structural elements made of metals and polymers are subsequently applied at the iwb as well as ILK. The LWF then joins and later disassembles several profiles with cover sheets before the actual recycling takes place at the IAM and the raw materials are distributed back to the sites to run through the process chain again. This technical pillar of the project is flanked by a virtual representation of the entire process chain. This is to be used both virtually and augmented in order to be able to carry out socio-technical analyses as well as training measures.

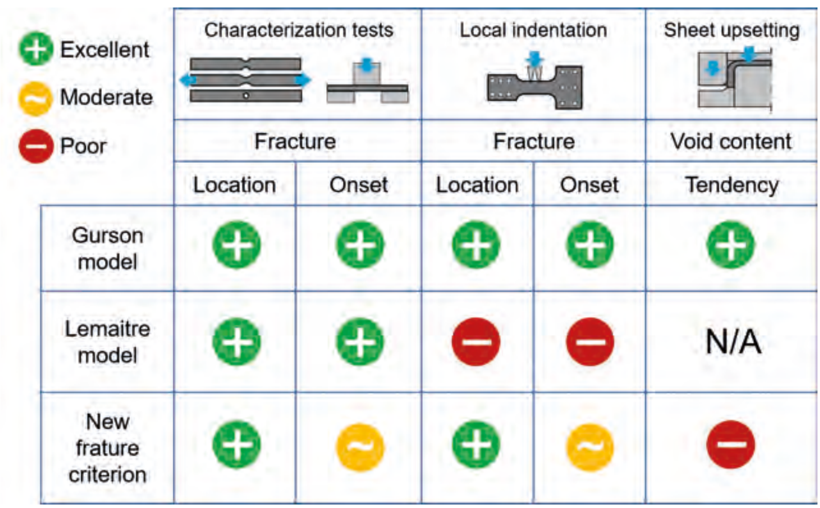


Virtual reality model of the KORESIL process chain

2.2.12 Analysis of Strain Path-Dependent Damage and Microstructure Development for the Numerical Design of Sheet-Bulk Metal Forming Processes

Funding	German Research Foundation (DFG)
Project	CRC/TR 73 • Subproject C4
Contact	Florian Gutknecht M. Sc.
Status	Completed

In collaboration with the Institute of Materials Science (IW) at Leibniz University Hannover, the development of voids and microcracks during forming and the influence on the subsequent component quality have been investigated over the past 12 years. For this purpose, different approaches for determining damage were compared and new material characterization methods were developed. These were used, among other things, to determine micromechanically motivated material parameters such as void nucleation in damage models. In addition, an analytical model for failure due to shearing from the sheet plane (Mode III) has been developed. A new fracture criterion has been added to the numerical damage models, which can be calibrated with few tests and it can be implemented comparatively easy (see figure). Investigations on forming processes have shown that a damage model for sheet bulk metal forming must consider a reduction of the void volume.

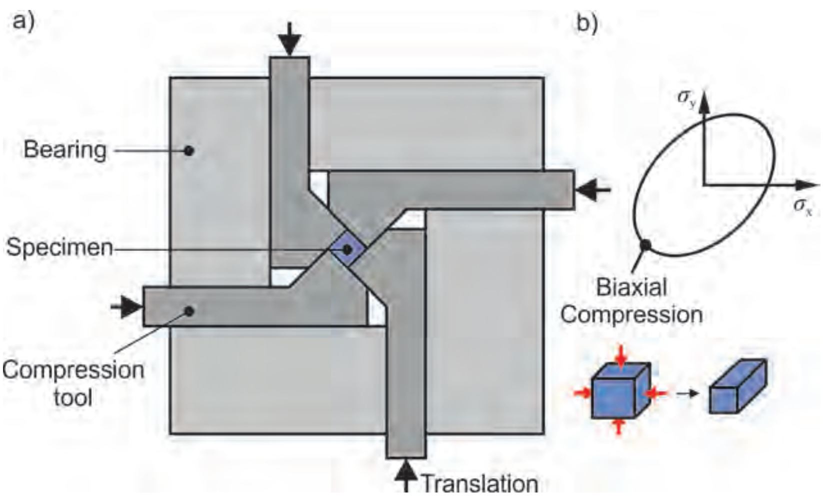


Evaluation of the accuracy of different damage models regarding the occurrence of failure

2.2.13 Prototype Development of a Device for Performing Equibiaxial Compression Tests for Material Characterization for Forming Technology

Funding	BMWi
Project	03THWNW002
Contact	Patrick Kotzyba M. Sc.

The overall project objective is the manufacturing and assembly, commissioning, and validation of a functional machine for performing equibiaxial compression tests for materials characterization for manufacturing technology. The mode of operation is based on the invention "Apparatus and method for performing compression tests on specimens for the characterization of materials and corresponding specimens" (AKZ: DE 102019001442), for which a patent application has been filed by the IUL. The basic operating principle is shown in Figure a. The device enables to form cube-shaped or cuboid specimens by applying a two-sided, biaxial pressure. Compared with conventional material characterization methods, such as tensile and upsetting tests, the favorable stress condition that arises when using the new machine leads to an increased formability of the inserted material specimens. This should enable the experimental recording of flow curves up to high strains.



a) Sketch of the biaxial compression test device, b) Stress state and strain state during biaxial compression

2.3 Department of Profile and Sheet Metal Forming

Head Felix Kolpak M. Sc.

The focus of the department of profile and sheet metal forming is on the development of new technologies to flexibly form tubes, profiles, and metal sheets and on the material characterization up to large strains and at elevated temperatures.

This year, a new machine to roll and draw tubes in a single setup was put into operation. The method enables a flexible cross section reduction of aluminum-based tubes without decreasing the tube's wall thickness. In the future, the method will be developed further to produce more complex profile geometries and to use higher strength materials. In addition, a new spring coiling machine was set up. In the corresponding research project the influence of forming and heat-treatment stages on the development of residual stresses in the spring coiling process is determined and an analytical model will be developed based on the observations (see figure).

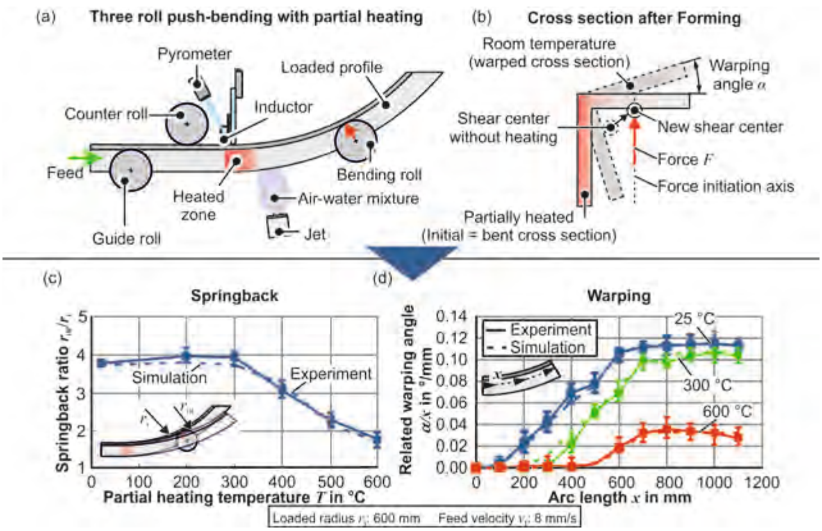
In the field of fundamental research the influence of multi-staged bending on the development of forming-induced damage is analyzed. In temperature-assisted forming, currently in property-controlled hot stamping, the forming-based processing of additively manufactured press hardening tools as well as profile bending with partial heating are investigated.

P. Rethmann, employee of the Department of Profile and Sheet Metal Forming, presents the test setup for the new spring coiling machine at the IUL

2.3.1 Kinematic Profile Bending with Locally Heated Cross Section

Funding	German Research Foundation (DFG)
Project	408302329
Contact	Eike Hoffmann M. Sc.

In this project the suitability of partial heating of asymmetric profiles for the reduction of geometrical deviations in bending is examined. In conventional bending of profiles with asymmetric cross section regarding the force initiation axis, the difference of shear center position and position of the force initiation axis leads to warping. To avoid warping, the profiles are partially heated through induction (see Figure a). Consequently, the position of the shear center changes due to thermal softening in the heated area. Through the change of position in direction of the force initiation axis the length of the torsional lever arm and, as a result, the torsion moment are reduced (see Figure b). For the geometrical result the heating temperature and the selection of the heated area is relevant. Currently, the behavior during bending of L-profiles with partial heating temperatures of up to 600 °C is investigated. In comparison with conventionally bent profiles a springback reduction of up to 56% (see Figure c) as well as a warping reduction of up to 76% has been achieved (see Figure d).

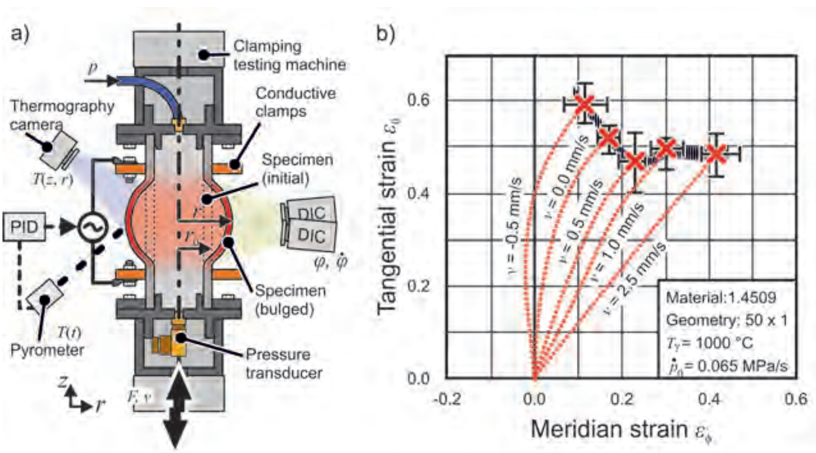


a) Process principle, b) Profile cross section after forming, c) Springback, d) Warping

2.3.2 Media-Based Profile Shaping and Kinematic Bending in a Continuous Process Using a Graded Temperature Field

Funding	BMWi/ZIM-ZF
Project	ZF4101119US9
Contact	Mike Kamaliev M. Sc.

Media-based forming processes at elevated temperatures are increasingly used to form closed profiles. In this context, the material characterization faces new challenges with regard to e.g. failure prediction. In order to record the forming limits at elevated temperatures, the “Hot-Tube-Bulge-Test” is being investigated at the IUL. In this test, tubes are sealed on both sides, heated to a forming temperature $T\gamma$, and isothermally formed up to bursting by an increasing internal pressure p (see Figure a). A DIC system is used to record the resulting strains, which are evaluated subsequently. In order to achieve different strain paths up to the crack and, thus, to achieve different failure stages, the experimental setup is superimposed by an axial displacement v. Due to the lack of standards for an evaluation, own failure criteria are defined. The resulting strain paths are not comparable with those of standardized tests (e.g. Nakajima), but apply to free forming under high internal pressure. An exemplary FLC for a ferritic stainless steel 1.4509 at 1000 °C is shown in Figure b.

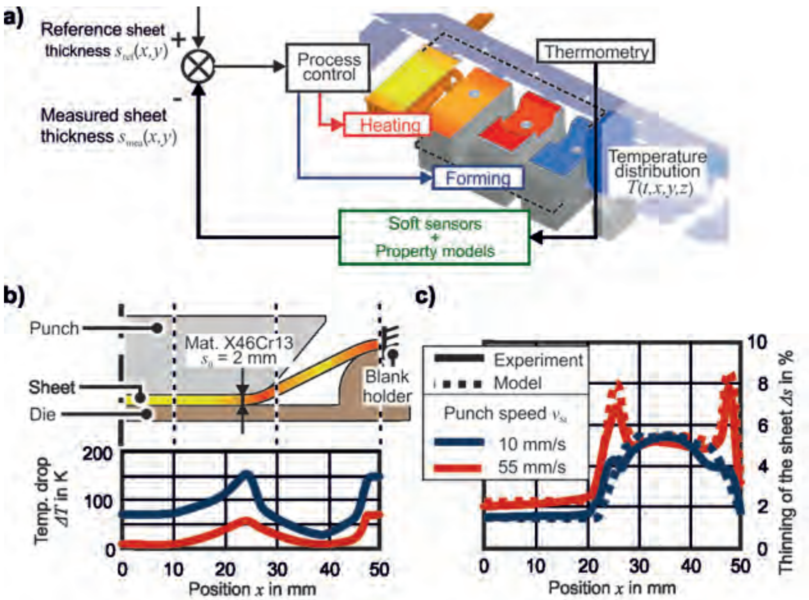


a) Hot-Tube-Bulge-Test setup, b) Determined forming limits at 1000 °C including the strain paths

2.3.3 Property-Controlled Multi-Stage Hot Sheet Metal Forming

Funding German Research Foundation (DFG)
Project 424334660 (SPP 2183)
Contact Juri Martschin M. Sc.

In multi-stage hot sheet metal forming the final microstructure and part geometry result from the thermo-mechanical history throughout the process. With the aim of implementing a closed-loop control for these properties, control-oriented property models are derived. As a general basis a process chain in a progressive die is assumed in which a sheet metal blank is first heated and then hot-formed and simultaneously quenched in several stages (see Figure a). For a real-time estimation of thinning during hot stretch drawing in the described multi-stage setup an element-based, time-discrete property model is developed. This model is coupled with a soft sensor that estimates the temperature distribution in the sheet on the basis of thermometric data for every calculation time step of the property model. For a first validation of the property model the temperature drop during hot stretch drawing (see Figure b) is experimentally determined and passed on to the property model. A comparison of thinning calculated with the property model shows good agreement with the experimental data (see Figure c).

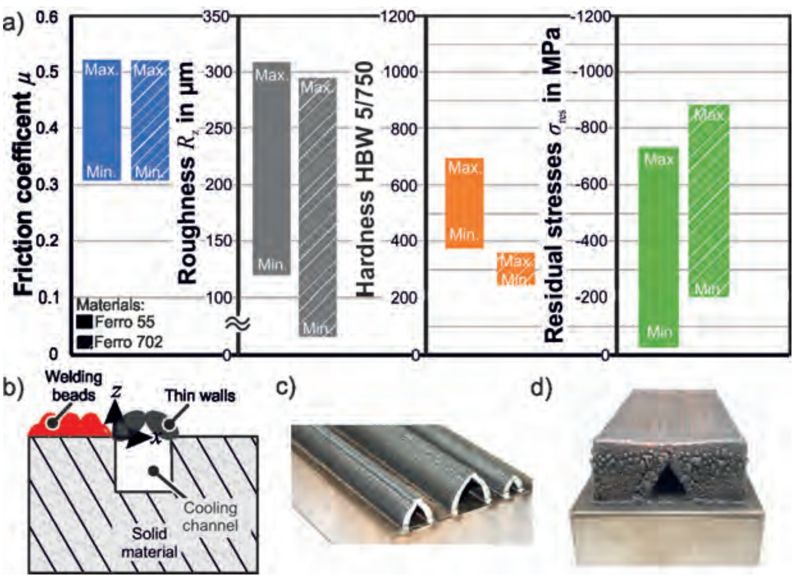


a) Closed-loop control and progressive die, b) Temperature drop during stretch drawing, c) Comparison of thinning

2.3.4 Functionalization of Additively Manufactured Hot Stamping Tools Using Ball Burnishing

Funding German Research Foundation (DFG)
Project 417202720
Contact Anna Komodromos M. Sc.

Hot stamping is used in sheet metal forming in order to exploit the increase in strength due to quenching. For this purpose, cooling channels, which are usually produced using machining processes, are integrated in the tools. The production of hot stamping tools using directed energy deposition (DED) is intended to enable the channels to be positioned close to the surface. Therefore, the properties of the additively manufactured surfaces in terms of roughness, hardness, friction, and residual stresses are first characterized (see Figure a). The initially rough surface after DED is then leveled by ball burnishing. This induces compressive residual stresses, which increase with higher rolling pressures. To manufacture the cooling channels, open cooling channel structures are milled into a solid material and then sealed using DED (see Figure b-d). When designing the cooling channels it is necessary to achieve a compromise between the additive manufacturability and the surface fraction, which effectively contributes to the heat balance on the tool surface.

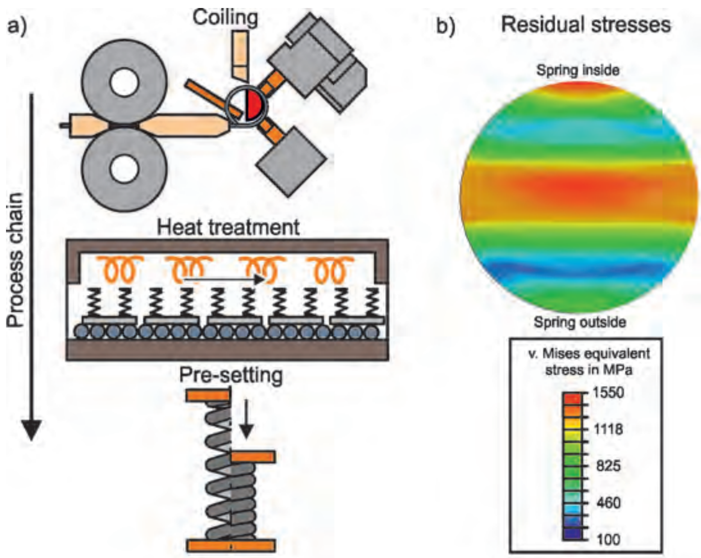


a) Surface properties, b-d) Additive manufacturing of cooling channels: procedure and preliminary tests

2.3.5 Development of a Model to Predict Geometry Changes in Spring Manufacturing Based on Plasticity Theory Considering Heat Treatment

Funding	AiF/IGF
Project	IGF 21490 N
Contact	Philipp Rethmann M. Sc.

Helical compression springs are manufactured in a process chain consisting of coiling, heat treatment, and pre-setting (see Figure a). Residual stresses are generated during the forming of the spring wire in the coiling machine (see Figure b). A thermally induced reduction of the yield stress during the subsequent heat treatment ensures a partial reduction of these residual stresses and a change in the spring dimensions. In the final step of pre-setting, the spring is subjected to plastic loading so that the length decreases and torsional residual stresses are introduced. The material properties of the spring wires, which are determined close to the process by tensile and torsion tests, have a major influence on the residual stresses and the resulting changes in shape. On the basis of experimental and numerical investigations of the sub-processes, a (semi-) analytical process model is developed by which the description of the geometry changes is possible. The model can, thus, be used to support the setup process of automatic spring coiling machines.

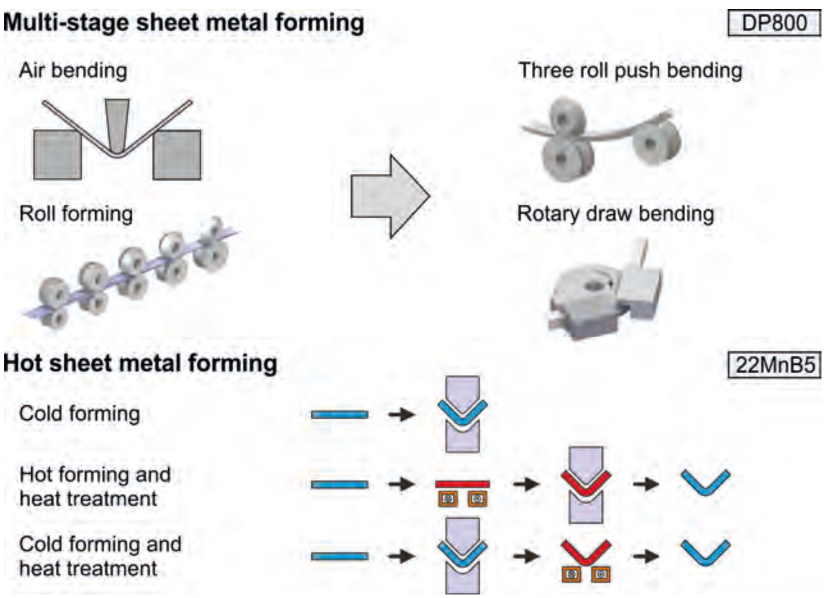


a) Process chain for the production of compression springs, b) Residual stresses in the wire cross section

2.3.6 Damage in Sheet Metal Bending of Lightweight Profiles

Funding	German Research Foundation (DFG)
Project	CRC/TRR 188 • Subproject A05
Contact	Philipp Lennemann M. Sc.

Processes such as air and die bending or roll forming are used to produce bent parts from high-strength steel materials. The results of the first funding period show that damage in sheet metal forming of DP800 dual-phase steel depends to a large extent on the stress state during forming. The reduction of damage leads to an increase in the performance of bent parts in terms of absorbed impact energy, stiffness, and fatigue strength.
The overall objective of the current second funding period is to understand the interaction of damage mechanisms under hydrostatic and deviatoric stress path changes in DP800 and to control the damage. For this purpose, the process chain of profile production is considered, where a straight profile is produced by roll forming or by air bending and then curved by three roll push bending or rotary draw bending. In the area of hot sheet forming, the damage-critical influences during press hardening of 22MnB5 are also identified.



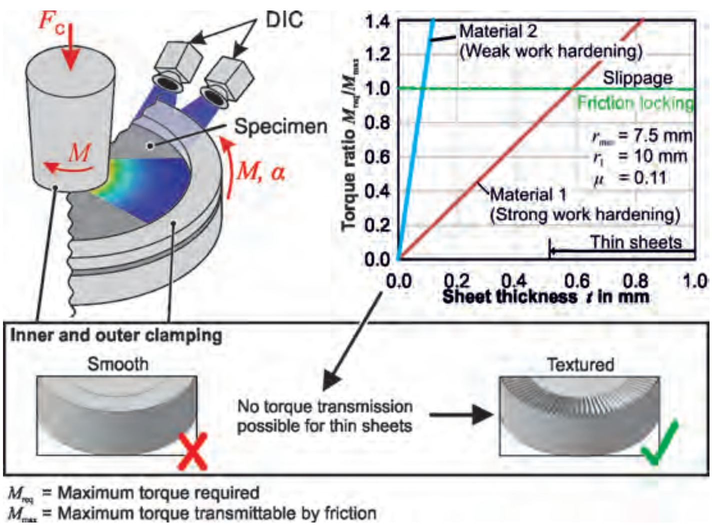
Experiments on damage investigation in multi-stage sheet metal forming and hot sheet metal forming

2.3.7 Preparing the Standardization of the In-Plane Torsion Test

Funding	AiF/FOSTA
Project	21137N/P 1320
Contact	Fabian Stiebert M. Sc

For the numerical design of sheet metal forming processes material properties up to high strains are required which cannot be determined accurately with conventional test methods such as the tensile test. Previous research work has shown that the in-plane torsion test (IPTT) is well suited to determine large strain flow curves. In this project, different influences on the test results in the IPTT are investigated and summarized for the creation of a test standardization. The aim is to establish the IPTT as a standard sheet metal testing method.

Investigations of the clamping surfaces showed that the torque transmission between punch and sheet is generally not possible for thin sheets (t = 0.5-3.0 mm) with smooth clamping surfaces and that texturing of the clamping surfaces is necessary (see figure). In addition, the influence of different textures on the homogeneity of the local strains was investigated. It was found that radial indents aligned transversely to the direction of the loading result in homogeneous deformation and, thus, are well suited for a torque transmission.

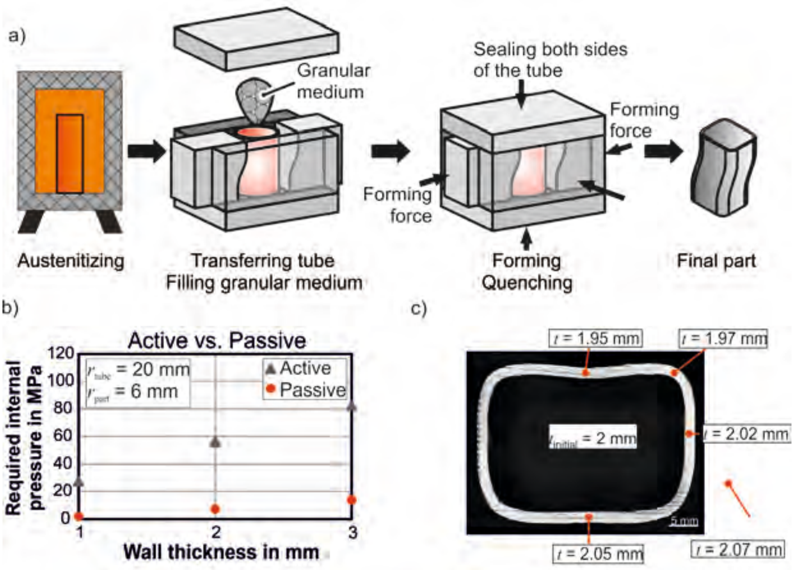


Consideration of the clamping surfaces for torque transmission in the in-plane torsion test

2.3.8 Passive Granular Medium-Based Tube Press Hardening

Funding	German Research Foundation (DFG)
Project	427196185
Contact	Siddharth Upadhya M. Sc.

Owing to their high temperature resistance and pressure withstanding capability, granular materials such as zirconia or quartz allow the process combination of hydroforming and press hardening. The active version of the process combination was already successfully implemented and investigated. Due to the non-hydrostatic distribution of pressure inside the medium, the length of the formable part is highly limited.
To overcome this drawback, the passive process variant was developed and is currently investigated. Unlike in the active process variant, the form giving tools apply the required forming pressure and the granular medium has a passive supporting function and prevents the buckling of the tube walls. The required internal pressures are less than 15% of that required in the active process and as an additional benefit the thickness of the part is homogenous throughout the part, thus aiding in lightweight design. In the next steps, a tool prototype will be developed and further investigations on the process and product properties will be conducted.

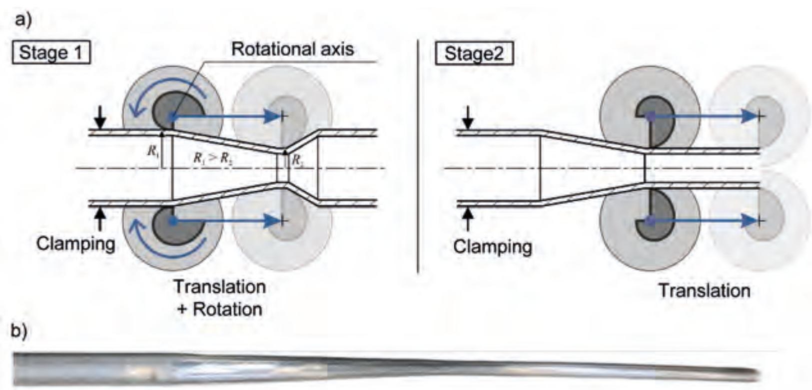


a) Process schematic, b) Required corner forming pressure, c) Cross section of a formed part

2.3.9 Process Development and Technology Transfer of a Combined Forming Process for the Production of Graded Profiles for Lightweight Applications (ProLeit)

Funding	BMWi
Project	03LB2015B
Contact	Niklas Hoenen M. Sc.

In collaboration with Otto Fuchs KG and MSG Maschinenbau GmbH, the BMWi-funded project is conducted with the objective to develop a combined rolling and drawing process for tubes and profiles (see figure). The purpose of the process is to locally reduce or even completely alter the cross section of extruded profiles with the goal to produce lightweight parts. The project involves the development and application of a machine prototype and analytical and numerical investigations to predict the resulting geometry and the process limits. The project will further explore the possibility of extending the applicability to advanced profile cross sections as well as high-strength materials such as aluminum alloys of the 7000 series and steels. This will require the successful development of lubrication systems, a precise machine control, and the accurate characterization of the materials. Finally, the knowledge developed through the analyses shall permit the development of a databank, which, along with the use of analytic tools, shall be able to predict product geometry and other characteristics.

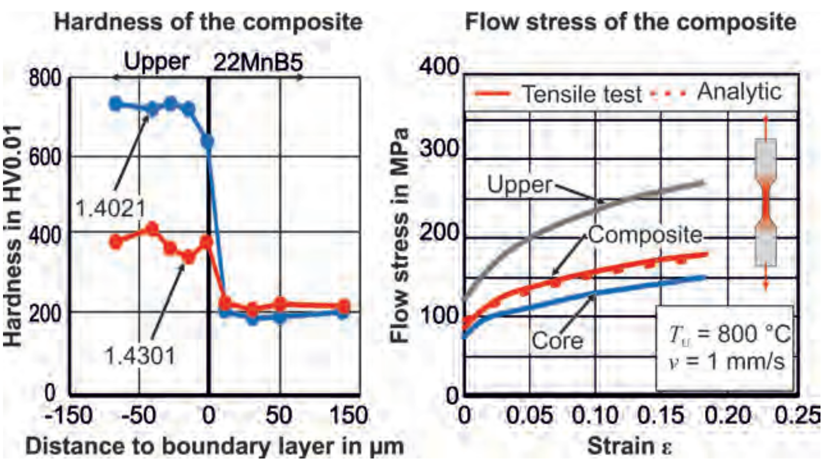


a) Combined rolling and drawing process, b) Formed workpiece (first tryout)

2.3.10 Analysis of the Application Potential of Roll-Clad MnB-Cr Steel Composites for Press Hardening

Funding	German Research Foundation (DFG)
Project	444548865
Contact	Markus Stennei M. Sc.

Press hardening is used to manufacture high-strength components. Due to the high process temperatures, the steel to be processed must be coated to protect it from scaling. As an alternative oxidation prevention, the manufacturability and formability of Cr-Mn steel composites is being investigated in this joint project together with the IBF of RWTH Aachen University. Stainless steel provides oxidation protection and enables more cost-effective and faster heating. In the project a martensitic stainless steel (1.4021) and an austenitic stainless steel (1.4301) are investigated as top layers. The measured hardness profile of the composites produced is shown in Figure a. Analytical models were presented and validated by experiments (see Figure b) in order to predict the resulting effective flow stress of the composite. In the future, these models will be used to design steel composites with different layer thickness ratios. Here, the focus is on the suitability of the new steel composites for use as semi-finished products for subsequent forming processes.

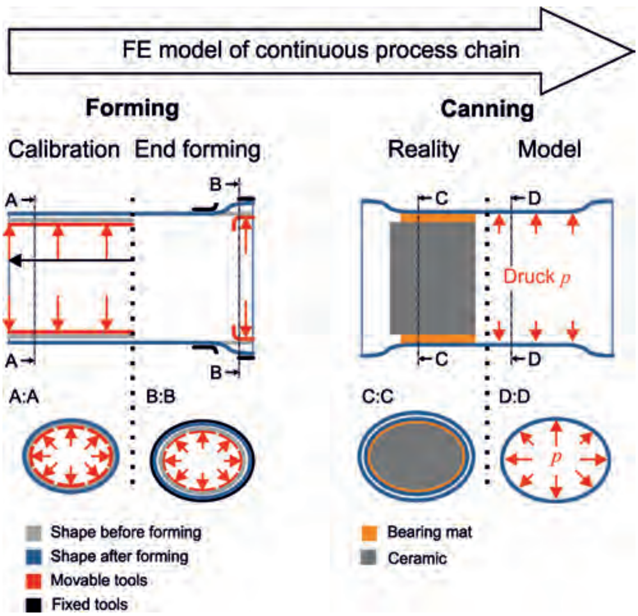


a) Hardness of the composite, b) Validation of the analytics

2.3.11 Shape Prediction and Improvement for Canning of Non-Round Tubes

Funding	ReCIMP
Contact	Markus Stennei M. Sc.
Status	Completed

The reduction of CO_2 emissions requires an improved scrap rate during production. For this purpose, the forming process chain (calibrating and end forming, see figure) and the deformation due to the insertion of a coated ceramic (canning, see figure) of non-round exhaust components were numerically examined in this project. One challenge was the consideration of unknown or variable process parameters in the simulation. The implementation of mechanical forming in the software was developed to predict the resulting shape with respect to the required accuracy. Numerical modeling of the subsequrent canning process was set up with a representive pressure due to the large tolerances during manufacturing. This pressure can be determined from given measurement data and imposed in the FEM software using a specially developed program. Using this approach, the influence of the canning process is now predictable with the desired accuracy.

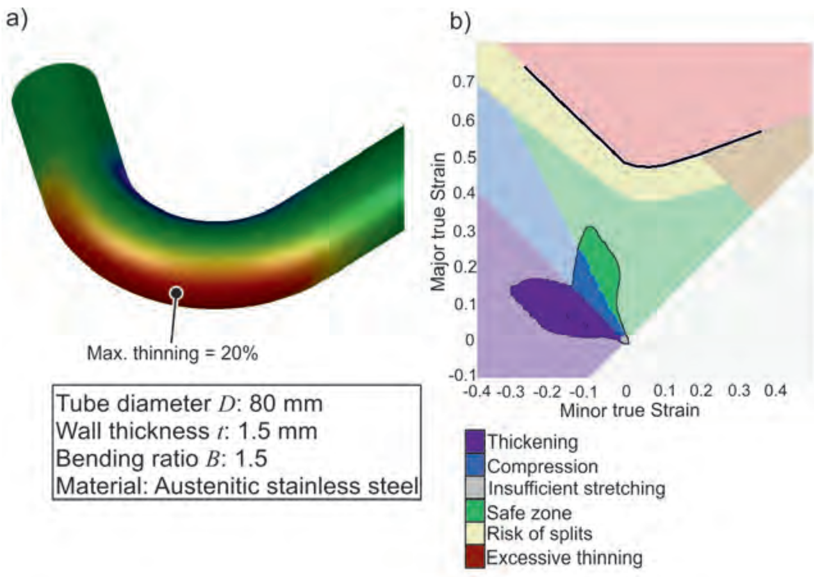


Consistent prediction of the shape along the process chain of forming and canning

2.3.12 Prediction of Wall Thinning during Rotary Draw Bending of Tubes

Funding ReCIMP
Contact Manish Chowdary Ghattamaneni M. Sc.

Austenitic stainless steel shows good formability, but its production leaves a CO_2 footprint about twice as high as the one of ferritic stainless steel grades. Therefore, a substitution of the steel grade enables a significant reduction of CO_2 emissions in rotary draw bending. Within this project experimental and numerical investigations are performed to analyze the wall thinning behavior of both materials (see Figure a). Moreover, strain paths are investigated (see Figure b). The analysis builds the basis for the development of an analytical model that enables the prediction of the wall thinning for a large number of different bending parameters. Based on this model, a process window is to be developed to display all parameter combinations that can be substituted by the resource-efficient ferritic steel grade.

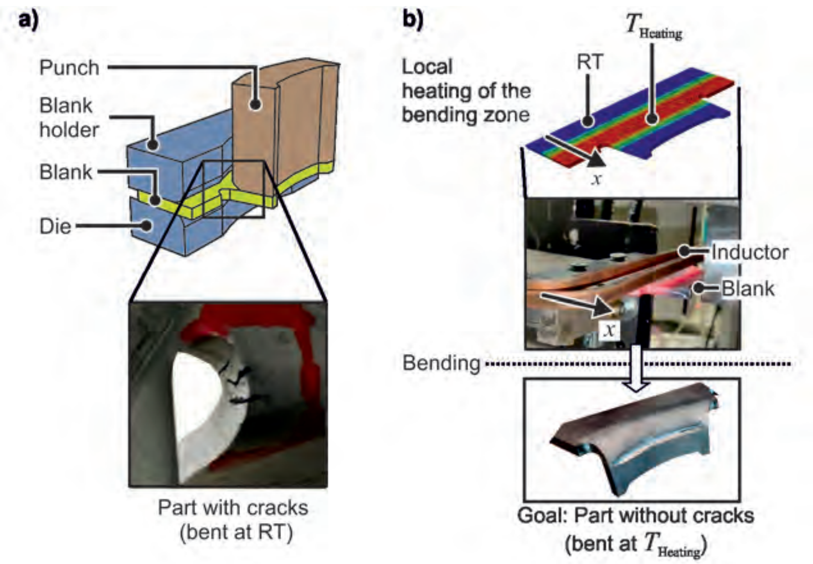


a) Estimation of wall thinning, b) Formability study using FLC from the numerical investigations

2.3.13 Increasing the Forming Limits by Heat-Assisted Bending below the Recrystallization Temperature

Funding	ReCIMP
Contact	Manish Chowdary Ghattamaneni M. Sc

Formability of metallic materials is limited. Common practice is to extend the forming limits by hot forming above the recrystallization temperature. A significant disadvantage of this method is that the initial microstructure is altered by heating. As a result, the properties of the heated material deviate from those of the initial material. The aim of this project is to extend the forming limits of press-hardenable manganese-boron steel sheets by providing temperature support below the recrystallization temperature without causing an undesirable change in the initial microstructure. Thus, hardening of the components after the bending step is still possible. In the case of the investigated component geometry made of manganese-boron steel cracks occur during bending at room temperature (RT) at the outer bend (see Figure a). To avoid these cracks, the bending step is preceded by local induction heating of the bending zone to the temperature $T_{Heating}$ (see Figure b).

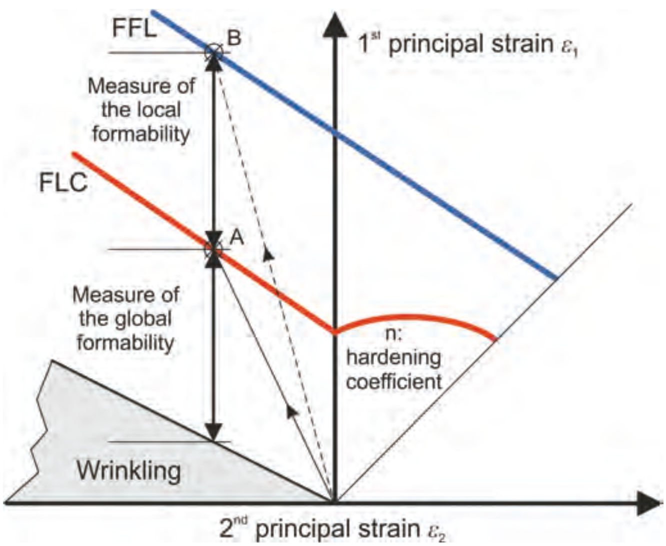


a) Design of the bending tool and part with cracks, b) Inductive heating before bending as well as component after bending

2.3.14 Formability Limits of Advanced High-Strength Steels

Funding ReCIMP
Contact Siddharth Upadhya M. Sc

Identifying methods to characterize the formability of advanced high-strength steels is the essential point of the work being carried out in this project. Forming limit curves (FLC) and fracture forming limit diagrams (FFLD) are the tools prevalently used to identify the limits of global and local formability, respectively. Normally, a number of different tests with different specimen geometries are required to identify these limits. Analytical models allow for a determination of these limits with a reduced number of tests, thus saving time and money. In the planned work the robustness of a newly developed FLC model by Faurecia will be investigated and its applicability across steel families will be determined. The influence of the point of necking determination method on the FLC will also be investigated. Simultaneously, the possibility of determining the FFLD via a simple testing method, such as tensile tests or shear tests, will be explored followed by an experimental validation of its accuracy.

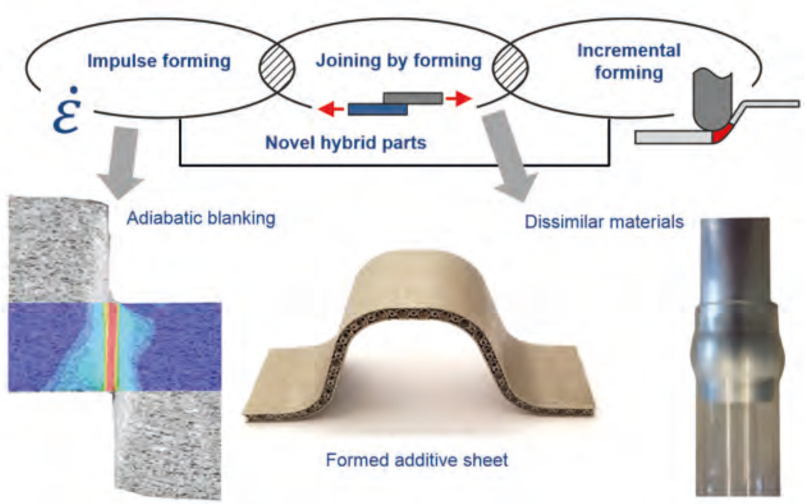


Limits of the global (FLC) and local (FFL) formability in the prinicipal strain space

2.4 Department of Non-Conventional Processes

Head Marlon Hahn M. Sc.

Processes whose degree of innovation exceeds that of considering conventional forming processes are researched and established in the department of non-conventional processes. This e.g. enables higher forming limits or an increased flexibility. Prior to a potential industrial application, a deep process understanding has to be gained. Experimental, numerical, and analytical methods are employed for this. The focus is on different time scales. On the one hand, there are quasi-static incremental processes yielding reduced process forces. On the other hand, there are highly dynamic processes with short but large and local process forces. Hybrid manufacturing approaches also belong to the group's portfolio. This refers to the tooling, the joining of dissimilar materials, as well as to novel semi-finished structured products with an enhanced degree of design and functional freedom. Here, the importance of additive processes for the benefit of forming technology continuously grows. In the respective fields of the group, currently nine researchers foster an intense and fruitful exchange with other national and international groups.

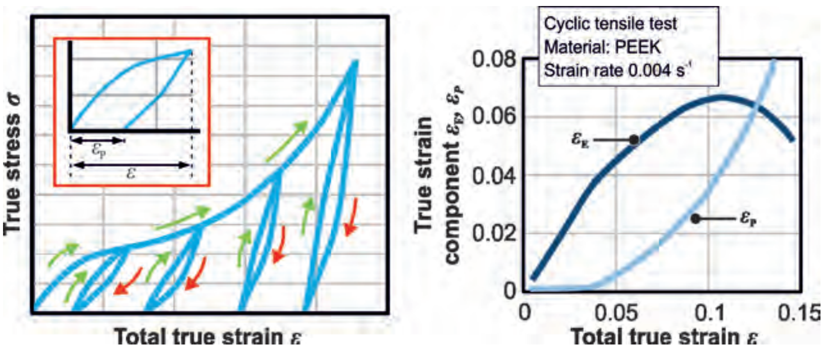


Innovative non-conventional processes

2.4.1 Automated Joining and Non-Destructive Testing of Tube-Fitting-Joints (AutoFit)

Funding	BMWi/DLR
Project	20W1905C
Contact	Florian Weber M. Sc.

In collaboration with PFW Aerospace, Steitz Präzisionstechnik. and the Fraunhofer Institute of Nondestructive Testing (IZFP), the Institute of Forming Technology and Lightweight Components (IUL) is working on this joint project since July 2020. By using the forming processes of hydraulic and electromagnetic expansion, a metallic (aluminum alloy 6061 T6) tube and a thermoplastic (polyetheretherketone, PEEK) tube are joined by a superposition of force-fit and form-fit. For the process design static and dynamic material properties are characterized. For the metallic joining partner, tensile tests as well as an inverse parameter identification via an electromagnetic ring expansion test are conducted. The material behavior of the PEEK is determined, i.a. by cyclic tensile tests, to separate elastic from plastic strains. Plastic true strains rise significantly above a value of total true strains of 0.038 and elastic true strains decrease for total true strains above 11% (see figure).

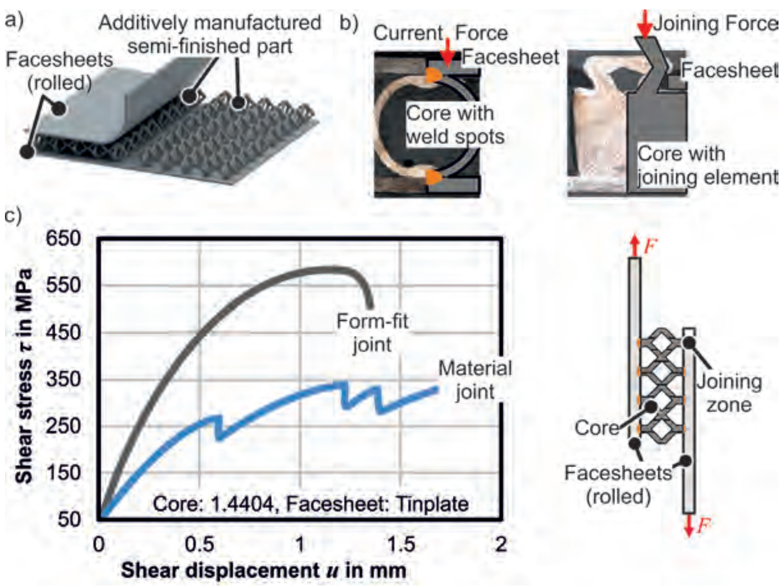


Scheme of the cyclic tensile test and experimentally determined elastic and plastic strains

2.4.2 Forming of Additively Manufactured Sandwich Sheets with Optimized Core Structures

Funding	German Research Foundation (DFG)
Profect	317137194
Contact	Stephan Rosenthal M. Sc.

In cooperation with the Institute of Product Engineering at the University of Duisburg-Essen, sandwich sheet composites with core structures optimized for forming are being developed. The additively manufactured core is joined with rolled cover sheets and enables the production of load-adapted semi-finished products to overcome the build-space restrictions of additive manufacturing machines. For composite manufacturing form-fit and material-fit processes are characterized in terms of their suitability for a subsequent forming operation by means of shear tests. The material bond is achieved by local welding of weld spots and cover sheets with short high-current pulses. In particular, the identification of the process parameters plays a central role. A form-fit connection is produced by a trunnion joint with trunnion geometries optimized for forming. Shear tests show a higher strength in favor of the form-fit connection (see figure). Improvements in the welding process are expected to enhance the performance of the material-joint connection.

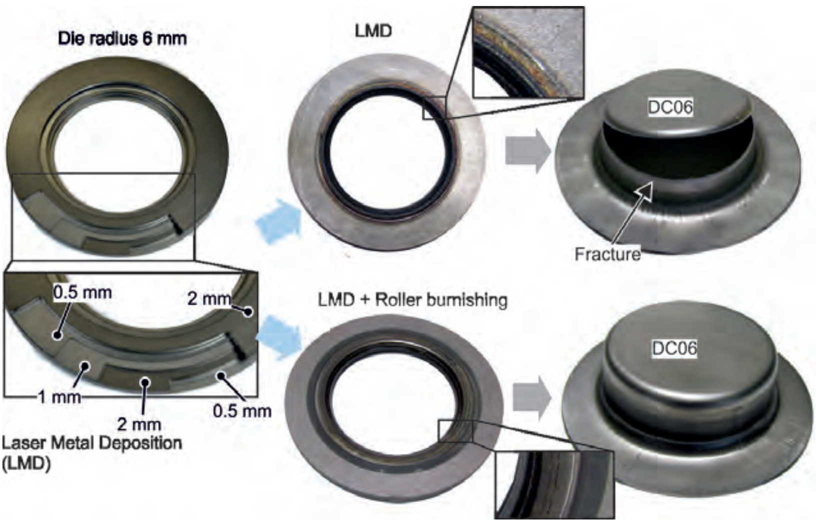


a) Large semi-finished sheet, b) Material-fit and form-fit joint, c) Shear strength of the connections and shear test

2.4.3 Reducing the Stair Step Effect for Dies Manufactured by Layer-Laminated Manufacturing by Additive and Formative Post-Processing

Funding	German Research Foundation (DFG)
Project	426515407
Contact	Hamed Dardaei Joghan M. Sc.

For tool design purposes, a semi-analytical model based on the beam theory is being developed for laminated sheet metal tools. The strength and hardness of the individual weld tracks are investigated on different sheet thicknesses of ferritic steels. Then, the occurring "stair-steps", which can vary due to the layering of the sheet laminations, are filled by laser metal deposition with different build-up strategies and process parameters. The surface area, hardness, and residual stresses of the welds and heat-affected zone are investigated, too. The effect of the initial temperature of the substrate on the mechanical properties of the welds is examined. The roughness of the welded surfaces is leveled by incremental roller burnishing. The results are transferred to a simple deep drawing die (see figure). In addition to energy consumption, the processing time, CO_2 emissions, and production costs of the combined process are determined and evaluated in comparison with conventional deep drawing dies. As a final step, the gained know-how will be transferred to a complex die as demonstrator.

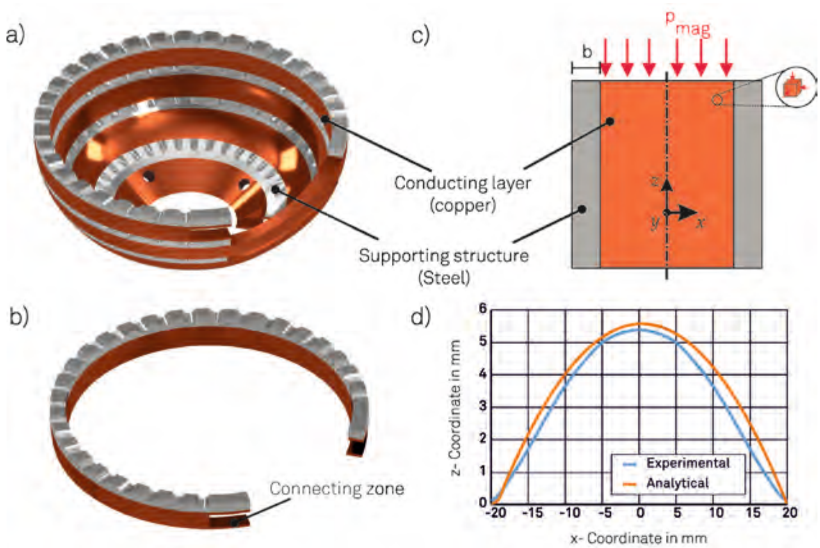


Manufacturing the deep drawing tool by hybrid manufacturing with deep drawing depth of 21 mm and deep drawing ratio of 1.9

2.4.4 Optimized Working Coil Windings for Electromagnetic Forming Employing Additive Manufacturing Techniques

Funding	German Research Foundation (DFG)
Project	259797904
Contact	Siddhant Prakash Goyal M. Sc.
Status	Completed

In collaboration with the Institute of Machine Tools and Factory Management (IWF) of TU Berlin, the project was conducted with the objective of investigating hybrid (multi-metallic) additively manufactured coils for electromagnetic forming for an increased tool life. The focus of research at the IUL was to study the parameters increasing the tool life, e.g. hybrid coils (see Figure a, b, and c). Due to the complex geometry of the hybrid coils, an assembly-based solution was proposed and developed which provides additional flexibility to the coil use. The reduction of plastification of the coil conductor was a further attempt using steel support elements on the sides. With this, a hydrostatic pressure in the coil is applied (see Figure c). Also, a semi-analytical computation method was elaborated to reduce the design effort compared to using coupled numerical simulations for complex multi-winding geometries. From the experiments the geometry of the coil and the workpiece were measured and compared to the introduced efficient computation method (see Figure d).

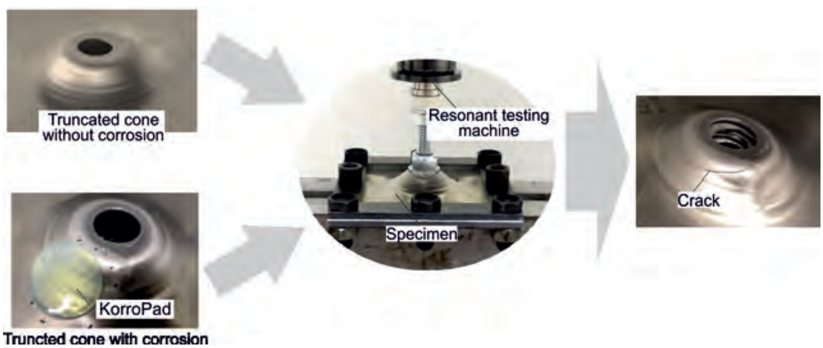


a) Assembly-based hybrid coil, b) Single ring, c) Side supports, d) Comparison experiment/prognosis (sheet work piece)

2.4.5 Improvement of Product Properties by Selective Induction of Residual Stresses in Incremental Sheet Metal Forming

Funding	German Research Foundation (DFG)
Project	372803376 (SPP 2013)
Contact	Fabian Maaß M. Sc.

In the third funding period of the priority program SPP 2013 a cooperation with the Chair of Materials and Surface Engineering of TU Chemnitz is established with the aim of predicting the component property improvement through residual stresses induced by forming technologies. The flexible forming process of Single Point Incremental Forming (SPIF) is used to set residual stresses in the components. A process enhancement that was developed in the last funding period enables the control of the residual stresses through superposition of tensile and compressive stresses during the forming process. Another aspect is to experimentally analyze the influence of corrosion on the residual stresses and vice versa during the manufacturing process as well as during the operation of the components (see figure). A goal of this project is to create a numerical prediction model for the structural strength for a part with a predefined residual stress state. This knowledge can be used to increase the structural strength of loaded components operating in corrosive environments.

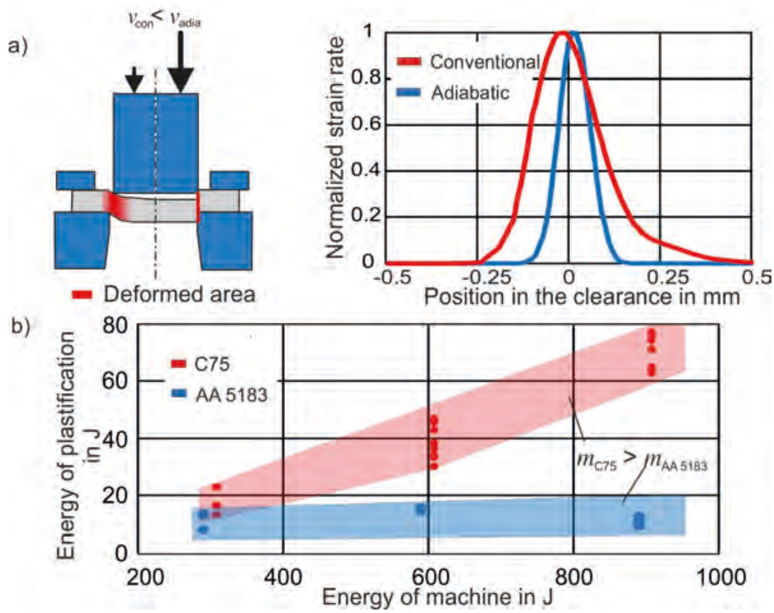


Comparative structural strength test with in-situ corrosion

2.4.6 Application and Analysis of Adiabatic Blanking

Funding	German Research Foundation (DFG)
Project	428780322
Contact	Fabian Schmitz M. Sc.

In adiabatic shear blanking the material is formed more locally due to the higher process speed compared to conventional blanking (see Figure a). With the duration of the impact being short ($t \approx 0.2$ ms), heat conduction is not active and accelerates temperature-induced softening of the material in the clearance. Acceleration and force measurements with a high resolution in time are used to determine the energy flow, in particular the conversion of the kinetic energy of the punch into dissipated plastic work of the material (forming energy) during the process. The forming energy required for adiabatic shear blanking increases with the initial energy of the machine and, hence, with the process speed. For materials with a low strain rate sensitivity m the increase of required energy for plastification is almost constant (see Figure b). If an adiabatic shear band is also formed, the dissipated plastic work of the material increases significantly. The project is conducted in cooperation with the Institute of Materials Science and Engineering (LWW) at TU Chemnitz.

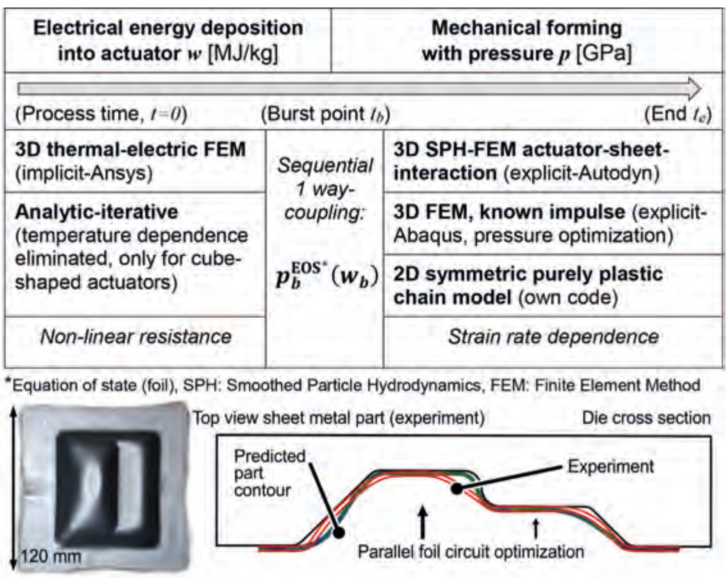


a) Comparison of strain localization, b) Effect of the strain rate sensitivity on forming energy

2.4.7 Forming by Locally Varying Vaporizing Actuators

Funding	German Research Foundation (DFG)
Project	391967465
Contact	Marlon Hahn M. Sc.
Status	Completed

The expansive pressure evolving during a capacitor bank discharge over thin aluminum foils (actuators) within just a few microseconds was used for flexible sheet metal forming. The project focused on the development and experimental validation of a multi-physical modeling and simulation procedure for this novel process. The aim was to be able to provide a predictive process design as well as to deepen the process understanding. For this, different combinable approaches were chosen, depending on effort and complexity (decreases in descending order in the table below), respectively. Especially the non-linear electrical properties of the foil actuator over the solid, liquid, and gaseous state and the strain rate-dependent flow stress of the blank material (1 mm thick DC01 steel, see figure) had to be taken into account. As approximate result, part-individual vaporization pressure distributions were identified and practically realized through adjusting the machine parameters, the foil circuitry, and its geometry.

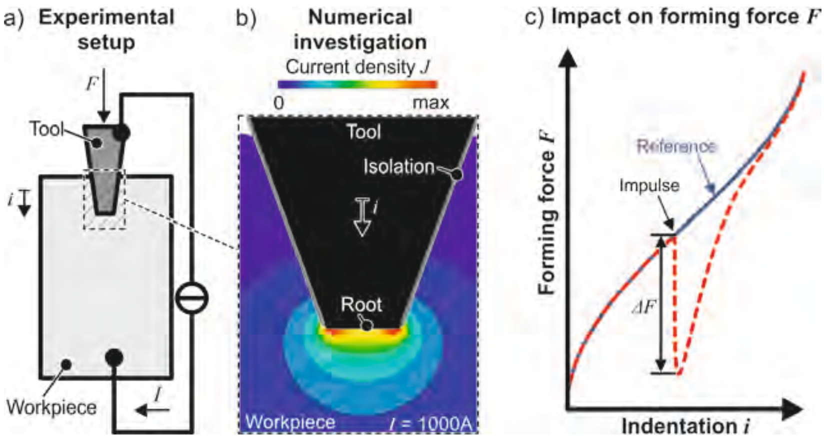


Researched computation possibilities and selected experiment

2.4.8 Fundamental Research and Process Development for the Manufacturing of Load-Optimized Parts by Incremental Forming of Metal Sheets – Incremental Sheet-Bulk Metal Forming (iSBMF)

Funding	German Research Foundation (DFG)
Project	CRC/TR 73 • Subproject A4
Contact	Dr.-Ing. Sebastian Wernicke
Status	Completed

In subproject A4 of the CRC Transregio 73, the main objective was the manufacturing of geometrically complex components from sheets with integrated functional elements by incremental forming operations. Adjusting the load capacity by thickening of the edge ensued the calibration of functional elements. It was investigated whether the strain paths resulting from different process strategies are usable for a targeted manipulation of the mechanical product properties. Numerical investigations of the iSBMF processes presented cyclic load changes. Experimental measurements of the resulting hardness revealed that it is not possible to fully utilize the strain hardening potential of the material observed in monotonous characterization. Another focus was the reduction of the high mechanical tool load by application of electrical pulses (see Figure a). Such pulses on locally insulated tools enable a high electrical current density J within the forming zone (see Figure b). This facilitates a temporary force reduction of more than 50% without losing strain hardening (see Figure c).

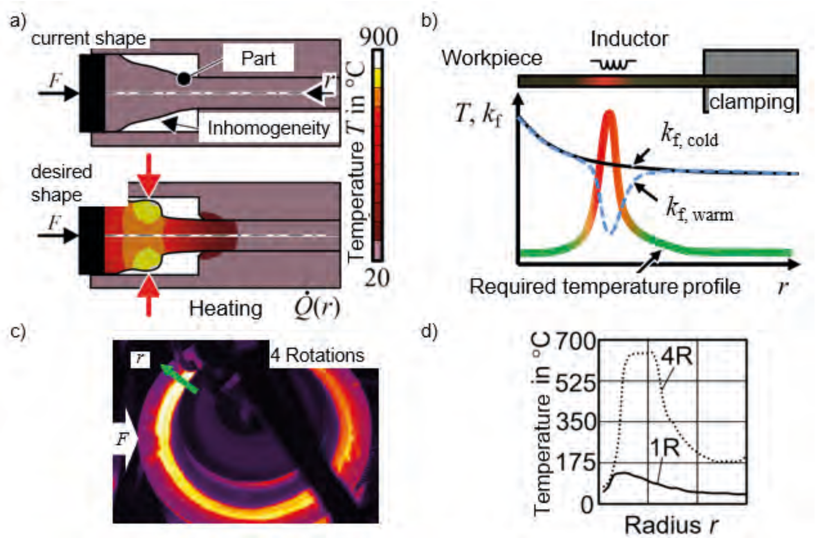


a) Schematic setup, b) Resulting current density, c) Measured impact on the forming force

2.4.9 Incremental Sheet-Bulk Metal Forming by Application of Thermally-Controlled Grading Mechanisms

Funding	German Research Foundation (DFG)
Project	CRC/TR 73 • Subproject T04
Contact	Stephan Rosenthal M. Sc.
Status	Completed

The subject of the transfer project was the extension of incremental sheet bulk metal forming (iSBMF) for hot sheet forming. The aim was to locally influence the flow stress by local heating (Figure a). An analytical approach was used to demonstrate the feasibility of this technology. This provided the required temperature profile for the local reduction of the flow stress (Figure b). In this way, homogenization of the material flow can be achieved. During the project, in particular heating proved to be challenging. Approaches for conductive, inductive, combined heating, and cryogenic cooling as well as laser heating are at the limit of what is technically possible. The required temperature gradient of ΔT = 850 °C over a width of 5 mm is currently not achievable due to the thermal conductivity of the material (Figures c-d). The successful collaboration was carried out with the industrial partners Winkelmann Powertrain Components, thyssenkrupp Hohenlimburg, Faurecia Autositze, and voestalpine High Performance Metals Deutschland.

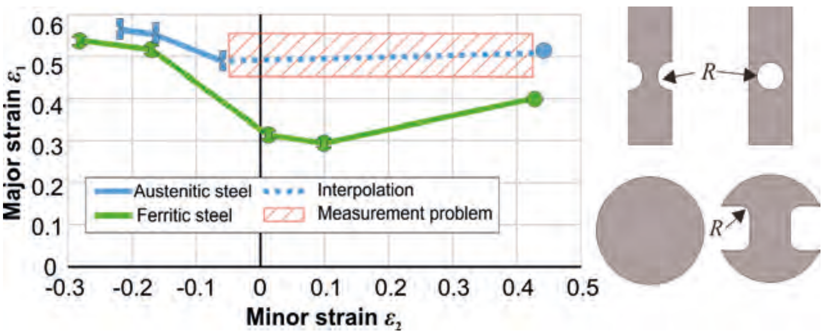


a) Cold/warm iSBMF, b) Required temperature field, c) Heated part, d) Resulting temperature field

2.4.10 Formability of High Temperature Stainless Steel Grades

Funding	ReCIMP
Contact	Florian Weber M. Sc.

The investigation on the formability of austenitic and ferritic high temperature stainless steels focuses on the substitution of austenitic steel grades. These steel grades are applied due to their better formability, but implicate a significantly worse CO_2 footprint compared to ferritic grades. Knowledge about the formability enables a targeted substitution suitable for the complexity of the product. The formability of the different materials is evaluated by forming limit curves determined by Nakajima tests and notched tensile tests. The materials with high formability show a limited applicability in Nakajima tests. In case of notched specimens, the material flows from unnotched areas of the Nakajima specimens, resulting in cracks outside the range of validity. Therefore, upcoming investigations focus on the optimization of the specimen geometry. Furthermore, the manufacturing process of the specimen and its influence on the crack initiation are under investigation.

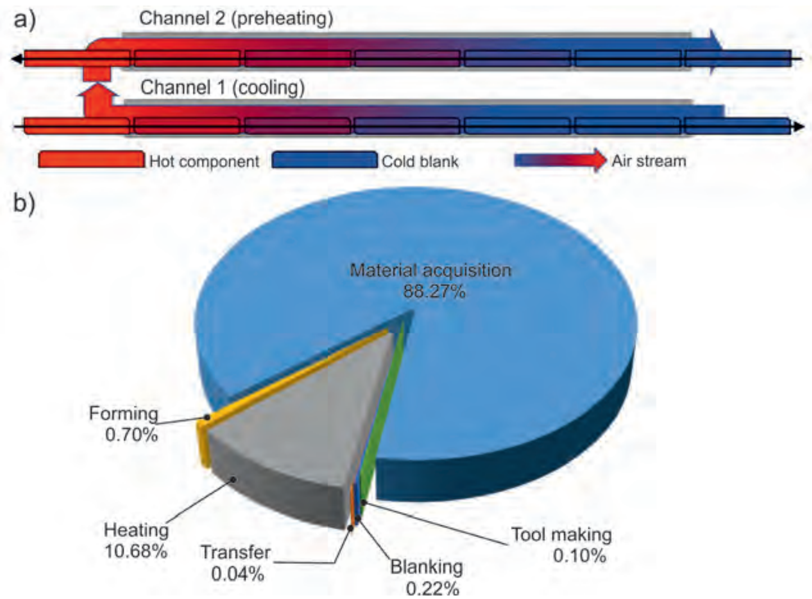


Experimentally determined forming limit curves and geometry of utilized specimens

2.4.11 Green Manufacturing – Analysis and Prediction of Emissions in an Industrial Hot Forming Process Chain

Funding	ReCIMP
Contact	Manish Chowdary Ghattamaneni M. Sc.

This project investigates the CO_2 emissions from the stage of material acquisition up to the final component. The first project stage focusses on the process chain in hot plate forging of gear racks. After identifying the impact of each sub-process step on the total CO_2 emissions, the project investigates measures for the reduction of CO_2 emissions. After the material acquisition, most CO_2 emissions arise from heating operations. Therefore, a process-dependent concept, like a counter-current heat exchanger, is analyzed to recover process heat. This heat exchanger transfers the heat of the formed components to the cold workpieces (see Figure b). Moreover, a developed analytical approach enables the prediction of the product-specific CO_2 emissions already at the product design stage. Further investigations focus on scrap reduction, which is responsible for the largest proportion of total CO_2 emissions (see Figure a).

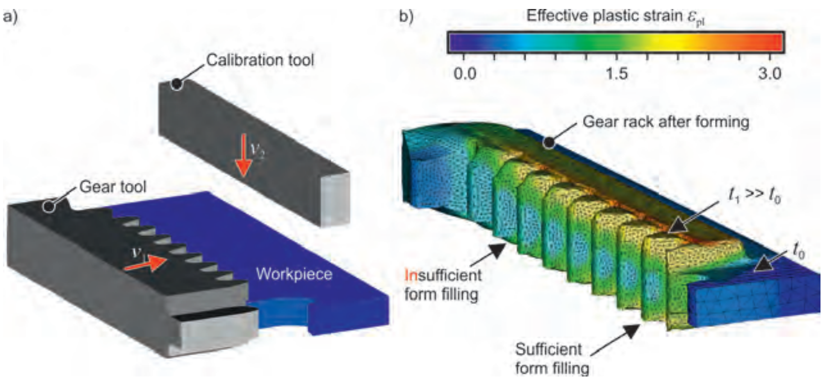


a) Concept of heat recovery, b) Proportion of part-specific CO_2 emissions for an exemplary hot plate forged gear rack

2.4.12 Hot Plate Forging of Load-Adapted Gear Racks

Funding ReCIMP
Contact Dr.-Ing. Sebastian Wernicke

The innovative technology of plate forging enables the forming of load-adapted components. The application of bulk forming operations on sheet metal allows for a local increase of the sheet thickness t. Compared to components with homogeneous thickness distribution, a significant mass, material and, thus, CO_2 reduction becomes attainable. This project focuses on hot plate forging of heat-treatable steels to reach the required hardness of gears already with the subsequent quenching process. The major challenge of this project is the avoidance of folding or insufficient form filling by a numerical optimization of the workpiece geometry. Beside the optimization of the workpiece geometry, the impact of the process parameters on the process energy and tool load is investigated. Further investigations focus on an additional thermo-mechanical load reduction by the application of numerically optimized cooling channels.



a) Schematic depiction of the plate forging process, b) Effective plastic strain distribution in the gear rack after forming

We gratefully acknowledge the funding of our research projects by:

AiF

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Further Activities

03

3 Further Activities

3.1 Awards

Leuphana University Lüneburg awards honorary doctorate to Prof. Matthias Kleiner

As part of the “Dies Academicus 2021”, Prof. Kleiner was awarded the first engineering honorary doctorate “Dr.-Ing. E.h.” of Leuphana University on July 7, 2021. The IUL’s head of institute is the elected president of the Leibniz Association since 2014 and is on leave to perform his duties. He received an honorary doctorate from the Faculty of Business and Economics for his outstanding contributions to engineering research and science management. Prof. Ben Khalifa, Institute Director at the Institute of Product and Process Innovation at Leuphana University and alumnus of the IUL, gave the laudatory speech. Prof. Tekkaya congratulated on site in Lüneburg on behalf of the entire IUL team.

Photo: Leuphana
Prof. Kleiner during his acceptance speech (left) with Prof. Spoun, President of Leuphana University

3.2 Events

Dortmund's 8th Colloquium on Tube and Profile Forming

Dortmund's 8th Colloquium on Tube and Profile Forming (German: Dortmunder Kolloquium zur Rohr- und Profilumformung – DORP) was held for the first time as a digital event on September 29, 2021. The main topics of the event were the networked production of tube and profile components, heat-assisted bending as well as sensor and actuator technology for the detection and control of bending errors. More than 65 participants and eleven presentations, seven of them from industrial partners and four from universities, provided a forum for exchange. The presentations were discussed intensively in so-called breakout sessions, which enabled a lively dialog within the community in the digital format. As a special highlight, the IUL presented forward-looking technologies for the bending of high-strength profiles with heat assistance and with compressive stress superposition (see figure). The demonstration of experiments as well as a guided tour through the experimental field were broadcasted live. The conference series will be continued with the 9th DORP in 2023.

Images of the live-streamed experiments and digital tour of the IUL's experimental area during the 8th DORP

International Conference on High Speed Forming – ICHSF

From October 13 until 15, 2021, the 9th International Conference on High Speed Forming (ICHSF), which is organized by the IUL together with The Ohio State University, took place. Due to the pandemic, it was an online substitution event for the postponed conference that was supposed to be held on site in Dortmund, 2020. More than 50 national and international researchers and industrial participants from Germany, China, America, France, Portugal, Scotland, England, India, Japan, Belgium, and South Korea provided a vital exchange in six sessions about the overall topics: forming and joining, innovations, process design and measurement, and characterization. 24 live presentations were given during the three conference days and they were additionally discussed in separate breakout-sessions. Furthermore, three selected keynote presentations were integrated into the conference for the first time, with consistent positive feedback. Dr. Mostafa Hassani from Cornell University, USA, gave a fundamentally oriented talk on constitutive material modeling and the corresponding parameter determination over a broad range of strain rates. Dr. Gilles Avrillaud from the company Bmax, France, showed the development steps of high speed forming processes in some current innovative industrial applications. And Prof. Brad Kinsey from the University of New Hampshire, USA, presented physical phenomena and perspectives in the field of impulse forming. The contributions will be publicly available on the TU Dortmund University Eldorado platform. The next conference of this series is to be held in 2023, again in Dortmund, following the old tradition of physical presence and interpersonal exchange.

ICHSF21 INTERNATIONAL CONFERENCE ON HIGH SPEED FORMING

Open Day at TU Dortmund University

On October 30, this year's Open Day at the TU Dortmund University took place in compliance with the current Corona protection measures. In cooperation with the Institute of Machining Technology (ISF) and the Chair of Materials Test Engineering (WPT), the IUL offered guided tours of the experimental area with machine demonstrations as well as an interactive forging show. Every full hour, groups of visitors were guided through the laboratories of the institutes by scientific staff. Here, a wide range of cutting, forming, and additive production machines as well as high-speed machines were presented and demonstrated, in some cases by means of exciting short experiments. In addition, visitors had the opportunity to take part in a forging show in front of the experimental hall and could forge nails together with the blacksmiths of the EVENT.SCHMIEDE in Solingen. Especially for the younger visitors this was a special event and an opportunity to experience substantial forming practice.

Group of visitors in the IUL experimental hall
Photo: Oliver Schaper/TU Dortmund University

Meeting of the IUL Industrial Advisory Board

The Industrial Advisory Board of the IUL, consisting of representatives of various industrial companies and associations, met on February 26, 2021. As in the previous year, the event was held as an online conference. Thus, despite existing contact restrictions, an exchange about current developments at the institute and in the companies could take place. With the 20th meeting, the IUL's industrial advisory board has long since become a permanent institution. Through the regular exchange in the committee, the companies gain insight into the current research projects of the institute and provide valuable input for future projects. Currently, 22 companies and associations are permanent members of the advisory board. This time, the discussion focused on flexibilization in forming technology. In a lecture, Prof. Tekkaya presented the main research areas of the IUL, which deal with this topic. Various incremental forming processes as well as additive manufacturing, but also deep drawing composite extrusion and torque-superimposed spatial profile bending should be mentioned here. There was also great interest on the part of industry and association representatives in the topics of simulation in forming technology, digital twins, and artificial intelligence. The 21st meeting of the Industrial Advisory Board on November 19, 2021, which was initially planned to be held on-campus, was also held in the form of an online conference at short notice due to the rising number of corona cases. The focus of the event was the topic of green manufacturing. Forming technology is already an efficient manufacturing process. The CO_2 footprint of components produced by forming technology is mainly due to the material input. To reduce this footprint, new approaches for direct recycling, such as chip extrusion, the targeted use of forming processes to increase the efficiency of the material, and new characterization methods, are being investigated at the IUL.

Furthermore, the IUL participated in the following events, some of which were also open to a non-scientific audience of different target groups:

- Dortmund University Days • January 20
- Girls*Day 2021 • April 22
- SchnupperUni • August 9-11

3.3 Participation in National and International Organizations: Prof. Dr.-Ing. A. Erman Tekkaya

Memberships of Research Boards

- acatech – Member of the “German Academy of Science and Engineering” (“Deutsche Akademie der Technikwissenschaften”)
- AGU – Member of the “German Metal Forming Association” (“Wissenschaftliche Arbeitsgemeinschaft Umformtechnik”)
- CIRP – Fellow of “The International Academy for Production Engineering”
- Council member of the “European Society of Experimental Mechanics”
- Curatorship member of “KARL-KOLLE Stiftung”, Dortmund, Germany
- DGM – Member of “Deutsche Gesellschaft für Materialkunde”
- FOSTA – Member of the Advisory Board of the “German Steel Federation” (“Forschungsvereinigung Stahlanwendungen e. V.”)
- GCFG – Member of the “German Cold Forging Group”
- I^2FG – Chairman and member of the “International Impulse Forging Group”
- ICFG – Member of the “International Cold Forging Group”
- ICTP – Advisory Member of the Standing Advisory Board of the “International Conference on Technology of Plasticity”
- JSTP – Member of the “Japan Society for Technology of Plasticity”
- Member of “DGM-Regionalforum Rhein-Ruhr”
- Vice president of the German consortium of “Türkisch-Deutsche Universität” (Turkish-German University)
- WGP – Member of the “German Academic Society for Production Engineering” (“Wissenschaftliche Gesellschaft für Produktionstechnik”)

Journals/Editorship

- Editor-in-Chief, “Advances in Industrial and Manufacturing Engineering (AIME)” (Elsevier)
- Deputy Editor, “Elsevier Series in Plasticity of Materials”
- Chairman of the Editorial Committee, “CIRP Annals” (Elsevier)
- Member of the Advisory Board, „Zeitschrift für wirtschaftlichen Fabrikbetrieb“ – ZWF
- Member of the Editorial Board, “Automotive Innovation” (Springer)
- Member of the Editorial Board, “CIRP Journal of Manufacturing Science

and Technology" (Elsevier)
- Member of the Editorial Board, "Journal of Production Processes and Systems"
- Member of the Expert Panel, "Heat Treatment and Materials" (HTM) (Carl-Hanser)
- Member of the International Advisory Committee, "International Journal of Material Forming" (Springer)
- Member of the Scientific Editorial Board, "Computer Methods in Materials Science"
- Member of the Scientific Editorial Board, "International Journal of Precision Engineering and Manufacturing" (Springer)
- Member of the Scientific Editorial Board, "Results in Engineering" (Elsevier)
- Member of the Scientific Editorial Board, "Romanian Journal of Technical Sciences – Applied Mechanics"

Further Memberships

- Chairman of the Scientific Committee, "The International Conference on High Speed Forming 2021" (ICHSF21)
- Chairmen of the "CIRP Task Force on Future Publishing"
- Member of the Advisory Committee, "The 13th International Conference on the Technology of Plasticity" (ICTP 2021), Columbus, USA
- Member of the CIRP Communication Committee
- Member of the Scientific Committee, "International Deep Drawing Research Group 2021" (IDDRG), Lorient, France
- Member of the Scientific Committee, "The 12th International Conference and Workshop on Numerical Simulation of 3D Sheet Metal Forming Processes" (NUMISHEET 2021), Toronto, Canada
- Member of the Scientific Committee, "The 31th CIRP Design Conference 2021", Enschede, The Netherlands

In Scientific Committees

- AiF – Arbeitsgemeinschaft industrieller Forschungsvereinigung "Otto von Guericke" e. V.
- ANR – French National Research Agency

- CIRP – International Academy for Production Engineering
- DFG – German Research Foundation, Member of “Fachkollegium 401 - Produktionstechnik” (Review Board on Production Engineering)
- ESF College of Expert Reviewers
- ICFG - International Cold Forging Group
- KIT - Karlsruhe Institute of Technology
- Nanjing University of Aeronautics and Astronautics, China
- The Ohio State University, USA
- The University of Sheffield
- University of Bath
- University of Cyprus
- Worcester Polytechnic Institute

For Journals

- Acta Materialia
- Advanced Manufacturing Technology
- Applied Mathematical Modelling
- Archive of Applied Mechanics
- ASME – Journal of Manufacturing Science and Engineering
- CIRP Annals – Manufacturing Technology
- Computational Materials Science
- Computer Methods in Applied Mechanics and Engineering
- Engineering Applications of Artificial Intelligence
- Engineering Computations
- Energy Reports
- Engineering Fracture Mechanics
- Engineering with Computers
- Forschung im Ingenieurwesen
- HTM Journal of Heat Treatment and Materials
- International Journal for Numerical Methods in Engineering
- International Journal of Advanced Manufacturing Technology
- International Journal of Damage Mechanics
- International Journal of Machine Tools and Manufacture
- International Journal of Material Forming

- International Journal of Materials and Product Technology
- International Journal of Mechanical Engineering Education
- International Journal of Mechanical Sciences
- International Journal of Mechanics and Materials
- International Journal of Precision Engineering and Manufacturing
- International Journal of Precision Engineering and Manufacturing – Green Technology
- International Journal of Solids and Structures
- Journal Material Characterization – An International Journal on Materials Structure and Behavior
- Journal of Applied Mathematical Methods
- Journal of Computational and Applied Mathematics
- Journal of Manufacturing Processes
- Journal of Manufacturing Science and Engineering
- Journal of Materials Processing Technology
- Journal of Mechanical Engineering
- Journal of Pressure Vessel Technology
- Journal of Production Engineering
- Manufacturing Letters
- Materials
- Materials & Design
- Materials and Manufacturing Processes
- Materials Science and Engineering A
- Mechanics of Materials
- Simulation Modelling Practice and Theory
- Steel Research International
- Strain: An International Journal for Experimental Mechanics
- Surface and Coatings Technology
- The International Journal of Advanced Manufacturing Technology
- ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb

3.4 Participation in National and International Organizations: Prof. Dr.-Ing. Matthias Kleiner

Scientific Academies

- Academia Europaea
- acatech – Council of Technical Sciences of the German Academy of Science and Engineering
- Berlin-Brandenburg Academy of Science and Humanity
- CIRP – The International Academy for Production Engineering
- German Academy of Natural Scientists Leopoldina
- European Academy of Sciences and Arts
- Indian National Science Academy
- Russian Academy of Engineering
- Swiss Academy of Engineering Sciences

Advisory Boards

- Global Learning Council, Chair
- Open Science Policy Platform
- STS Council and Board – STS-Forum Science and Technology in Society, Japan
- Member of the Supervisory Board Futurium gGmbH
- Advisory Committee Japan Science and Technology Agency (JST) Tokyo
- Board of Trustees, Max Planck-Institute of Molecular Cell Biology and Genetics, Dresden
- International Advisory Board for the Development of Competence Centers on Artificial Intelligence Research in Germany, chair
- Member of International Advisory Board of Moonshot R&D at Japan Science and Technology Agency (JST) Tokyo
- Board of Evaluation of Doctoral Centres of Universities of Applied Sciences in Hessen,Chair

University Advisory Boards

- Chairman of the University Council, Johann Wolfgang Goethe-University, Frankfurt (until April 2021)
- Board of Trustees, TU Berlin
- Board of Trustees, Julius Maximilian-University Würzburg
- International Advisory Board Faculty of Engineering, Twente University
- Board of Govenors Jacobs University Bremen gGmbH (until September 2021)

Foundation Advisory Boards

- Board of Trustees, Deutsche Telekom Foundation
- Scientific Advisory Board, Fritz Thyssen Foundation
- Scientific Advisory Board of the Excellence Initiative Johanna Quandt – Charité Foundation
- Advisory Board, Werner Siemens-Stiftung, Switzerland

Professional Chairs

- AGU – Working Group on Forming Technology
- WGP – German Academic Society for Production Engineering
- Board of Trustees, FOSTA Research Association for Steel Application

Consultant and Advisory Board

- Tang Prize International Advisory Board, Taipei
- Member of the Jury for the "Deutscher Innovationspreis"
- Member of the Jury of the Georg von Holtzbrinck Prize for Science Journalism
- Board of Trustees of the "Zukunftspreis" of the Federal President Cooperation

Cooperation Advisory Boards

- Advisory Board, ALHO Holding
- Advisory Board, Siepmann Werke
- Advisory Board, Winkelmann Group

International Exchange

04

4 International Exchange

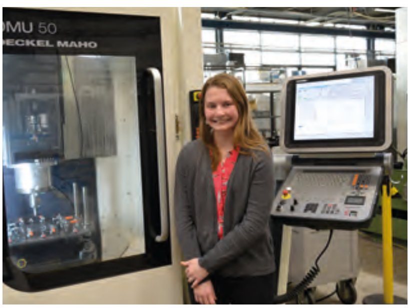
Prof. Paulo A. F. Martins

Prof. Paulo Martins from the “Instituto Superior Técnico” at Technical University of Lisbon visited the IUL from October to November 2021. During his stay, Prof. Martins dealt with a wide range of research questions. While developing concepts for the systematic analysis and restructuring of forming technology curricula in the context of university teaching, he also worked out an analytical model for the process of rotary draw bending that accurately predicts the change in wall thickness during the forming of stainless steel tubes. In addition, his profound expertise in forming thermoplastic materials enabled him to give advice on process design for hydroforming of metals and polymers.

Prof. Paulo A. F. Martins

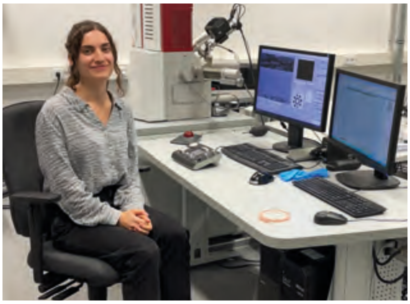
Elizabeth Mamros

Elizabeth Mamros, a PhD candidate from Prof. Brad Kinsey and Prof. Jinjin Ha’s research group at the University of New Hampshire, visits the IUL from June 2021 to July 2022 as an IIE-GIRE grantee and Fulbright scholar. During her research visit with the department of non-conventional processes, Ms. Mamros investigates different process variants of incremental sheet metal forming. The focus of her process analysis is on strain path control during the forming process to create tailored product properties. Additional research topics include the phase transformation of stainless steel during the forming process and the implementation of phase transformation in the numerical process model. The basic mechanisms are investigated using the single point incremental forming process and concepts for stress-superposed incremental sheet



Elizabeth Mamros in front of the incremental forming machine forming are utilized to intentionally influence the strain paths during forming. Elizabeth Mamros will carry out further investigations using a multi-tool incremental forming concept, which is under development at the IUL.

Clémence Pinot

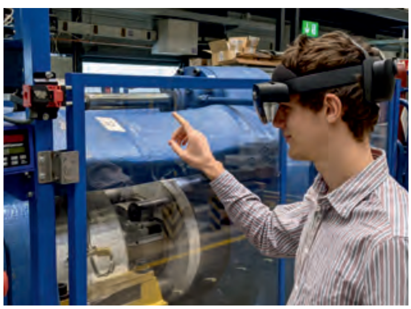


Exchange student Clémence Pinot examining chip-based profiles by means of electron microscope scanning

During the winter semester 2021/22, Ms. Clémence Pinot from École Centrale Nantes in France visited the IUL. As part of her scientific internship in the department of bulk metal forming, Ms. Pinot investigated the influence of oxygen on the oxidation of aluminum chips and profiles during the chip extrusion process. The resource-saving process is used to directly recycle aluminum chips into profiles without the energy-intensive step of remelting. The aim of her work was to determine the effects of the parameters' homogenization temperature and homogenization time on the formation of different phases such as aluminum oxide or magnesium oxide, which influence the welding of the chips during the process. The investigations were carried out metallographically by means of light microscopy and scanning electron microscopy. The findings obtained are used to explain the underlying physical processes during welding of the aluminum chips and to design the process with regard to an improved welding.

Antoine de Percin

For the winter semester 2021/22, Antoine de Percin supported the IUL team in the area of Virtual and Augmented Reality (VR/AR). Antoine is studying general engineering in his master's degree at the selective university CentraleSupélec, Gif-sur-Yvette, France. He has already been involved in the development of AR serious games as part of his coursework. He therefore uses his skills in a



Exchange student Antoine de Percin examining the self-developed learning environment using AR glasses supportive way in the KORESIL project of the IUL. In addition to the investigation of a complete material cycle with a total of five processing steps, the project deals with the development of virtual and augmented teaching/learning environments. To this end, the machines and materials used are first virtualized so that learners can interact virtually with this process chain. The bridge to the interaction of real and virtual objects is then realized via AR glasses. Antoine has implemented, in addition to the visual processing, a variety of different functions that allow users to manipulate or influence the virtual and augmented reality.

Excursion Offer for Visiting Researchers

On October 19, the international guest researchers visiting the IUL had the opportunity to get to know a little of the Ruhr area's atmosphere. The group cycled to lake Phoenix, the site of the former Phoenix-West blast furnace plant in Dortmund-Hörde which has now been transformed into a modern technology park and residential area, and to Rombergpark, a botanical garden in the southern part of Dortmund.

Prof. Paulo Martins (Portugal), Robin Gitschel (IUL), Elizabeth Mamros (USA), Clémence Pinot (France), Antoine de Percin (France), Dr. Ramona Hölker-Jäger (IUL) and Prof. A. Erman Tekkaya (IUL) (from left to right)

Technical Equipment

05

5 Technical Equipment

Presses

- Adiabatic blanking machine, 1 kJ, AdiaClip by MPM Émalec
- Blanking and forming press with servo drive, 4000 kN, MSD2-400 by Schuler
- C-frame eccentric press, 630 kN, PDR 63/250 by Schuler
- Extrusion press, 10 MN (direct), suitable for curved profile extrusion by SMS Meer
- Extrusion press, 2.5 MN, LPA 250 t by Collin
- Hydraulic drawing press, 10 MN triple action, M+W BZE 1000-30.1.1 by Müller-Weingarten
- Hydraulic drawing press, 1000 kN, HPSZK 100-1000/650 by HYDRAP
- Hydraulic drawing press, 2600 kN, triple action, HZPUI 260/160-1000/1000 by SMG

Further Forming Machines

- 5-Axis-milling machine, DMU 50 by DMG MORI
- CNC rotary draw bending machine, DB 2060-CNC-SE-F by Transfluid Maschinenbau
- Hydraulic punching machine, 220 kN, TruPunch 5000 by Trumpf
- Machine for electromagnetic forming, 1.5 kJ, PPT SMU 1500 (recuperationable), self-built at IUL
- Machine for electromagnetic forming, 32 kJ, Magneform 7000 by Maxwell
- Machine for electromagnetic forming, 6 kJ, SMU 0612 FS by Poynting
- Machine for incremental profile forming, self-built at IUL
- Machine for incremental tube forming, IRU2590 by Transfluid Maschinenbau
- Multi-axes forming press, five axes of motion up to 100 kN, prototype by Schnupp
- Press brake, 1300 kN, TrumaBend V 1300X by Trumpf
- Profile bending machine with stress superposition by rolling, self-built at IUL
- Roll forming machine RAS 24.10 by Reinhardt Maschinenbau

- Rolling Mill with two work rolls, BW 200 by Mühlacker
- Spinning machine, APED 350NC by Leifeld
- Spring coiling machine, FUL42 by Wafios
- Swivel bending machine, FASTI 2095 by FASTI
- Three-roller-bending machine, RZM 108-10/5.5 by FASTI
- TSS-3D Profile bending machine, self-built at IUL

Additive Manufacturing Machines

- Combined 5-axis machining and laser deposition welding center, Lasertec 65 3D by Sauer/DMG MORI
- FDM-based 3D printers for thermoplastic materials (2x Ultimaker 3, 1x Ultimaker 3 Extended, 1x Creality Ender 5)
- Powder bed machine for additive manufacturing, Lasertec 30 SLM by DMG MORI

Material Testing Machines

- In-plane torsion test setup, self-built at IUL
- Plastometer, 1 MN, self-built at IUL
- Roughness Tester, Marsurf XR1 and GD26 by Mahr
- Servo-hydraulic testing machine with HT-resistance heating system up to 1200 °C and protective gas vacuum chamber, LFV-100-HH by Water + Bai
- Sheet metal testing machine, 1000 kN, BUP1000 by ZwickRoell
- Sheet metal testing machine, 200 kN, 142/20 by Erichsen
- Universal testing machines (1x 10 kN Erichsen, 1x 100 kN ZwickRoell, 4x 250 kN ZwickRoell)

Measurement Technique and Electronics

- 2D Laser Position Sensor, scanCONTROL 3012-50/BL by Micro-Epsilon
- 3D-coordinate measurement machine, PRISMO VAST 5 HTG by Zeiss (in cooperation with the Institute of Machining Technology, TU Dortmund University)
- 3D-Profilometer, VR-5200 by Keyence
- 3D-video measuring system, A250 by Optomess
- 3MA-II measurement system by Fraunhofer IZFP

- Density measurement system, IMETER V6 by MSB Breitwieser MessSysteme
- Digital oscilloscopes with 4 channels (HDO6104A and Waverunner 104 MX by LeCroy, TDS420A by Tektronix)
- Hardness tester, Diatestor 2 RC/S by Wolpert
- Infrared Camera, Infratec VarioCam HD head 680 S by Infratec
- Infrared measuring device, PYROSKOP 273 C
- Large volume SEM, Mira XI by Visitec (in cooperation with the Institute of Machining Technology and the Lehrstuhl für Werkstofftechnologie, TU Dortmund University)
- Laser extensometer for universal testing machines, laserXtens 2-120 HP/TZ by ZwickRoell
- Laser-based Photon-Doppler Velocimeter for the measurement of high workpiece velocities
- Laser Surface Velocimeter for non-contact velocity measurement
- Light optical microscope, adapted for polarization, Axio Imager.M1m by Zeiss
- Optical 3D deformation analysis: 4x ARAMIS (2x 5M + 1x 4M + 1x 2M) and 1x ARGUS by GOM
- Optical 3D digitizer: 2x ATOS Triple Scan and 1x TRITOP by GOM
- Optical 3D motion analysis, 1x PONTOS 4M by GOM
- Optical frequency domain reflectometer, space- and time-resolved measurement of temperature and strain, ODiSI-B10 by Polytec
- Pressure Measurement System using thin film tactile pressure sensors, I-Scan System by Tekscan
- Pyrometer, Near infrared and multi-wavelength, 3 pc. (Metis M308, Metis M316 and Metis M318) by Sensortherm
- Residual stress measurement by means of hole drilling technique and Electronic Speckle Pattern Interferometry (ESPI), Prism by Stresstech
- Residual stress measurement by means of hole drilling technique and strain gauge measurement, Milling Guide RS-200 by Micro-Measurements
- Tabletop SEM-EDX: Coxem EM-30 PLUS by RJL Micro & Analytic
- Thermal imaging camera, thermoIMAGER TIM M-1 by Micro- Epsilon
- Thickness measuring device, CL 304 by Krautkrämer
- Ultrasonic Thickness Sensor, 38DLPLus by Olympus
- X-ray diffractometer for measuring residual stresses, Xstress 3000 by Stresstech

Miscellaneous

- Belt grinding machine, PB-1200-100S by Baier
- CNC turning machine, NEF 400 by DMG MORI
- DC-Power Supply, LAB/HP 4020 by ET-System
- Electrolytic polishing and etching machine, Kristall 650 by Stresstech
- Encapsulated postprocessing cabin for additive manufactured parts, ENESKApostpro by joke Technology
- Etching and polishing station, LectoPol-5 by Struers
- High-frequency generator, 10 kW, Axio 10/450 by Hüttinger
- High-performance metal circular saw, AL 380 by Häberle
- Hydraulic power units and pressure intensifiers up to 4000 bar (3x)
- Hydrostatic roller burnishing tools, HG13 and HG6 by Ecoroll
- Industrial robots, 3x 6-axes robot (KR 5 sixx R650, KR 90 R3700 prime K and KR 30-3) by KUKA
- Laser processing center, LASERCELL TLC 1005 by Trumpf
- Measuring rack, HP-4-2082 by Boxdorf
- Medium-frequency generator, 40 kW with coax transformer, TruHeat 3040 und 7040 by Trumpf
- Mitring band sawing machines, HBS 265 DG by Klaeger
- Roll seam welding machine, UN 63 pn by Elektro-Schweißtechnik Dresden
- Several machines for machining purposes
- Tabletop cut-off machine Discotom-100 by Struers (in cooperation with the Institute of Machining Technology, TU Dortmund University)
- Tensile testing punch press, 1200 kN, ZS1200CN by Schütz + Licht
- Tensile test specimen grinder, PSM 2000 by Schütz + Licht

Kooperationen | Cooperations

06

Kooperationen | Cooperations

Auf diesem Wege möchten wir uns für die vielfältige Zusammenarbeit im Jahr 2021 bedanken, ohne die unser gemeinsamer Erfolg nicht möglich wäre.

At this point we would like to express our gratitude to the large number of various cooperation partners in 2021 which have added to our joint success.

Industriebeirat des IUL | IUL Industrial Advisory Board

Das Gremium des Industriebeirates vermittelte auch im Jahr 2021 wichtige Impulse hinsichtlich des industriellen Forschungsbedarfes. An dieser Stelle möchten wir uns für diese wertvolle Zusammenarbeit bedanken.

In 2021, the Industrial Advisory Council provided yet again significant input regarding the need for research from an industrial point of view. We would like to take this opportunity to express our gratitude for this valuable cooperation.

- Gerhard Bürstner, Ing.-Büro Gerhard Bürstner
- Marius Fedler, Kunststoff-Institut für die mittelständische Wirtschaft NRW GmbH
- Dr. Frank O. R. Fischer, Forschungsinstitut für Anorganische Werkstoffe – Glas/Keramik
- Patrick Großhaus, Egon Grosshaus GmbH & Co. KG
- Rainer Hank, TRUMPF Werkzeugmaschinen GmbH & Co. KG
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- Wolfgang Heidrich, Aluminium Deutschland e. V.
- Jörg Höppner, Verband Metallverpackungen e. V.
- Dr. Stefan Keller, Speira GmbH
- Dr. Lutz Keßler, ThyssenKrupp Steel Europe AG
- Dr. Lukas Kwiatkowski, Otto Fuchs KG
- Prof. Gideon Levy, TTA – Technology Turn Around
- Hans Mulder, Tata Steel Research & Development Product Application Centre
- Franz-Bernd Pauli, Franz Pauli GmbH & Co. KG
- Rainer Salomon, Forschungsvereinigung Stahlanwendung e. V. (FOSTA)
- Dr. Hendrik Schafstall, simufact engineering GmbH
- Dr. Eduard Schenuit, Zwick GmbH & Co. KG
- Prof. Karl Schweizerhof, DYNAmore GmbH
- Dr. Hosen Sulaiman, Faurecia Autositze GmbH
- Mario Syhre, GKN Driveline Deutschland GmbH
- Adolf Edler von Graeve, KIST Kompetenz- und Innovationszentrum für die StanzTechnologie Dortmund e. V.
- Patrick Vonmüllenen, Feintool Technologie AG

Universitäre Kooperationen auf nationaler Ebene | University cooperations at national level

- Fachgebiet Metallische Werkstoffe, Institut für Werkstoffwissenschaften und -technologien, Technische Universität Berlin
- Fachgebiet Werkstoffprüftechnik, Technische Universität Dortmund
- Fachhochschule Südwestfalen
- Gemeinschaftslabor für Elektronenmikroskopie, Rheinisch-Westfälische Technische Hochschule Aachen
- Institut für Angewandte Materialien – Werkstoffkunde, Karlsruher Institut für Technologie (KIT)
- Institut für Bildsame Formgebung, Rheinisch-Westfälische Technische Hochschule Aachen
- Institut für Eisenhüttenkunde, Lehr- und Forschungsgebiet für Werkstoff- und Bauteilintegrität, Rheinisch-Westfälische Technische Hochschule Aachen
- Institut für Kunststoffverarbeitung, Rheinisch-Westfälische Technische Hochschule Aachen
- Institut für Mechanik der Bauwissenschaften, Universität Duisburg-Essen
- Institut für Mechanik, Technische Universität Dortmund
- Institut für Produktionstechnik und Umformmaschinen, Technische Universität Darmstadt
- Institut für Umformtechnik, Universität Stuttgart
- Institut für Werkzeugmaschinen und Fabrikbetrieb, Technische Universität Berlin
- Laboratorium für Werkstoff- und Fügetechnik, Universität Paderborn
- Lehrgebiet Konstruktions- und Fertigungstechnik, Hochschule Hamm-Lippstadt
- Lehrstuhl Baumechanik, Technische Universität Dortmund
- Lehrstuhl Fertigungstechnik, Universität Duisburg-Essen
- Lehrstuhl für Konstruktion und Fertigung, Brandenburgische Technische Universität Cottbus-Senftenberg
- Lehrstuhl für Umformtechnik und Gießereiwesen, Technische Universität München
- Lehrstuhl für Umformtechnik, Universität Siegen
- Lehrstuhl für Werkstofftechnologie, Technische Universität Dortmund
- Lehrstuhl Hybrid Additive Manufacturing, Ruhr-Universität Bochum
- Max-Planck-Institut für Eisenforschung GmbH, Düsseldorf
- Professur für Baumechanik, Universität der Bundeswehr München
- Professur für Theoretische Elektrotechnik und Numerische Feldberechnung, Helmut-Schmidt-Universität, Universität der Bundeswehr Hamburg
- Professur Virtuelle Fertigungstechnik, Technische Universität Chemnitz
- Professur Werkstoffwissenschaft, Technische Universität Chemnitz

- wbk Institut für Produktionstechnik, Karlsruher Institut für Technologie
- Werkzeugmaschinenlabor, Rheinisch-Westfälische Technische Hochschule Aachen

Universitäre Kooperationen auf internationaler Ebene | University cooperations at international level

- Department of Materials Science and Engineering, The Ohio State University, Ohio, USA
- Department of Mechanical Engineering, Gifu University, Gifu, Japan
- Department of Mechanical Engineering, Instituto Superior Técnico, University of Lisbon, Portugal
- Department of Mechanical Engineering, Section of Manufacturing Engineering, Technical University of Denmark, Lyngby, Denmark
- Department of Mechanical Engineering, University of New Hampshire, New Hampshire, USA
- Department of Mechanical Science and Engineering, Hiroshima University, Higashi-Hiroshima, Japan
- École Nationale Supérieure d‘Arts et Métiers (ENSAM), ParisTech, Paris, France
- George W. Woodruff School of Mechanical Engineering, Georgia Tech, Georgia, USA
- Institut de Chimie et des Matériaux Paris-Est, Paris, France
- KAIST – Korea Advanced Institute of Science and Technology, Daejeon, Republic of Korea
- Laboratory of Microstructure Studies and Mechanics of Materials, Arts et Métiers ParisTech (Metz campus), France
- Mechanical Engineering College of Tongji University, Jiading Campus, Shanghai, China
- Nagoya University, Nagoya, Japan
- School of Mechatronics Engineering, Harbin Institute of Technology, Harbin, Heilongjiang, China
- Türkisch-Deutsche Universität, Istanbul, Turkey

Nationale und internationale Kooperationen im industriellen Umfeld | Industrial cooperations at national and international level

- Airbus Helicopters
- Alfred Konrad Veith GmbH & Co. KG
- alutec metal innovations GmbH & Co. KG
- apt Extrusions GmbH & Co. KG
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- Benteler International AG
- Bilstein GmbH & Co. KG
- BMW AG
- BÖHLER-UDDEHOLM Deutschland GmbH
- borit Leichtbau-Technik GmbH
- CARL BECHEM GMBH
- CENIT AG
- Centroplast Engineering Plastics GmbH
- C-TEC Constellium Technology Center
- Daimler AG
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- Deutsche Edelstahlwerke Specialty Steel GmbH & Co. KG
- DYNAmore GmbH
- ElringKlinger AG
- F. W. Brökelmann Aluminiumwerk GmbH & Co. KG
- Faurecia Group
- Festo SE & Co. KG
- FLORA Wilh. Förster GmbH & Co. KG
- Franz Pauli GmbH & Co. KG
- Freudenberg Sealing Technologies GmbH & Co. KG
- FRIMO Group GmbH Composites & Tooling Technologies
- Gebr. Wielpütz GmbH & Co. KG
- Gerhardi AluTechnik GmbH
- Goekeler Messtechnik GmbH
- GSU Schulungsgesellschaft für Stanz- und Umformtechnik mbH
- HAI Extrusion Germany GmbH
- Heggemann AG
- HELLA GmbH & Co. KGaA
- HMT Höfer Metall Technik GmbH & Co. KG
- HoDforming GmbH
- HUECK Extrusion GmbH & Co. KG
- Hydro Aluminium Deutschland GmbH
- inpro Innovationsgesellschaft für fortgeschrittene Produktionssysteme in der Fahrzeugindustrie mbH
- Johnson Controls Hilchenbach GmbH
- Kirchhoff Automotive GmbH

- Kistler Instrumente AG
- KODA Stanz- und Biegetechnik GmbH
- Kunststoff-Institut Lüdenscheid (KIMW GmbH)
- MATFEM Partnerschaft Dr. Gese & Oberhofer
- MK Metallfolien GmbH
- Mubea Unternehmensgruppe
- NETZSCH – Pumpen & Systeme GmbH
- Otto Fuchs KG
- Outokumpu Nirosta GmbH
- Poynting GmbH
- PWF Aerospace GmbH
- S+C Extrusion Tooling Solutions GmbH
- Salzgitter Mannesmann Forschung GmbH
- Salzgitter Mannesmann Precision Tubes GmbH
- Schnupp GmbH & Co. Hydraulik KG
- Schondelmaier GmbH Presswerk
- Schuler AG
- Schwarze-Robitec GmbH
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- SMS Meer GmbH
- SSAB Svenskt Stål AB
- Steitz Präzisionstechnik GmbH
- STURM GmbH
- Tata Steel
- thyssenkrupp Federn und Stabilisatoren GmbH
- thyssenkrupp Rasselstein GmbH
- thyssenkrupp Steel Europe AG
- TM Lasertechnik GmbH
- transfluid Maschinenbau GmbH
- Trimet Aluminium SE
- TRUMPF Hüttinger GmbH + Co. KG
- TRUMPF Werkzeugmaschinen GmbH + Co. KG
- Viessmann Werke GmbH & Co. KG
- voestalpine AG
- voestalpine High Performance Metals Deutschland GmbH
- Vossloh AG
- wefa Westdeutsche Farben GmbH
- Welser Profile Deutschland GmbH
- Wilke Werkzeugbau GmbH & Co. KG
- WILO SE
- Zapp Precision Metals GmbH
- ZWEZ – CHEMIE GmbH

In addition, several companies with disclosure agreements.

Verbände | Associations

- acatech – Deutsche Akademie der Technikwissenschaften e. V.
- AGU – Arbeitsgemeinschaft Umformtechnik
- AiF Arbeitsgemeinschaft industrieller Forschungsvereinigungen „Otto von Guericke“ e. V.
- Aluminium Deutschland e. V.
- Aluminium-Leichtbaunetzwerk
- ASM International
- CIRP – The International Academy for Production Engineering
- DAAD – Deutscher Akademischer Austauschdienst e. V.
- DFG – Deutsche Forschungsgemeinschaft
- DGM – Deutsche Gesellschaft für Materialkunde e. V.
- EFB – Europäische Forschungsgesellschaft für Blechverarbeitung e. V.
- FGM – Fördergesellschaft Metallverpackungen mbH
- FOSTA – Forschungsvereinigung Stahlanwendung e. V.
- FSV – Forschungsgesellschaft Stahlverformung e. V.
- GCFG – German Cold Forging Group e. V.
- I^2FG – International Impulse Forming Group e. V.
- IBU – Industrieverband Blechumformung e. V.
- ICFG – International Cold Forging Group
- IDDRG – International Deep Drawing Research Group
- IMU – Industrieverband Massivumformung e. V.
- ITA – International Tube Association
- VDFI – Verband der deutschen Federnindustrie e. V.

Stiftungen | Foundations

- KARL-KOLLE-Stiftung
- Stifterverband Metalle e. V.
- VolkswagenStiftung
- Wilo-Foundation

Abgeschlossene Arbeiten | Completed Theses

07

Abgeschlossene Masterarbeiten[1] | Completed Master of Science Theses[2]

Adams, Tom
Tekkaya, A. E.; Kamaliev, M.
Anwendungsorientierte Charakterisierung von Chromstählen für die Warmumformung
Application-oriented characterization of chromium steels for hot forming

Bosse, Gerrit
Tekkaya, A. E.; Kamaliev, M.
Bestimmung der Grenzformänderungsdiagramme nichtrostender Stahlrohre bei erhöhten Temperaturen
Determination of forming limit diagrams of stainless steel tubes at elevated temperatures

Bürstner, Fabio M.
Tekkaya, A. E.; Traphöner, H.
Analyse und Weiterentwicklung des ebenen Torsionsversuchs mit resistiver Probenerwärmung
Analysis and improvement of the in-plane torsion test with resistive specimen heating

Frigge, Alexander D.
Tekkaya, A. E.; Rosenthal, S.
Beurteilung der mechanischen Leistungsfähigkeit additiv hergestellter Sandwichstrukturen
Mechanical performance of additively manufactured sandwich structures

Gerlach, Jan
Tekkaya, A. E.; Schowtjak, A.
Vorhersage der Schädigungsevolution mittels künstlicher neuronaler Netzwerke
Prediction of damage evolution using artificial neural networks

Ghattamaneni, Manish C.
Tekkaya, A. E.; Hahn, M.
Untersuchung des Aufprall-Lichtblitzes bei der Verschweißung zweier metallischer Bauteile mittels elektromagnetischer Umformung unter Berücksichtigung verschiedener Parameter des Fügeaufbaus
Investigation of impact light flash during welding of two metallic components by means of electromagnetic forming for different process parameters

Guajardo Araluce, Roberto
Sehrt, J. T. (RUB); Komodromos, A.
Untersuchung einer pyrometerbasierten Temperaturregelung beim Laserpulverauftragsschweißen von Ti-6Al-4V
Investigation of pyrometer-based temperature control in directed energy deposition processing of Ti-6Al-4V

1 Originaltitel ist fett gedruckt.
2 Original title written in bold.

Hassan, Kardo
Tekkaya, A. E.; Grodotzki, J.
Performancevergleich additiv und umformtechnisch gefertigter Bauteile mit topologieoptimierter Zwischenform
Performance-focused comparison of parts manufactured using additive and forming technologies including topology-optimized intermediate configurations

Hennes, Julian
Tekkaya, A. E.; Rosenthal, S.
Herstellung hybrider Sandwichblechverbunde mit additiv gefertigtem Kern mittels Widerstandsschweißen
Manufacturing of hybrid sandwich sheets with additively manufactured core by resistance welding

Hübers, Mathias
Tekkaya, A. E.; Hoffmann, E.
Experimentelle Charakterisierung des Biegens von asymmetrischen Profilen bei halbwarmer, partieller Querschnittserwärmung
Experimental characterization of bending of asymmetric profiles with semi-hot, partial cross-sectional heating

Kaya, Deniz
Tekkaya, A. E.; Gutknecht, F.
Entwicklung eines Werkzeuges zur Erzeugung eines senkrechten Dehnpfadwechsels in der Blechmassivumformung
Development of a tool for the generation of an orthogonal strain-path change in sheet-bulk metal forming

Kilicaslan, Baki
Tekkaya, A. E.; Traphöner, H.
Bewertung von Kompensationsstrategien zur Reduzierung des Rücksprungverhaltens beim Umformen ultrahochfester Mehrphasenstähle
Evaluation of compensation strategies to reduce springback behavior when forming ultra-high-strength multi-phase steels

Kleinhorst, Lars
Tekkaya, A. E.; Maaß, F.
Analyse von Eigenspannungen in Bauteilen hergestellt durch zuspannungsüberlagerte inkrementelle Blechumformung
Residual stress analysis of tensile stress-superposed incrementally formed components

Kupka, Nick A.
Tekkaya, A. E.; Rosenthal, S.
Untersuchung elektro-plastischer Effekte bei der kontinuierlichen Ausformung von Funktionselementen durch inkrementelle Blechmassivumformung
Investigation on electro-plastic effects during continuous forming of functional elements by plate forging

Miederhoff, Phil
Tekkaya, A. E.; Komodromos, A.
Analytische und numerische Untersuchungen additiv gefertigter und glattgewalzter Werkzeugoberflächen für das Presshärten
Analytical and numerical investigations of additively manufactured and ball-burnished tool surfaces for hot stamping

Mohanasundararaju, Veerendra K.
Tekkaya, A. E.; Hahn, M.
Entwicklung und Analyse von Aufbau und Vorgehensweise für dünne Werkzeuge mit einer Abstützung durch scherverzähende Fluide in der Hochgeschwindigkeitsumformung
Development and analysis of a testing device and procedure for thin tools backed by a shear thickening fluid in high speed forming

Najafi Koopas, Rasoul
Tekkaya, A. E.; Schmitz, F.
Untersuchung der Beeinflussung mechanischer Eigenschaften durch die mechanische Bearbeitung an Bauteiloberflächen mittels mikromechanischer Simulationen
Investigation of the influence of mechanical properties due to mechanical processing at component surfaces using micro-mechanical simulations

Orejarena Osorio, Nicolás
Tekkaya, A. E.; Dardaei Joghan, H.
Bewertung verschiedener Strategien zur Reduzierung des Treppenstufeneffekts bei laminierten Bauteilen durch koaxiales Laserpulverauftragschweißen
Evaluation of different strategies for reducing the staircase effect of laminated parts by coaxial laser powder deposition

Osmanoglu, Emre
Tekkaya, A. E.; Gitschel, R.
Heißschmiedesimulation eines Bauteils aus 304L
Hot forging process simulation of a part made of 304L

Paßmann, Lukas
Tekkaya, A. E.; Kamaliev, M.
Numerische Modellierung des Temperaturgestützten-Innenhochdruck-Profilumformens
Numerical modeling of temperature-assisted profile forming

Pavani, Monica
Tekkaya, A. E.; Goyal, S.
Numerische und experimentelle Analyse der elektromagnetischen Eckenumformung mit Hybridleitern
Numerical and experimental analysis of electromagnetic corner forming using hybrid conductors

Reihani Masouleh, Alborz
Tekkaya, A. E.; Stennei, M.
Analyse der Prozessgrenzen neuer Werkstoff- und Bauteilkonzepte für das Presshärten
Analysis of the process limits of new material and component concepts for press hardening

Rethmann, Philipp
Tekkaya, A. E.; Martschin, J.
Untersuchung des Streckbiegens und Tiefziehens mit Wärmebehandlung zur Herstellung von Hutprofilen aus X46Cr13 in mehrstufigen Werkzeugen
Investigation of stretch bending and deep drawing with heat treatment for the production of hat-shaped profiles from X46Cr13 in multi-stage tools

Sauerwald. Philipp
Tekkaya, A. E.; Maaß, F.
Analyse von Eigenspannungen in Bauteilen hergestellt durch zuspannungsüberlagerte inkrementelle Blechumformung
Residual stress analysis of tensile stress-superposed incrementally formed components

Singethan, Norman
Tekkaya, A. E.; Lennemann, P.
Charakterisierung des Kaltbiegeverhaltens vorvergüteter Rohre
Characterization of a cold bending process of pre-hardened tubes

Stücka, Roman Y.
Tekkaya, A. E.; Komodromos, A.
Untersuchung additiv gefertigter Kühlkanäle in Presshärtewerkzeugen
Investigation of additively manufactured cooling channels in hot stamping tools

Umesh, Shravana
Tekkaya, A. E.; Wernicke, S.
Entwicklung und Analyse von Kühlkanälen in Umformwerkzeugen für die Blechmassivumformung von Zahnstangen
Development and analysis of cooling channels within the forming tools in the plate forging of a gear rack

Wigger, Henrik
Tekkaya, A. E.; Rosenthal, S.
Entwicklung eines formschlüssigen Fügeverfahrens zur Herstellung von hybriden Sandwichverbundbauteilen
Development of a joining-by-forming process to manufacture hybrid sandwich sheets

Winoto, Bill F.
Tekkaya, A. E.; Dardaei Joghan, H.
Entwicklung eines semi-analytischen Modells für laminierte Umformwerkzeuge unter Prozessbelastungen
Development of semi-analytical model for laminated forming tools under process forces

Abgeschlossene Bachelorarbeiten | Completed Bachelor of Science Theses

Beckmann, Simon
Tekkaya, A. E.; Gitschel, R.
Anwendbarkeit von konventionellen Wärmebehandlungsstrategien beim Verbundfließpressen
Applicability of conventional heat treatment strategies in composite cold extrusion

Cakan, Berkan
Tekkaya, A. E.; Schowtjak, A.
Analyse von Porencharakteristika auf die effektiven Materialeigenschaften
Analysis of void characteristics on the effective material behaviour

Caspari, Fabian
Tekkaya, A. E.; Kotzyba, P.
Untersuchung des Verbundstrangpressens mit Verstärkungselementen unter der Verwendung von Aluminiumwerkstoffen
Investigation of composite hot extrusion with reinforcements using aluminum materials

Damm, Jannis
Tekkaya, A. E.; Stiebert, F.
Analyse des Einflusses der Fertigungstoleranzen von Nutproben auf die Prüfergebnisse im ebenen Torsionsversuch
Analysis of the influence of manufacturing tolerances of grooved specimens on test results in the in-plane torsion test

Dobrowolski, Fabian
Tekkaya, A. E.; Komodromos, A.
Einfluss einer erweiterten Reibungsmodellierung beim direkten Presshärten
Effect of an advanced friction modeling for direct hot stamping

Eisenbach, Moritz; Gersting, Marlin
Tekkaya, A. E.; Schowtjak, A.
Prozessoptimierung in der Umformtechnik basierend auf künstlichen neuronalen Netzen mit Anwendung auf die Schädigung beim Rollformen
Process optimization in metal forming based on artificial neural networks with application to damage analysis in roll forming

Engels, Luca
Tekkaya, A. E.; Kolpak, F.
Fließkurvenermittlung mittels fließgepresster Blechproben
Determination of flow curves by utilization of cold extruded sheet metal specimens

Ewering, Felix
Tekkaya, A. E.; Lennemann, P.
Rollierplattieren – Herstellung von Verbundrohren durch temperaturgestütztes Rollieren
Flow-forming-plating – Manufacturing of composite tubes by temperature-assisted flow-forming

Gerlach, Torben
Tekkaya, A. E.; Gitschel, R.
Prozessgrenzen beim Fließpressen einer Stahl-Magnesium-Verbundwelle
Process limits in cold extrusion of steel-magnesium composite shafts

Hainmann, Till S.
Tekkaya, A. E.; Wernicke, S.
Emissionsanalyse einer industriellen Prozesskette zur Warmumformung von Blechteilen
Analysis of emissions in an industrial hot forming process chain for the manufacture of sheet metal components

Hamm, Jakob
Tekkaya, A. E.; Dardaei, H.
Untersuchung und Beurteilung der Strategien zur Verbindung lamellarer Stahlbauteile durch einzelne Schweißnähte mittels Laserpulverauftragschweißen
Investigation and evaluation of strategies for joining laminated steel parts by single welds using laser powder cladding

Kasperek, Fabian O.
Tekkaya, A. E.; Gebhard, J.
Untersuchung und Konstruktion eines Modells zum Kontinuierlichen Strangpressen
Investigation and design of a model for continuous bar extrusion

Olgar, Cem
Tekkaya, A. E.; Rosenthal, S.
Materialcharakterisierung additiv hergestellter Halbzeuge aus Edelstahl - Untersuchung der Skaleneffekte
Material characterization of additively manufactured parts made from stainless steel – investigation of scale effects

Pantel, Nils
Tekkaya, A. E.; Wernicke, S.
Steigerung der Energieeffizienz beim Blechmassiv-Warmumformen eines Zahnprofils mittels numerischer Prozessanalyse
Enhancement of the energy efficiency in sheet-bulk hot forming of a gear profile based on numerical process analysis

Wimmelmeier, Felix
Tekkaya, A. E.; Rosenthal, S.
Tiefziehen additiv gefertigter Sandwichbleche mit strukturierten Kernen
Deep drawing of additively manufactured sandwich sheets with a structured core

Abgeschlossene Projektarbeiten | Completed Project Theses

Azadi Tinat, Mohammad R.
Tekkaya, A. E.; Schmitz, F.
Simulation des adiabatischen Trennens mit SPH (Smooth particle hydrodynamics)
Simulation of adiabatic blanking with smooth particle hydrodynamic

Beckmann, Simon
Tekkaya, A. E.; Kolpak, F.
Herstellung hohler Wellen durch Verbundfließpressen mit verlorenem Kern
Production of hollow shafts by composite extrusion with lost core

Hainmann, Till
Tekkaya, A. E.; Maaß, F.
Einrichtung eines Versuchsaufbaus zur Zugspannungsüberlagerung in der inkrementellen Blechumformung
Experimental setup for tensile stress-superposed incremental forming

Hojenski, Christian
Tekkaya, A. E.; Komodromos, A.
Analyse des Reibverhaltens additiv gefertigter und glattgewalzter Oberflächen für Presshärtewerkzeuge
Analysis of the friction behavior of additively manufactured and ball-burnished surfaces for hot stamping tools

Lashkari, Mohammedjavad
Tekkaya, A. E.; Goyal, S.
Studie über den Fließdruck bei der elektromagnetischen Impuls-Eckenfüllung
Study of the yield pressure in electromagnetic impulse corner filling

Marin, Gabriel
Tekkaya, A. E.; Komodromos, A.
Analyse der Eigenspannungen von durch Laserpulverauftragsschweißen und Glattwalzen hergestellten Werkzeugstahl-Oberflächen
Analysis of residual stresses of tool steel surfaces manufactured by direct energy deposition and ball burnishing

Najafi Koopas, Rasoul
Tekkaya, A. E.; Clausmeyer, T.
Experimentelle Untersuchung und numerische Simulation der Wärmebehandlung ultradünner Streifen mit der Finite-Element-Methode
Experimental investigation and numerical simulation of ultrathin strip heat treatment using the finite element method

Neshanth, Paskaran; Reese, Niklas
Tekkaya, A. E.; Dardaei Joghan, H.
Erstellung einer Berechnungsmethode für die produktionstechnische Bewertung von Fertigungskombinationen mit Schicht-Laminat-Verfahren und Laserpulverauftragschweißen
Development of a calculation method for the production-technical evaluation of manufacturing combinations with metal layer laminate processes and laser powder cladding

Ogunsolu, Oluseyi
Tekkaya, A. E.; Goyal, S.
Numerischer Ansatz zur Optimierung von Hybridleitern bei der elektromagnetischen Umformung
Numerical approach for optimization of hybrid conductors in electromagnetic forming

Olgar, Cem
Tekkaya, A. E.; Rosenthal, S.
Materialcharakterisierung additiv hergestellter Halbzeuge aus 316L
Material characterization of additively manufactured 316L parts

Orejarena Osorio, Nicolás
Tekkaya, A. E.; Grodotzki, J.
Tiefzieh- und Gesenkschmiedesimulationen in Abaqus
Deep drawing and closed die forging simulation in Abaqus

Pavani, Monica
Tekkaya, A. E.; Goyal, S.
Design einer montagebasierten Spule für die Eckenfüllung mit elektromagnetischer Umformung
Design of assembly-based coil for corner filling using electromagnetic forming

Schrage, Olaf
Tekkaya, A. E.; Martschin, J.
Untersuchung des Warmkragenziehens von X46Cr13 Blechmaterial
Investigation of hot hole-flanging of X46Cr13 sheet material

Sureshkumar, Pushkaran
Tekkaya, A. E.; Martschin, J.
Numerische Untersuchung des Warmkragenziehens von X46Cr13-Blechmaterial in einem Folgeverbundwerkzeug
Numerical study of hot-hole flanging of X46Cr13 sheet material in a progressive die

Sundarajan, Praveen K.
Tekkaya, A. E.; Martschin, J.
Numerische Modellierung des Presshärtens von X46Cr13-Blechmateria
Numerical modeling of press hardening of X46Cr13 sheet

Wimmelmeier, Felix
Tekkaya, A. E.; Rosenthal, S.

Konstruktion von einem modularen Werkzeugsatz für die Umformung von Sandwichblechen

Construction of a modular tool for forming of sandwich sheets

Ausgewählte Veröffentlichungen und Vorträge | Selected Publications and Lectures

08

Zeitschriftenbeiträge | For SCI-Journals

Gutknecht, F., Traphöner, H., Clausmeyer, T., Tekkaya, A. E., 2021. Characterization of Flow Induced Anisotropy in Sheet Metal at Large Strain. Experimental Mechanics, DOI: 10.1007/s11340-021-00776-9.

Hahn, M., Tekkaya, A. E., 2021. Part-Optimized Forming by Spatially Distributed Vaporizing Foil Actuators. International Journal of Material Forming 14 (6), pp. 1391-1401.

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Kolpak, F., Hering, O., Tekkaya, A. E., 2021. Consequences of Large Strain Anisotropic Work-hardening in Cold Forging. International Journal of Material Forming 14, pp. 1463-1481.

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