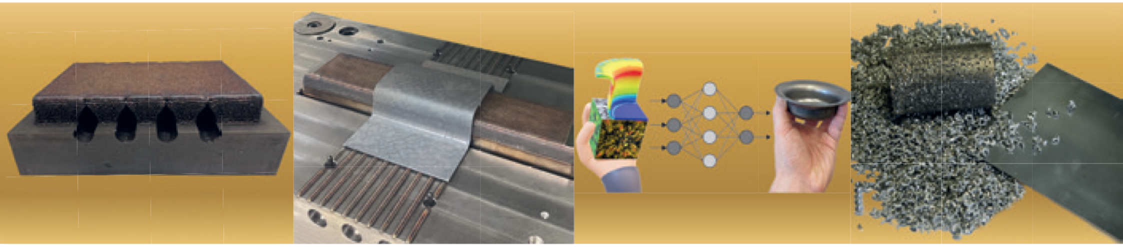

50 Jahre IUL
Dortmunder Umformtechnik

Activity Report 22

technische universität
dortmund

Institute of
Forming Technology and
Lightweight Components

Activity Report

22

technische universität
dortmund

Imprint

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Figure 3:
Machine learning, augmented reality

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Preface

Dear readers,

This year we celebrated our 50th anniversary! On September 8, 2022, we were able to honor 50 years of "Dortmunder Umformtechnik" with a scientific colloquium with internationally renowned scientists and other guests. Professors Zhigang Wang (Gifu University, Japan), Peter Groche (TU Darmstadt, Germany), Frederic Barlat (Pohang University, South Korea), Glenn Daehn (The Ohio State University, USA), Dirk Mohr (ETH Zurich, Switzerland) as well as Erman Tekkaya (TU Dortmund, Germany) contributed exciting topics with their presentations according to the IUL-typical motto "Innovation & Impulses". The highlight of the subsequent dinner that day was the presentation of a beautiful bell from the company Feintool (Switzerland) in recognition of the many years of good cooperation. The second day of the festivities on September 9 began with a bicycle tour through beautiful Dortmund with a stop at the company ThyssenKrupp Rothe Erde Germany GmbH. In the afternoon, IUL alumni shared their retrospective views on three eras of metal forming in Dortmund. The State Secretary of the Ministry of Culture and Science of the State of North Rhine-Westphalia, Ms. Gonca Türkeli-Dehnert, the Rector of TU Dortmund University, Prof. Manfred Bayer, the Dean of the Faculty of Mechanical Engineering, Prof. Jörn Mosler, the Chairman of the AGU, Prof. Mathias Liewald, the Spokesman of the DFG's Review Board for Production Engineering, Prof. Wolfram Volk, and the Chairman of FOSTA, Mr. Jürgen Alex, paid tribute to Dortmund's forming technology in their addresses. My colleague Prof. Matthias Kleiner was given a solemn farewell celebrating his retirement. The evening event, which was attended by numerous alumni as well as research partners from industry and academia, showed just how large the "Dortmunder Umformtechnik" family is.

Mr. Vonmüllenen (Feintool, Switzerland) presenting the IUL bell

After the Corona pandemic hit our daily lives in February 2020, we were all happy to see it turn into an epidemic after two years at the end of 2022. However, we were shocked by the Russian invasion of Ukraine on February 24, 2022. Although the war is unfortunately not over yet, lasting changes caused by this cruel war can already be seen. Economically, deglobalization will pose great challenges to our manufacturing technology. Research-wise, this will require major efforts to reduce costs through even more extensive automation and smarter manufacturing processes, but it will also require innovation down to the smallest operations. For these innovations, we will increasingly make our contribution available to industry through science-based forming technology. This war has also increased the drive for sustainable, low-energy manufacturing. Finally, we will have to rethink and consider the manufacturing of components for the safety and defense industry.

While we have almost reached the end of the Corona pandemic, the effects of this disaster also continue. We were all privileged to discover online meetings and working from home. Both have proven to be useful even after the pandemic. For many IUL employees the home office has become an indispensable way to better balance personal and professional life, allowing them both more time to attend to the needs of their families, but also to increase their effectiveness at work. Online meetings help tremendously in conserving resources and also allow for an increased frequency and spontaneity of meetings, especially when held with geographically dispersed members. An impressive example of this development is our lecture series “Exchange of experiences between industry and university”, which has almost quadrupled its number of participants due to the online version. Nevertheless, with these new possibilities, the danger of losing human contacts and gestures, which serve both to communicate content and to strengthen personal relationships, should not be lost sight of. An unrestricted home office for new young employees will prevent the spirit of academic life from being transferred at the IUL. Conversations with experienced colleagues in the hallway, in the kitchen, in the dining hall, in front of the elevator, etc. are all features of the IUL School. Similarly, the conversations at events during breaks and during lectures (even though they are actually not supposed to be!) are a valuable way of shareing knowledge.

The IUL was again very successful in terms of research in 2022. For example, this year we were able to start the DFG research group FOR FUNDAM³ENT on “Adiabatic Shear Cutting” (speaker: Prof. Thomas Lampke) together with our colleagues from Chemnitz, Munich, and Freiburg. In November 2022, we received the pleasant news about the Alexander Humboldt Fellowship for Dr. Shiori Gondo, National Institute of Advanced Industrial Science and Technology (AIST)/Japan. Dr. Gondo will conduct research on incremental sheet metal forming at IUL for two years, starting July 2023. We have also received approval from the Royal Society (UK) to support collaboration with the University of Sheffield (Prof. Hassan Ghadbeigi) at the end of 2022. In this collaboration, shear cutting of high-Si steels will be studied. Chip extrusion attracts more and more national, but also international attention. In summer, following the suggestion of British researchers, a BBC team visited our institute to film the process of sheet metal chip extrusion for a documentary on the subject of sustainable metal processing. In addition, we were able to start a fruitful collaboration in this field with several French scientists, leading to the submission of an ANR-DFG research proposal in early 2023.

The important results achieved that can now be used by science and industry could only be acquired together with all our staff members. I would like to express my sincere thanks for the outstanding achievements of the IUL team. It has been a great pleasure and honor for me, again this year, to work with all the talented members of the IUL team. But I would also like to take this opportunity to sincerely thank our national and international partners from science, industry, associations, and research funding for their support and cooperation.

A. Erman Tekkaya

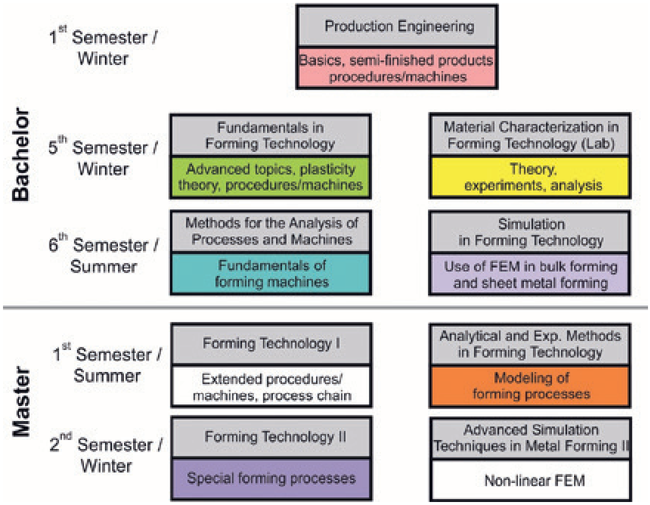
Education

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 were:

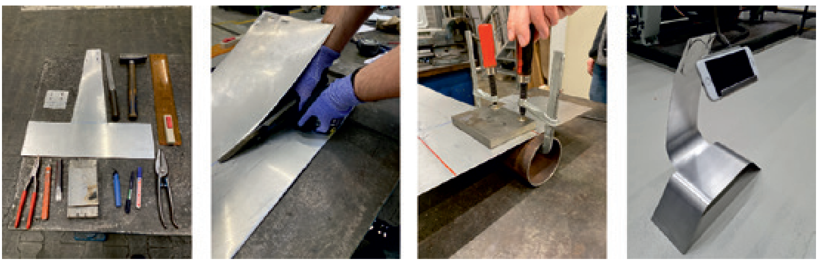
- Property control of semi-finished products
- Lecture series on forming technology
- Laboratory work A as part of the Master's Program in Mechanical Engineering
- Laboratory work B as part of the Bachelor's Program in Industrial Engineering

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
- Property control of semi-finished products
- Aluminum – Basic Metallurgy, Properties, Processing, and Applications
- Laboratory Work – Material Characterization in Forming Technology

Thanks to the gradual relaxation of the Corona measures, teaching contents could take place increasingly in presence again since winter semester 2021/22. Since summer semester 2022, the IUL offers all lectures on campus. Nevertheless, some elements from digital teaching have been retained and will be provided to students in the future. This includes, for example, the hybrid lecture format in which students can participate in the lecture on campus as well as from home, or lecture recordings which in some courses are made available to students after the classroom lecture.

Due to the good response to the team competition on the topic of forming technology “The Art of Forming”, which was held for the first time in winter semester 2021/2022 for all first semester students of the lecture series Production Engineering, this was offered again at the beginning of winter semester 2022/2023. The idea is to have the students work together in randomly assembled small groups of five to ten people to create a forming-based exhibit on a given topic and with given starting materials. In addition, to gain initial hands-on experience in the experimental lab, this format also provides the opportunity for students to get to know each other. At the end, a prize is awarded to the winning team.



Example design in team competition forming technology WS 2021/2022

In the area of the international master's program "Manufacturing Technology" (MMT), the 12th "Welcome Event" for the new students took place on October 4, 2022. While in the last two years the welcome had to take place digitally due to the pandemic, this year we were very happy to welcome the students in person again. After an introduction of the new students, organizers, and supervisors of MMT, they were welcomed by Prof. Tekkaya, the initiator of the study program introduced in 2011. Afterwards, Mr. Mohamad Houmani, a former MMT student, talked about his experiences during his studies. The event ended with a guided tour through the experimental area of the IUL and a joint lunch.

Towards the end of the year 2022, on December 8 and 9, Prof. Yoshinori Yoshida from Gifu University in Japan was a guest at the IUL. Prof. Yoshida is the director and coordinator of the exchange program G-CADET. The aim of this program, which he presented at the IUL, is to expand the international cooperation in engineering sciences. We are very pleased that after a break due to Corona we will be able to welcome Japanese students in Dortmund again next year and that German students will be able to start their journey to Japan.

In 2022, the following guest lecturers have contributed to the course offer at the IUL:

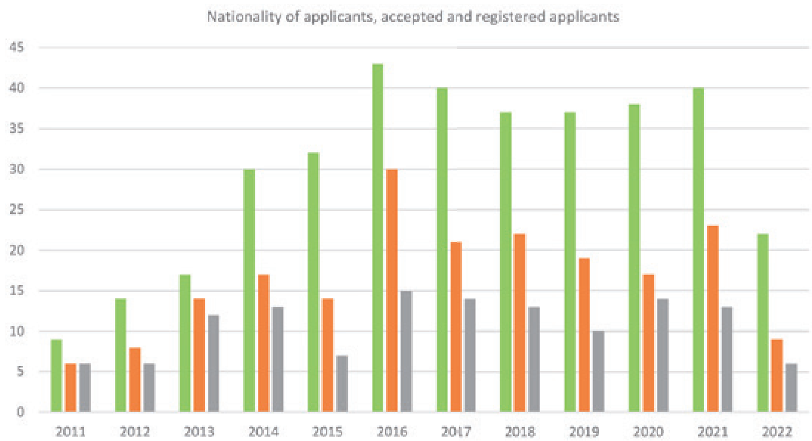
- Prof. J. Hirsch, Aluminium Consulting - Königswinter
- Prof. J. Sehrt, Ruhr-Universität Bochum
- Prof. P. A. F. Martins, Instituto Superior Técnico, Universidade de Lisboa, Portugal
- Dr. G. Georgiadis, Excelix Ltd.
- Dr. K.-F. Karhausen, Speira GmbH
- Dr. J. Ostrowski, Quaker Houghton
- Dr. S. Gies, 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.
Dr.-Ing. Dipl. Wirt-Ing. Ramona Hölker-Jäger

The application process for the four-semester English-taught Master's program "Master of Science in Manufacturing Technology" (MMT) in the field of production and manufacturing technology, which started in 2011, was switched to the online application portal "UniAssist" this year, which manages all international applications at TU Dortmund University. For the start of studies in winter semester 2022/23, 25 excellent students were selected from 427 applications from 22 nations to start their studies at TU Dortmund University. Twelve of them started their studies at the Faculty of Mechanical Engineering, including four female students. This means that the class of 2022/23 has a high proportion of women. The DAAD-organized cooperation with the Turkish-German University in Istanbul was terminated this year because the goals agreed in the cooperation contract could not be implemented in the long term.



Diversity of nationalities of applicants, accepted, and registered applicants

In order to further expand diversity in this international degree program, the coordination team analyzed the students' countries of origin and prospective students and then took measures to inform prospective students from other countries about the MMT program. As part of these measures, newsletters were sent out in cooperation with the DAAD and advertisements were placed on the DAAD country pages to draw attention to the program and the application deadline.

The “Halftime Analysis”, which was very well received last year, where students could give feedback on the first half of their studies and where they received the necessary information for the upcoming two semesters, especially on the laboratory, project and master’s thesis, was unfortunately not accepted by as many students this year. Therefore, the coordination team is currently developing new ways of student evaluation. Currently, the re-accreditation of the degree program, which will be completed next year, is being prepared. In the course of this, some changes have been made to the study plan. The module “Interdisciplinary Qualification” (as e.g. the German language course) is no longer planned for the third semester, but for the first two semesters. In addition, a new elective course on the subject of “Reliability Engineering” was added to the range of courses.

At the beginning of the new semester, the students were welcomed back on campus by Prof. Tekkaya, the head of the study program, at a welcome event in the lecture hall of Mechanical Engineering Building III. After the welcome event the students were able to exchange ideas with fellow students and representatives of the department during a get-together which was followed by a guided tour through the experimental hall of the IUL. As part of the “Welcome Week”, the students were offered various workshops on topics such as scientific writing, the peculiarities of the German university system, or an introduction to intercultural encounters.

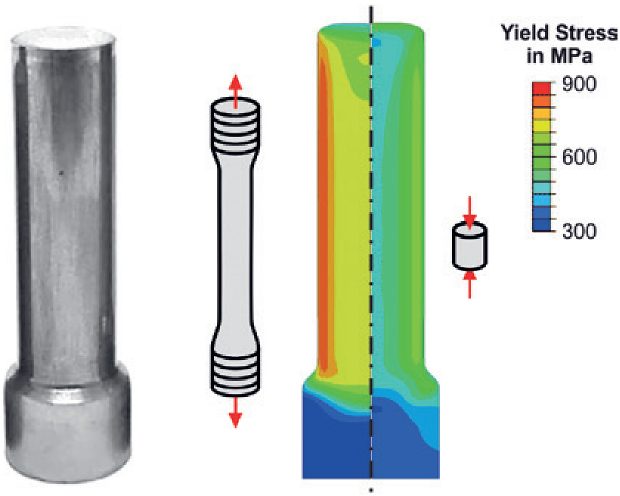
MMT batch of 2022 at the Welcome Event

Further information: **www.mmt.mb.tu-dortmund.de**

1.3 Doctoral Theses

Kolpak, Felix	Anisotropic Hardening in Cold Forging: Characterization, Simulation and Consequences
Series	Dortmunder Umformtechnik, Volume 115
Publisher	Shaker Verlag, 2022
Oral exam	February 8, 2022
Advisor	Prof. Dr.-Ing. A. E. Tekkaya
Co-examiner	Prof. Dr. F. Yoshida, Hiroshima University, Japan

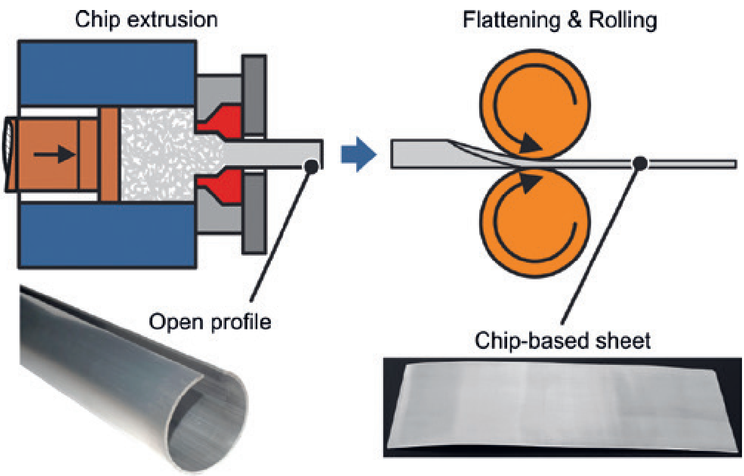
In the scope of this thesis typical cold forging materials are characterized with regard to their anisotropic work-hardening behavior exhibited at large strains. Tension, torsion, and upsetting of material specimens pre-strained by forward rod extrusion reveal the material's work-hardening behavior under a variety of different strain paths. It was shown that all investigated materials exhibit an extensive Bauschinger effect, work-hardening stagnation, and permanent softening which are, up to now, rarely considered in cold forging simulations.
The experimental data is utilized to select, modify, and fit constitutive models of increasing complexity. Various hardening models were applied to the simulation of basic single and multi-stage cold forging processes, revealing that the flow stress and residual stresses as well as the ejector forces are strongly affected by strain path changes which cannot be captured with the common assumption of isotropic work-hardening.



Yield Stress distribution in forward extruded rods, considering anisotropic hardening

Schulze, André	Hot Extruded Sheets from Aluminum Chips: Production, Characterization, and Formability
Original title	Bleche aus stranggepressten Aluminiumspänen: Herstellung, Charakterisierung und Umformbarkeit
Series	Dortmunder Umformtechnik, Volume 118
Publisher	Shaker Verlag
Oral exam	November 22, 2022
Advisor	Prof. Dr.-Ing. A. E. Tekkaya
Co-examiner	Prof. Dr.-Ing. H. J. Maier, Leibniz University Hannover

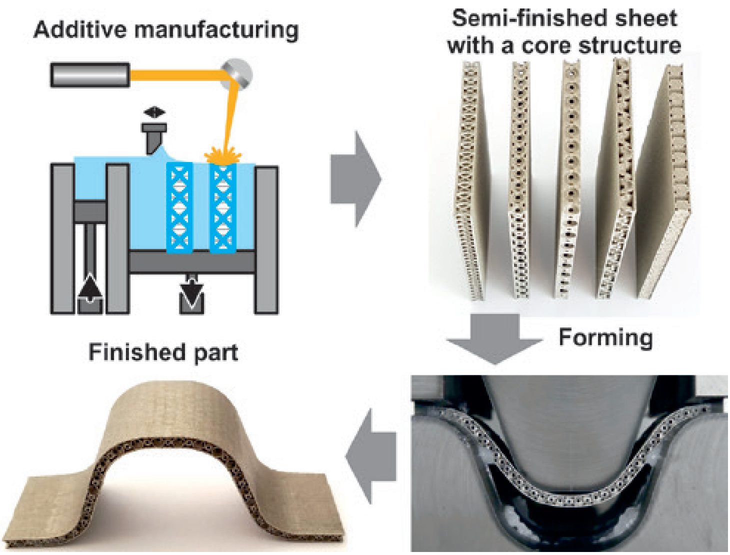
The extraction of aluminum and its further processing into products is associated with high energy demand and greenhouse gas emissions. In addition, the consequences of climate change lead to increasing demands on energy efficiency, emission reduction, and resource conservation. Direct recycling of aluminum scrap without remelting enables energy, greenhouse gas, and material savings.
A new process chain consisting of hot extrusion of aluminum chips to a cylindrical open profile with subsequent flattening and rolling for the production of sheets based on aluminum chips is presented. The capability for further plastic forming operations of the sheets was examined in air bending and deep drawing experiments. The analysis of the bent components or deep-drawn cups shows no significant differences between the ones made of chips and those made of cast material.



Process chain for the production of chip-based sheet

Rosenthal, Stephan	Forming of additively manufactured sheets with a structured core
Original title	Umformung additiv gefertigter Bleche mit strukturiertem Kern
Series	Dortmunder Umformtechnik , Volume 117
Publisher	Shaker Verlag
Oral exam	December 7, 2022
Advisor	Prof. Dr.-Ing. A. E. Tekkaya
Co-examiner	Prof. Dr.-Ing. habil. G. Witt, UDE

Additive manufacturing (AM) technology offers great potential for lightweight applications and is increasingly being used for industrial applications. A disadvantage of this process is the long production time and the limited build size. The aim of this work is to develop and investigate a new process combination for the time-efficient production of formable sheets with a structured core. A combined process of AM and subsequent forming of the semi-finished sheet with core structure is developed, which offers an increase in time efficiency of up to 380% compared to direct production of the parts in final geometry. The processes of bending and deep drawing for additively manufactured semi-finished sheet metal parts with core structure is analyzed. For bending, a process window is developed with the minimum bending radius $R_i/H = 2.35$ (R_i: bending radius on the inside of the sheet, H: sheet thickness). For deep drawing, a maximum drawing ratio of $\beta = 1.4$ is identified.



Process of additive manufacturing and subsequent forming

Education

01

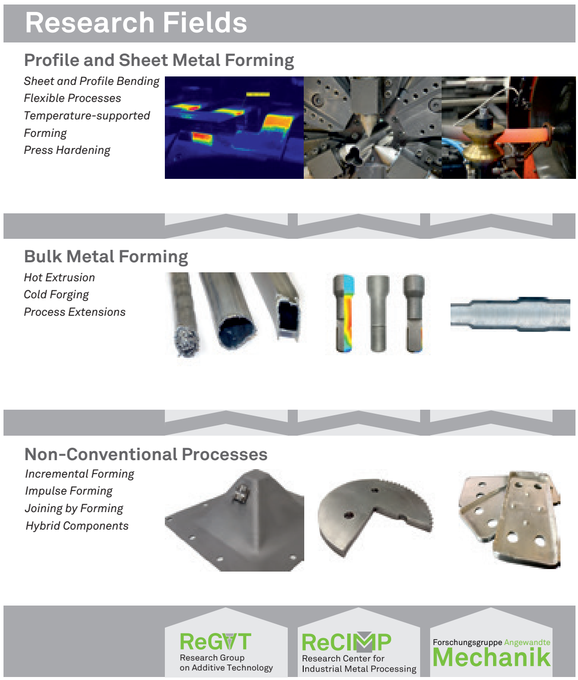
Research

02

2 Research

With their research, the employees (37 scientists, 13 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 new methods such as continuous extrusion 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 continuous extrusion of profiles reduces energy consumption and, thus, also reduces CO_2 emissions compared to discontinuous extrusion as the usual discard is smaller and there are no dead times.

National and international awards such as the SME Gold Medal for Prof. A. Erman Tekkaya, the Outstanding Paper Award at the North American Manufacturing Research Conference (NAMRC) 2022 with American co-authors, and the dissertation award of the TU Dortmund University for Dr. Felix Kolpak are evidence of the successful research at the institute. Participation in the Collaborative Research Centers TRR 188 (on-site spokesperson Prof. Tekkaya), in two Priority Programs (SPP 2013 and SPP 2183), and in the recently approved research group "Functional Surfaces through High-Speed Adiabatic Processes: Microstructure, Mechanisms and Model Development – FUNDAM³ENT" are proof of the institute's research strength. 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

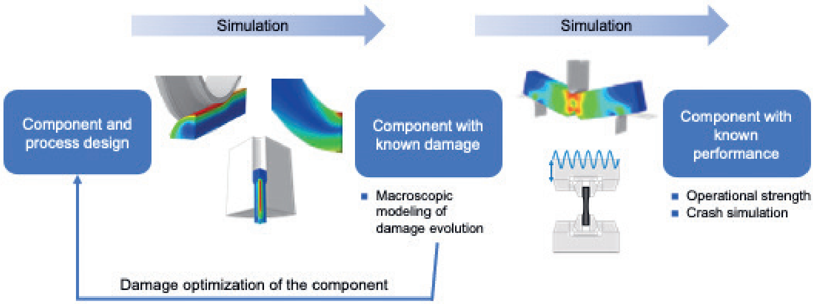
2.1.1 Collaborative Research Center Transregio 188 – Damage Controlled Forming Processes

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

Forming processes play an important role in the manufacture of highly stressed metallic components – not only in order to achieve the intended component geometry, but also to adjust the component properties. For this purpose, forming-induced changes in residual stresses, strain hardening, or microstructure are exploited in a targeted manner. This has not yet been the case for material damage, although it is known that under unfavorable conditions it can lead to premature component failure. In TRR 188, it was also shown that the amount of material damage accumulated in the forming process significantly influences the performance of the components even before the occurrence of a failure event. Material damage is, thus, a non-negligible parameter for component properties.

The goal of TRR 188 is, therefore, to precisely know the damage caused by the forming process during the manufacture of components to selectively adjust it for the improvement of component properties and to precisely determine the performance of the components. This is achieved, on the one hand, by damage control along the entire process chain and, on the other hand, by coupling process and damage models for damage-controlled component and process design. The figure illustrates the use of simulation models in the design process. In this way, the full potential of the material used is safely exploited and components with customized and guaranteed high performance can be realized.

In the first funding period (2017-2020), the primary objective was to develop a fundamental understanding of the processes and damage mechanisms on different scales using various sheet metal and bulk forming processes and to make them describable with models. Efficient characterization methods have been developed and redefined to quantify the damage and the mechanisms at work. For the prediction of the damage first modeling approaches from the micro to the macro scale were developed and validated based on experimental data. A fundamental result of the first funding period was the proof that the material damage influences the performance of the components even before the occurrence of a failure event and that the damage level can be controlled by the targeted choice of the process design. Thus, the results obtained in the first funding period demonstrate the fundamental feasibility of the TRR 188 vision.



Simulation chain – from design to performance (presentation Gerlach, IUL, industrial colloquium 2022)

In the currently running second funding period (2021-2024) the understanding of damage, its mechanisms, and the mechanism interaction will be further deepened. Based on more complex forming processes and the linking of processes along the process chain, the damage evolution under load paths, in which not only the hydrostatic but also the deviatoric stress component changes strongly, is investigated. In addition, temperature influences during hot forming and in intermediate and subsequent heat treatment steps are included. Here, with regard to damage control, it is necessary to investigate what influence the microstructure established during hot forming has on damage accumulation in the subsequent cold forming steps of the process chain and, ultimately, on the damage tolerance of the formed components. Another important aspect is whether the effects of strain hardening, residual stress, microstructure development, and damage can also be separated at elevated temperatures and in complex components in order to represent their influences on the component properties in an isolated manner.

The increase in complexity is also reflected in multi-scale modeling. The damage models developed in the first funding period are to be expanded with regard to load path dependence and the consideration of temperature dependencies and their influence on damage. With the modeling of rate dependencies, the influence of the time-dependent deformation history is also to be represented. This includes both the rate-dependent microstructure evolution and the higher influence of strain rates on the macroscopic mechanical behavior at high forming temperatures. Furthermore, the large number of observed damage mechanisms makes a model extension to mechanism interaction mandatory. The challenges are, on the one hand, the coupling of the different effects and, on the other hand, the separation of their influence on the modeling of damage. At the end of the work, the individual models are to be linked to form a uniform tool in order to be able to simulate process chains holistically and to optimize them with regard to performance.

The basis for the previously mentioned research work in the areas of process technology and model development is an experimentally validated, quantitative determination of the correlation between the parameters of the forming processes, the resulting damage, and the achievable performance of the components. Therefore, four overall objectives are pursued in the project area characterization:

- Identification of damage mechanisms,
- Characterization of damage states,
- Measurement of component performance, and
- Design of damage-tolerant microstructures.

First research results from the second funding period were presented to a broader expert audience at the 3rd Industrial Colloquium on May 10, 2022. Together with almost 100 international participants from industry and research, the approaches to damage control in forming processes and their benefits in industry as well as future development trends were discussed at the Dortmund Congress Centre, Germany. The ten lectures and an accompanying poster presentation dealt with damage formation and control in various cold and hot forming processes up to shear cutting and blanking. Important topics included the effects of forming-induced damage on component performance and modeling approaches to predict and optimize component damage. The variety of application examples presented by the invited speakers from industry and renowned research institutes as well as the great response from the participants underlined the high relevance of the topic for manufacturing technology and beyond. For this reason, the discussion is to be continued as part of the 4th Industrial Colloquium in November 2023. It will then be hosted by RWTH Aachen University, which is currently the spokesman university of TRR 188.

At RWTH Aachen University (spokesman university) the project managers come from the Institute of Metal Forming (IBF), the Steel Institute (IEHK), and the Institute for Physical Metallurgy and Materials Physics (IMM) of the Faculty of Georesources and Materials Engineering as well as the Laboratory for

Machine Tools and Production Engineering (WZL) of the Faculty of Mechanical Engineering and the Central Facility for Electron Microscopy (GFE). In Dortmund the projects are 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) of the Faculty of Mechanical Engineering and by the Chair of Structural Mechanics (BM) of the Faculty of Architecture and Civil Engineering. The Institute for Applied Materials - Materials and Biomechanics (IAM-WBM) of 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. Stephan Rosenthal

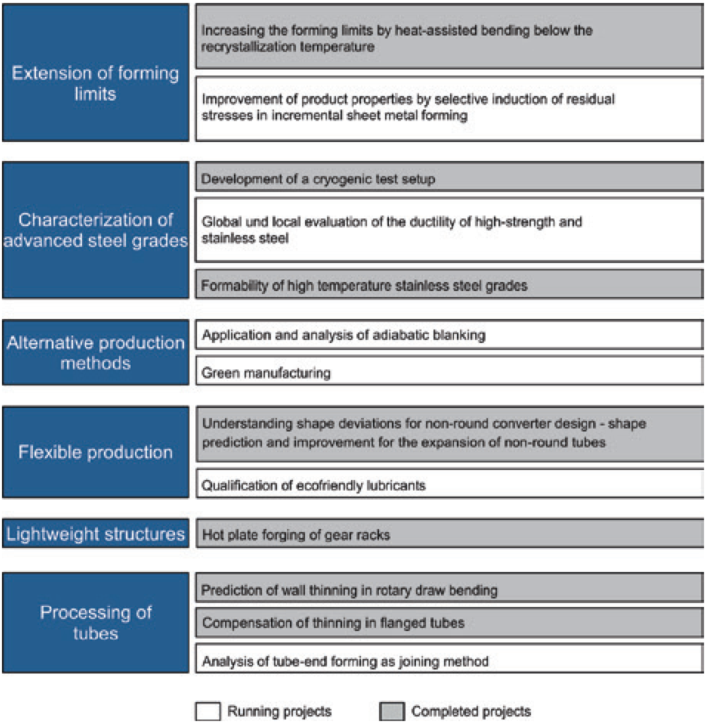
The cooperation with the international automotive supplier Forvia-Faurecia, established since 2013, was successfully continued in the year 2022. The "Research Center for Industrial Metal Processing" (ReCIMP) is an application-oriented research cooperation of the IUL with the divisions "Faurecia Automotive Seating" and "Faurecia Clean Mobility". ReCIMP collaborates on a wide range of innovative projects in the fields of process development, materials science, and lightweight construction. The overarching objective of each project is to improve and deepen basic knowledge of the processes and process chains. In addition, there is a focus on identifying and investigating new scientific research areas in the field of manufacturing technology. The synergies resulting from cooperations with other industrial companies and research institutions are a welcome side effect. In addition, the IUL's cooperation with Forvia-Faurecia also promotes a practical collaboration at the company's various sites.

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 2022.

The researchers are supported by a large number of student assistants and students who prepare project, bachelor, or master theses in the projects. Since the establishment of the research center, far more than 70 students have been involved in ReCIMP projects. For several current scientific employees of the IUL a thesis initiated in ReCIMP was the first step towards a scientific career. The cooperation is particularly effective when the research topics initially dealt with in the research center lead to fundamental questions and research fields for externally funded projects – as has happened several times in recent years.



Research topics worked on in 2022

In the field of characterization of modern steel materials, investigations into the evaluation of global and local formability were continued in 2022. Depending on the manufacturing process chain, one of the two properties is more important than the other. However, there are also cases where a good balance of global and local formability is of interest. Forming limit curves and fracture deformation diagrams are used for this purpose. Work in this project aims at a faster and more economical determination of these parameters by means of analytical approaches. In response to increasing political and corporate efforts to reduce CO_2 emissions, concepts were developed over the course of 2022 dealing with the potential for cutting waste in progressive die stamping. Another project on resource-saving production is concerned with testing environmentally friendly lubricants. Lubricants based on mineral oil are to be replaced by lubricants made from an environmentally friendly fluids for deep drawing.

In the area of the exhaust system, non-round tubes are increasingly used, especially for catalytic converters, for reasons of optimum utilization of installation space. Numerical methods and models for automated process design are being developed as part of a ReCIMP project to accurately predict the component geometry after production. In particular, the last process step – the stuffing of a ceramic component – is in the focus of the considerations. In order to be able to carry out tests for alternative drive concepts in the future, a test chamber was developed in 2022 that allows component and material testing at cryogenic temperatures of up to -100° C.

A project to predict wall thickness thinning during rotary draw bending investigates the possible substitution of austenitic stainless steels with ferritic stainless steels. In this context, the reduced deformation capacity of ferritic stainless steels must be taken into account. The aim is to replace austenitic stainless steels, which are poor from the point of view of the CO_2 balance, with ferritic steels. Corresponding process windows with substitution recommendations are being developed for this project. A project initiated in 2021 on increased deformation by temperature-assisted bending below the recrystallization temperature focuses on preventing cracks during bending of shear-cut plate edges and was finalized in 2022. Such cracks occur in particular in higher-strength steels and must be avoided at all costs in the area of safety-relevant seat components. Another project is concerned with the service life prediction of fasteners produced with tubes by the buckling process. In this case, cracks occur during the forming operation of the bulge on the side of the tube that is actually subjected to compression. These cracks reduce the service life and their origin is not yet fully understood.

Further information on the individual projects can be found in the respective sections on ReCIMP.

2.1.3 ReGAT – Research Group on Additive Technology

Head Dr.-Ing. Dipl.-Wirt.-Ing. Ramona Hölker-Jäger
Dr.-Ing. Stephan Rosenthal
Hamed Dardaei Joghan M. Sc.

The working group "ReGAT – Research Group on Additive Technology" investigates various approaches to combine additive manufacturing with forming technology. The research spectrum ranges from the combination of formative and additive manufacturing processes to the forming processing of additively manufactured semi-finished products and additively manufactured tools for forming technology. For the experimental implementation two different additive manufacturing machines for processing metal powders are available at the IUL (see Figure 1):

- 5-axis-milling machine integrated with a unit of laser metal deposition, DMG MORI Lasertec 65 3D Hybrid
- Powder bed-based selective laser melting (SLM), DMG MORI Lasertec 30 SLM

In addition to the metal machines, the IUL also has three FDM (Fused Deposition Modeling) machines for processing polymers. The polymer-based machines are used for the production of fixtures or prototype models. In addition, the FDM and SLM machines are also used for teaching purposes in lectures and laboratories.

The Lasertec 65 3D Hybrid offers the possibility to integrate different forming processes such as incremental forming or ball burnishing on the same machine. In the same setup it is possible to deposit functional elements additively and, finally, to improve the surface roughness of the deposited area by a milling process. This stategy is being done as a research project funded by the DFG (385276922). In another project (DFG 417202720) the production of complex cooling channels for hot stamping dies and the adaptation of the surface structure of blank holders in hot stamping is studied. Laser metal deposition makes it possible to produce complex, near-surface cooling channels which cannot be manufactured using conventional subtractive processes.

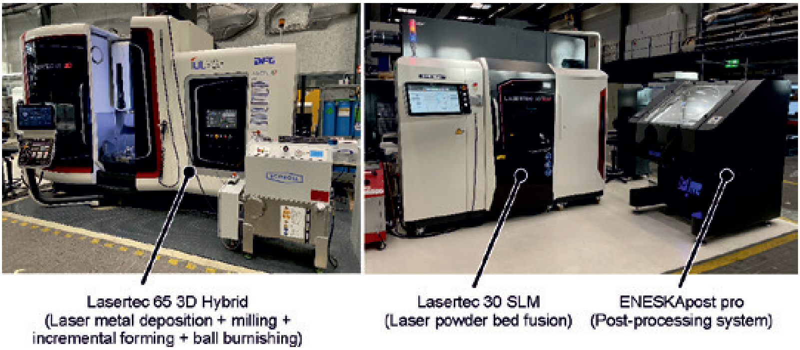


Figure 1: Machines for additive manufacturing based on metal powder at the IUL

In addition to the completely additively manufactured forming tools, a new concept for hybrid additive laminated deep drawing tools is investigated (see Figure 2). In the new manufacturing approach the stair step effect of sheet lamination is reduced by depositing metal powder. Three different post-processing methods are investigated to improve the surface roughness of the deposited areas: ball burnishing, milling, and laser polishing. The results of the project (DFG 426515407) show a successful application of this novel process in the manufacture of deep-drawing dies. The main advantages of the hybrid process include low energy consumption, short manufacturing time in comparison to fully deposited parts by LMD, and it requires no additional hardening process contrary to the conventional method.

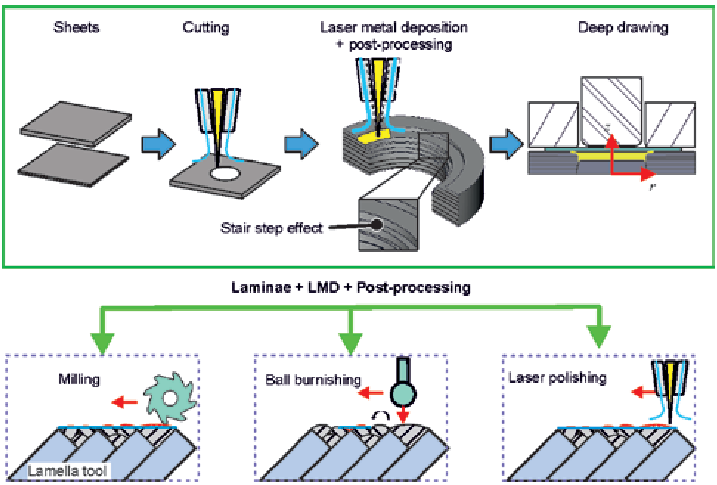


Figure 2: Process route for hybrid additive metal laminated tooling

The Selective Laser Melting (SLM) machine working in the powder bed offers the possibility to produce filigree and complex geometries. In the current project (DFG 317137194), to increase productivity and overcome the limitations of building space, the complex core sheets are manufactured additively and cold-rolled sheets are joined to the core sheets. This allows several semi-finished products for the core structure to be arranged between two large-area cover sheets. The sandwich composite sheets are characterized by bending and deep drawing (Figure 3). In addition, this offers a lightweight construction with the possibility of function integration and load-fit lightweight design. This research project is in collaboration with the Institute of Product Engineering (IPE) at the University of Duisburg-Essen.

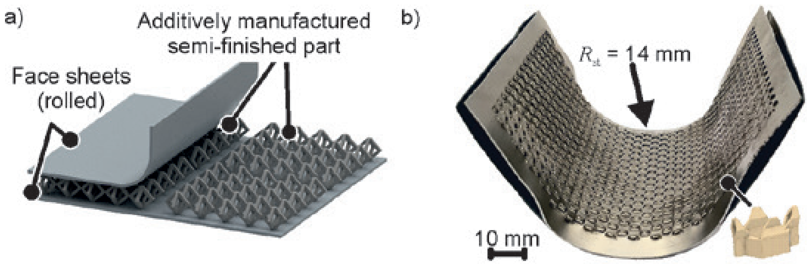


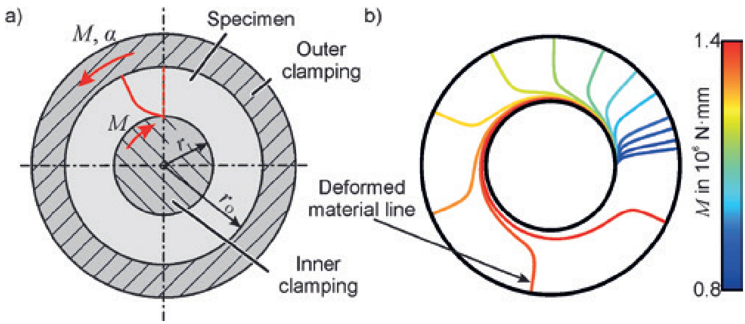
Figure 3: a) Principle of additively manufactured semi-finished part, b) Sandwich sheet after bending

The research results achieved motivate the ReGAT team to transfer the potential arising from additive manufacturing to other forming processes.

2.1.4 Research Group Applied Mechanics

Head 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 the IUL. The development and application of the aforementioned methods is conducted for the forming technologies available at the institute: bulk, sheet and profile forming as well as non-conventional forming methods. The researchers at the IUL also contribute their expertise to national cooperative projects, e.g. with a project led by Prof. Tekkaya and Dr. Clausmeyer within the research group "Functional surfaces by adiabatic high-speed processes: Microstructure, Mechanisms and Model Development – FUNDAM³ENT".



Principle sketch: Analytical model of the in-plane torsion test: a) Sketch of the specimen, b) Deformation of radial lines and the torque in the in-plane torsion test

Other projects in which the methods supported by the Research Group Applied Mechanics play an important role include a DFG project on property control in hot forming, an EFRE project on the development of a biaxial compression test rig, and an AiF project on the modeling of microstructure in extrusion, especially with the newly developed parameter identification methods. The research group members present their work to the public in journals, lectures, and at conferences. In 2022, the researchers were pleased to exchange ideas with international scientists during their research visits to the IUL. Particularly close collaborations took place with Dr. Abhijit Brahme, Dr. Muhammad Waqas (both from the Computational Mechanics Research

Group of the University of Waterloo, Canada), and Prof. Frédéric Barlat from the "Graduate Institute of Ferrous Technology of Pohang University of Science and Technology" in South Korea.

The exchange with the Canadian scientists resulted in an article published in the International Journal of Solids and Structures on the prediction of void development using machine learning methods. Fabian Stiebert, Dr. Heinrich Traphöner, and Prof. Tekkaya summarized the advantages and disadvantages of different current methods for determining yield curves at large strains with Prof. Sam Coppieters (Belgium), Prof. Tudor Balan (France), and Prof. Toshiko Kuwabara (Japan). One way to determine the yield curves of sheets at very large strains is the in-plane torsion test. Nils Cwiekala (now University of Oxford), co-author of the IUL, and Prof. Peter Haupt (University of Kassel) used a new analytical model to describe the deformation and the resulting stresses in this test (see figure).

2.2 Department of Bulk Metal Forming

Head Dr.-Ing. André Schulze

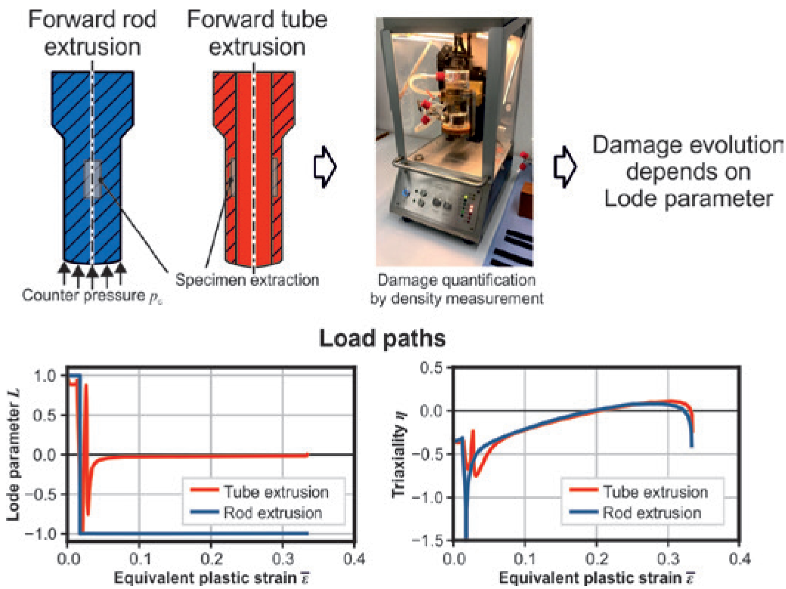
The department of bulk metal forming predominantly works in the field of hot extrusion and cold forging. The objectives contain fundamental research of the mentioned processes as well as the new and further development of process variants. Fundamentally, the influence of anisotropic hardening is investigated and a process for continuous hot extrusion is designed and analyzed using a model material. Methods and models are developed for the prediction of damage evolution during cold forging, radial swaging and microstructure evolution during hot extrusion. On this occasion, artificial neural networks are also used. In hot extrusion, the process development aims at lightweight-oriented process designs and resource conservation. For this purpose, the grading of mechanical properties over the profile cross-section, the direct recycling of aluminum chips into sheets and their further processing by forming operations and the occurrence of undesired longitudinal weld seams during the process are investigated.

Members of the department of bulk metal forming in front of the 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.

Forming processes do not only bring materials into a desired shape, but also significantly change their properties. One reason for this is the nucleation, growth and coalescence of microscopic voids in metals during forming. These are referred to as damage and influence the product performance of manufactured components during their service life. In the first funding period of the project, it was demonstrated that components with increased performance can be produced by increasing the hydrostatic pressure during the forming process. The influence of the deviatoric stress state is now also investigated through specific process control in forward rod extrusion and forward tube extrusion. By applying a counter pressure during forward rod extrusion, the hydrostatic pressure can be adjusted to equal the pressure in forward tube extrusion. In this way, the influence of deviatoric stress on damage evolution can be studied separately from the influence of hydrostatic stress by density measurements.

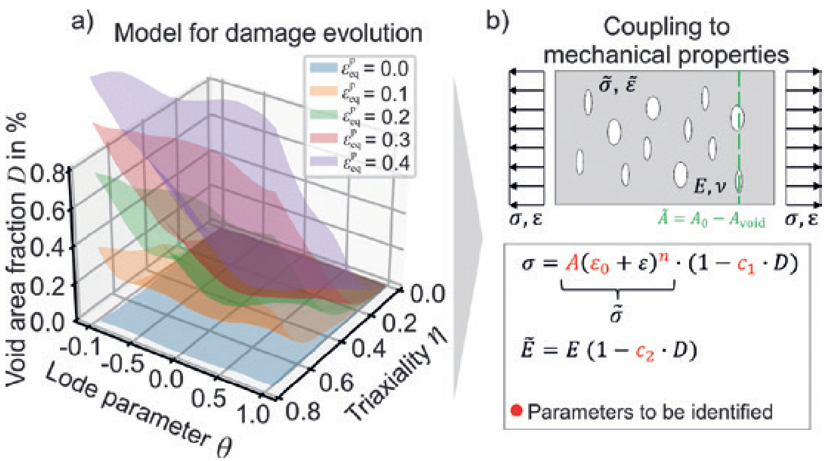


Experimental procedure to investigate lode angle dependency of damage evolution

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 main objective of the CRC/TRR 188 is the improvement of product properties by damage-controlled forming. The focus of subproject S01 is on the accurate prediction of void fractions and their effects on mechanical properties and, ultimately, on the performance of manufactured products. For this reason, an AI-based model was developed (see Figure a), which was trained with high-resolution scanning electron microscope data to predict the void evolution in a dual-phase steel. The model provides good quantitative results for various tensile and bending tests. In the next step, the model was coupled to the mechanical properties using the homogenization approach of effective stresses (see Figure b) and calibrated using load-displacement curves of various tensile tests. The model is able to predict the void area fractions as well as to represent the experimental load-displacement curves. Furthermore, it was observed that other void properties such as void orientation, void shape, and void number also affect the material degradation.

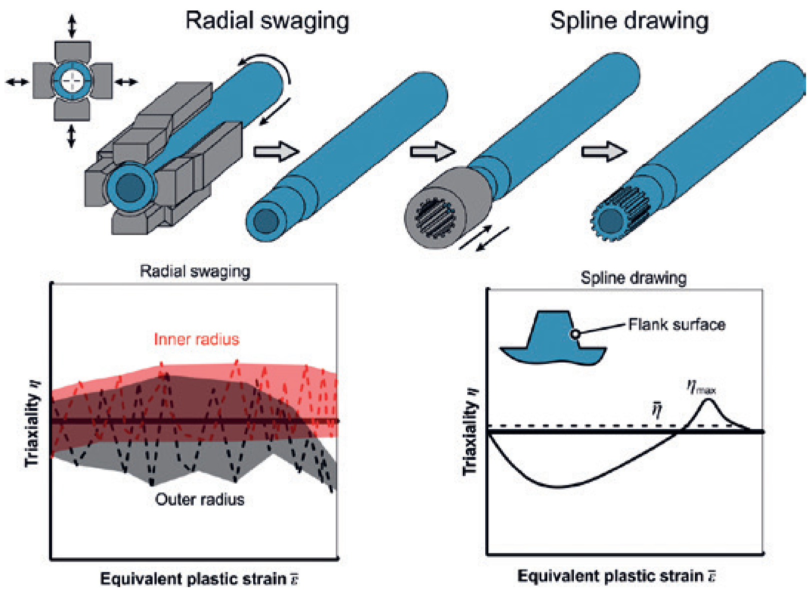


Development of a coupled damage model

2.2.3 Damage Evolution in the Production of Drive Shafts by Radial Swaging and Spline Drawing

Funding	German Research Foundation (DFG)
Project	CRC/TRR 188 • Subproject T01
Contact	Tanmoy Rakshit M. Sc.

The electrification of vehicles leads to an increase in their weight due to additional battery units. In addition, increased acceleration and braking torques are observed, which have to be transmitted by hollow drive shafts, so-called Monobloc Tubular Shafts (MTS). The project will investigate the production of drive shafts capable of high loads by means of radial swaging and spline drawing. Radial swaging is an incremental forming process with an oscillating load path and constant load change. In the second process step, spline drawing is used to produce the final spline on the radially swaged component. The influence of the process route and the process parameters on the local damage of the components is determined experimentally. In addition, the effects of annealing and quenching on the damage development of the Monobloc Tubular Shafts are determined. The aim is to design a process chain with regard to reduced damage to the components in order to achieve a longer service life up to failure under dynamic load.

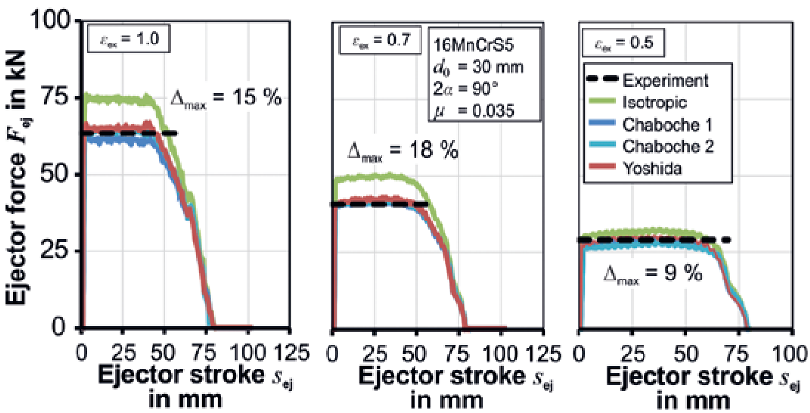


Oscillating load path in radial swaging and the load path on the flank surface of a tooth

2.2.4 Influence of the Multiaxial Bauschinger Effect in Cold Forging

Funding	German Research Foundation (DFG)
Project	418815343
Contact	Dr.-Ing. André Schulze

In complex cold forging process chains, certain material zones are sometimes formed multiple times. If a local load reversal occurs in such cases, this can lead to anisotropic hardening phenomena, which have a significant effect on the yield stress of the material. To predict process forces and product properties in process simulations, these phenomena must be taken into account in material models. In order to calibrate such models, a methodology based on tensile, torsional, and upsetting tests on material pre-strained by forward rod extrusion is developed. With this approach, anisotropic strain hardening effects can be characterized up to high plastic strains of $\varepsilon_p = 1.6$. To investigate the effect on the predictive accuracy of process simulations, the ejection of a component after forward rod extrusion is simulated. A comparison of the simulated ejector forces with experimentally determined values shows that a precise prediction is only possible when anisotropic hardening is taken into account.

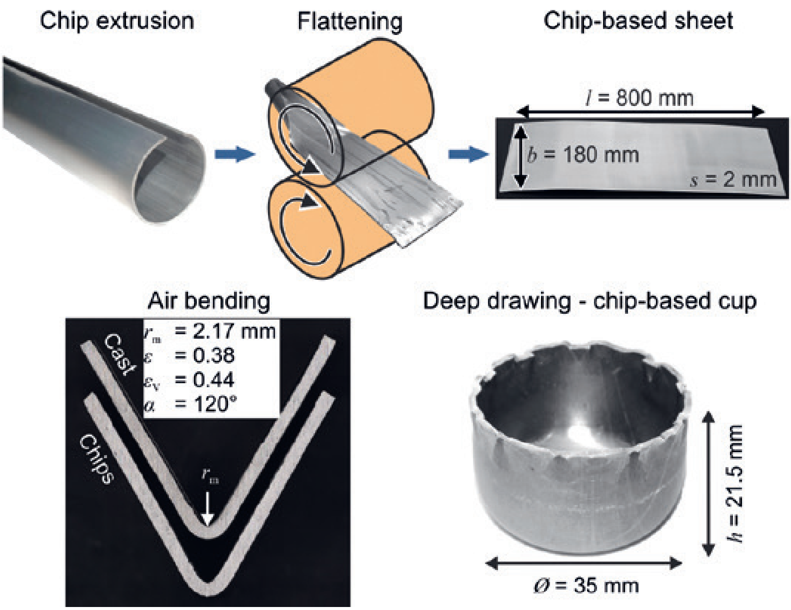


Numerically determined ejector forces in comparison with experiments

2.2.5 Production of Sheets by Hot Extrusion of Aluminum Chips

Funding	German Research Foundation (DFG)
Project	437426733
Contact	Dr.-Ing. André Schulze

Compared to the conventional remelting process route, the direct processing of aluminum chips into semi-finished and final products is an energy- and resource-saving recycling method. A new process chain, consisting of hot extrusion of aluminum chips to a cylindrical open profile, flattening, and subsequent rolling for the production of chip-based sheets is investigated. An analytical model and numerical methods are used to investigate the physical processes during the welding of the chips in the individual process steps and to predict the weld quality. The properties of the hot extruded chip-based sheets are examined by tensile tests and microstructural investigations. The formability of the sheets can be increased by a heat treatment consisting of a solution annealing followed by natural aging. As a result, there are only minor differences 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.

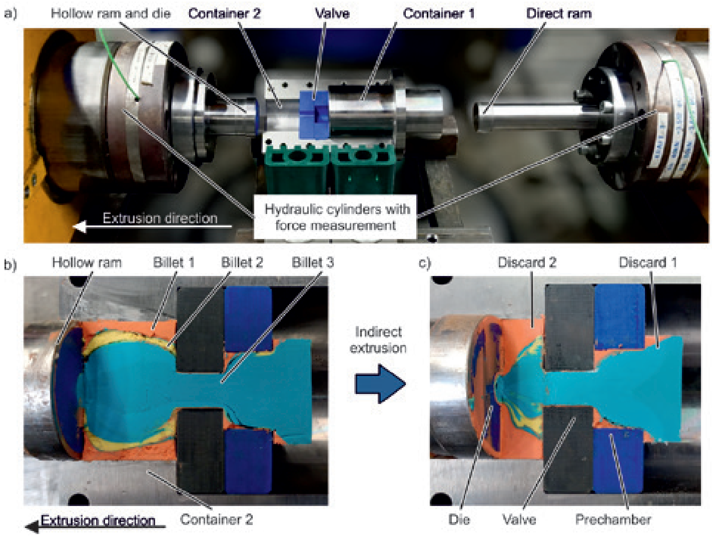


Production of chip-based sheets and further processing by bending and deep drawing

2.2.6 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. To investigate the material flow and the process forces, a scaled setup of a continuous extrusion press is used with a plasticine model material (see Figure a). The plasticine has a similar flow behavior as aluminum at high temperatures, which means that the results can be transferred to the real process. For example, the material flow can be observed directly with differently colored plasticine billets. Figure b shows the filling of the second container after three extrusion cycles immediately before the indirect extrusion phase and Figure c after the indirect extrusion phase.

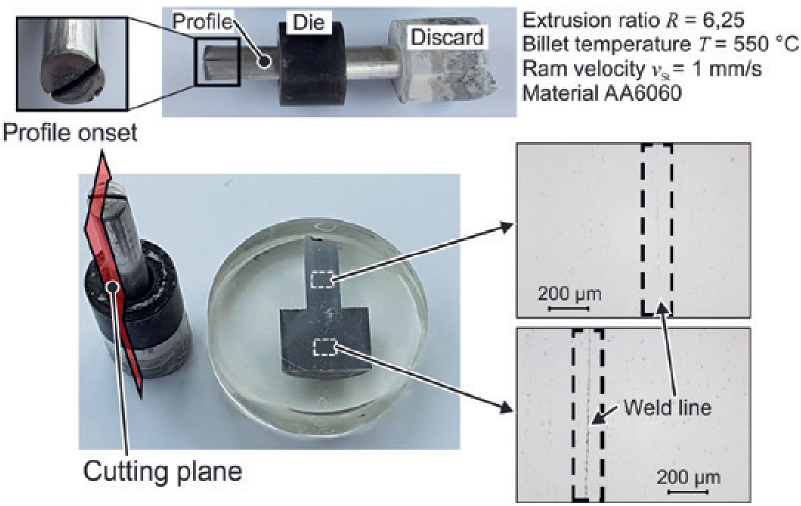


a) Experimental setup, b) and c) Material flow before and after indirect extrusion phase

2.2.7 Solid-State Bonding of Oxide-Covered Aluminum Surfaces in Metal Forming

Funding	German Research Foundation (DFG)
Project	470385288
Contact	Dr.-Ing. André Schulze

Solid-state bonding is a physical process by which material composites can be produced by applying pressure to two surfaces. By definition, solid-state bonding takes place at a temperature below the melting temperature of the composite partners and without adding a filler material. So far, processes as roll cladding or recycling processes for the direct recycling of aluminum scrap have only been investigated with regard to their process-specific parameters and their influence on the resulting bond. Up to now, there is no sufficient transferability of the physical relationships. In this research project the quantitative determination of the influence of physical factors on the local welding of oxide-covered surfaces is conducted. To produce weld seams, an experimental method based on hot extrusion is used which allows the targeted welding of two oxide-covered surfaces under known forming conditions as well as the sample extraction with a known weld seam position. The knowledge gained is used to generalize and validate existing welding models.

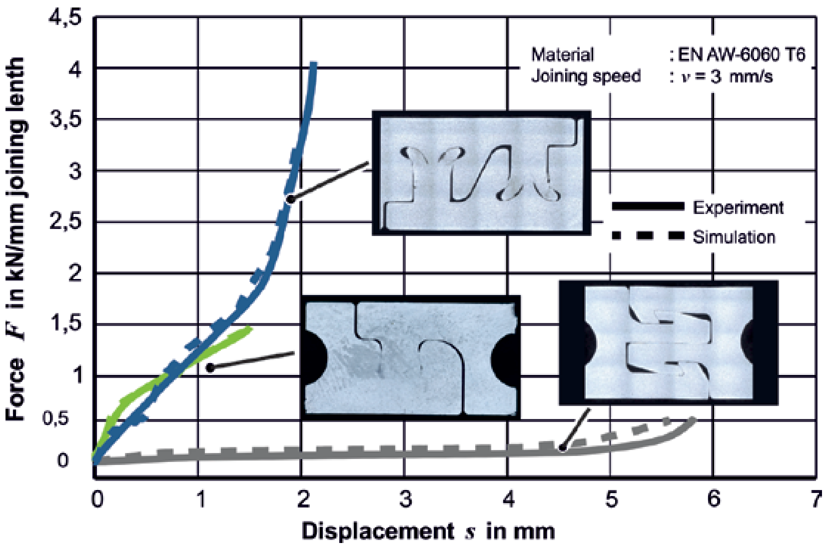


Profile extruded from half billets and detection of the weld line (optical microscope)

2.2.8 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, a new type of aluminum hot extruded profile concept is developed to produce tight base assemblies for battery housings using a mechanical single stroke joining process. The longitudinal mechanical joint replaces the currently used time and cost-intensive friction stir welding. It is investigated in which way the geometry, the process, and the properties of the aluminum profiles can be modified to obtain a joint that meets the tightness requirements and also achieves high load-bearing capacities. The joint is formed between flat contact surfaces, which eliminates the need for complex tool designs. To evaluate the joint quality, force curves from the joining process and micrographs of the resulting joint geometries are analyzed and load-bearing capacities are investigated by shear tensile tests. Measurements done by a helium sniffer leak detector have already shown high leak tightness of the joints. Further investigations will show the performance under cyclic loading and bending.

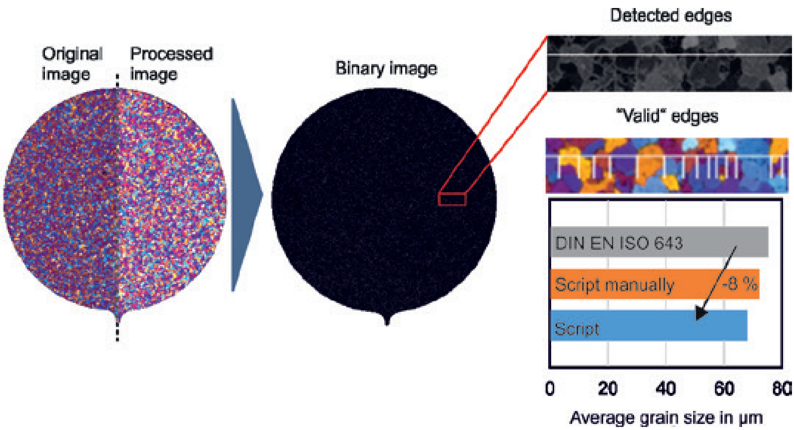


Longitudinal joining: comparison of joining simulation and experiments

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

Funding	AiF/Stifterverband Metalle
Project	21682 N
Contact	Oliver Schulz M. Sc.

The mechanical properties of extruded profiles depend significantly on the resulting microstructure. Thus, in order to ensure a more accurate prediction of the product properties by numerical simulations, the mapping of the microstructure evolution needs to be included. For the development of a feasible and efficient numerical approach to predict the microstructure, it is first necessary to create an experimental database containing hot upset and scaled hot extrusion tests. To automate the grain size determination, a script is developed which uses suitable filters to obtain a sharper contrast and existing edge detection algorithms (i.e. canny edge detector) to determine the grain boundaries. Based on the number of cut grain boundaries, the grain sizes are calculated using the line intersection method. To validate the script, the grain size is calculated manually using the intersection lines from the script and intersection lines according to DIN EN ISO 643. A maximum deviation of 8% could be observed for undeformed specimens.

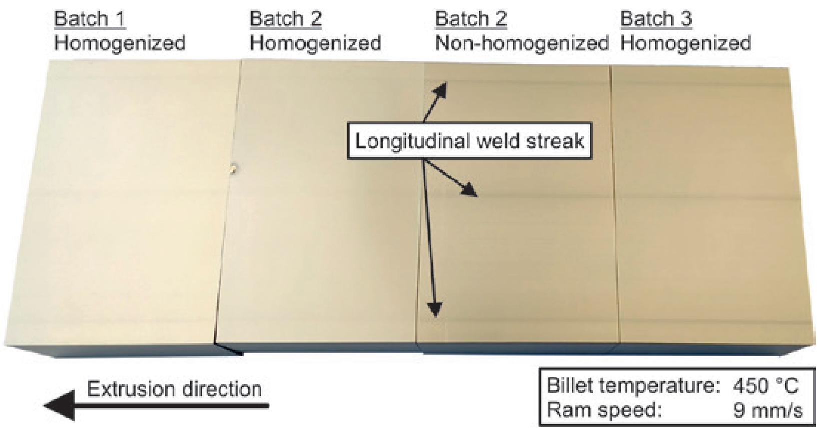


Schematic workflow of the automatic script to calculate grain size

2.2.10 Investigation of the Influence of Alloy Composition on the Formation of Longitudinal Weld Streak Defects in Anodized Hot Extruded Profiles

Funding AiF/Stifterverband Metalle
Project 22610 N
Contact Jan Flesch M. Sc.

In the case of hot extruded, anodized hollow aluminum profiles to be used as visible components, the process error of longitudinal weld streaks leads to rejection by the customers and, thus, to scrap. In the first phase of the project, the negligible influence of the extrusion parameters (billet temperature, ram speed) on the appearance of longitudinal weld streaks could already be proven. Instead, depending on the alloy composition and the homogenization state of the billets, different intensities of weld streaks were recorded. The visibility of the seam is due to etch pits in the micrometer range, which are caused by varying degrees of material removal during etching. This project therefore focuses on the correlation between microstructural characteristics (dislocations, precipitations) and the intensity of the weld streak. It will be investigated to what extent this can be influenced by the alloy composition, the degree of homogenization, and a downstream heat treatment of the profiles.

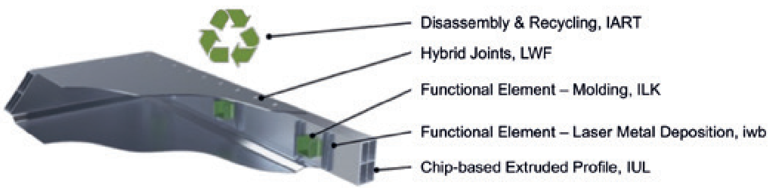


Influence of the pouring batch and homogenization of the billet on the weld streak formation

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. Dipl.-Inform. Alessandro Selvaggio

In order to analyze a closed process cycle, the joint project KORESIL combines the expertise of the IUL with that of the Institute for Lightweight Structures and Plastics (ILK, TU Dresden), the Institute for Machine Tools and Industrial Management (iwb, TU Munich), the Laboratory for Materials and Joining Technology (LWF, Paderborn University), and the Institute of Processing Machinery and Recycling Technology (IART, TU Bergakademie Freiberg). A battery box profile was chosen as the demonstrator, which is extruded from chips at the IUL and recycled at the IAM. Structural elements made of metals and polymers are subsequently applied at the iwb and ILK. The LWF then joins and later disassembles several profiles with cover sheets. In addition, the entire process chain will be digitally mapped for socio-technical analyses as well as training measures. Recyclate-based billets can now be successfully used within the process chain. The fully recycled profiles are provided to the partners of the project. At the same time, the digitized environment, depicting the process chain and its processes, can be used to train manual steps and to evaluate the cognitive strain of the researchers.

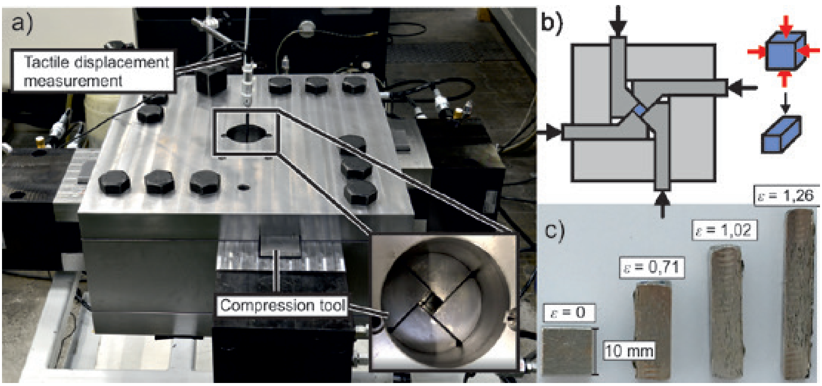


Demonstrator of the KORESIL process chain

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

Funding	BMWK
Project	03THWNW002
Contact	Patrick Kotzyba M. Sc.
Status	Completed

The overall project objective was the manufacturing, assembly, commissioning, and validation of a functional machine for performing equibiaxial compression tests for materials characterization. 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 operating principle (see Figure b) leads to a uniform forming of cube- or cuboid-shaped specimens by applying a two-sided, i.e. biaxial, compressive stress condition. The machine shown in Figure a, which has been put into operation, permits this kinematics and is capable of forming metallic materials up to equivalent strains of $\varepsilon = 1.3$ (see Figure c). By installing pressure sensors, the force applied to the specimen can be calculated. Tactile displacement sensors measure the displacement directly on the specimen. The measured values are converted into stress and strain and can be used for flow curve calculation.

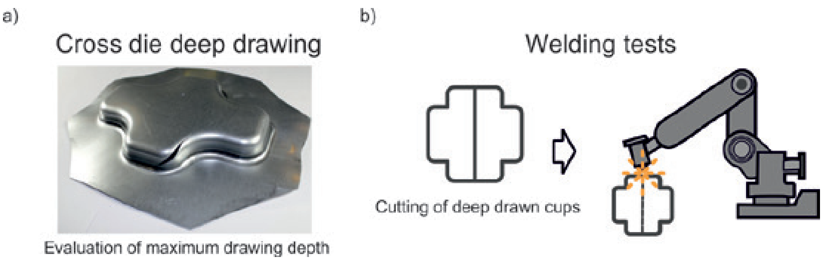


a) Structure of the equibiaxial compression test, b) Principle sketch, c) Formed tin specimen

2.2.13 "Green" Lubricants

Funding ReCIMP
Contact Robin Gitschel M. Sc.

Deep drawing represents one of the major sheet metal forming processes in automotive engineering. For the production of complex geometries of body and structural components, lubrication of the tools is usually inevitable. Conventional deep drawing lubricants are made from mineral oils. Since the lubricants remain on the workpieces after forming, they have to be washed off with great effort in order not to impair subsequent process steps, such as welding operations. The resulting water consumption, as well as the use of mineral oils pose a potential hazard to humans and the environment. Alternatively, so-called "green" lubricants made from renewable raw materials and without toxic additives can be used. In order to evaluate their application for complex deep-drawn parts, a cross die geometry is deep drawn with green lubricants from various manufacturers. The suitability of the lubricants can be quantified by evaluating the achieved drawing depths and the welding quality in subsequent welding tests.



Investigation of green lubricants in a) Deep drawing and b) Subsequent welding

2.3 Department of Profile and Sheet Metal Forming

Head Joshua Grodotzki M. Sc.

The team of the profile and sheet metal forming department investigates various aspects of research in the fundamental and application-oriented areas. In addition to the development and testing of innovative machines and processes, the limits of material characterization at high strain rates and high temperatures are being expanded.

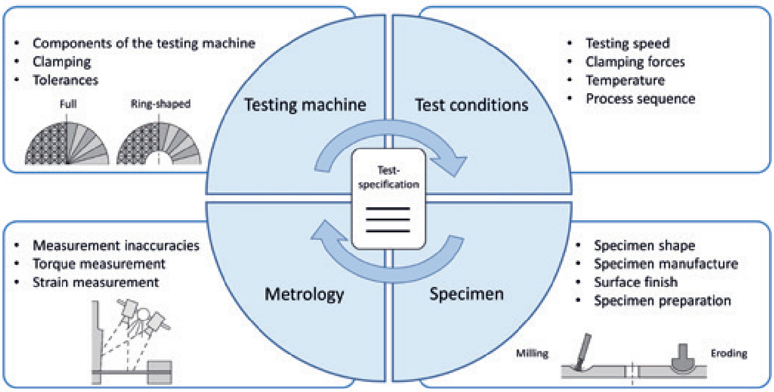
Currently, the basic investigations for the in-plane torsion test are being finalized, which will form the basis for a standardized test specification. In addition, the temperature-supported internal high-pressure forming process was used to determine process-related forming limits and flow curves. In the sheet metal forming processes, the focus was on quantifying the influence of load path changes on damage evolution. In the case of property-controlled, multi-stage hot sheet forming, thermo-mechanical parameter sets were identified which allow the targeted adjustment of product properties. For roll-clad MnB-Cr steel composites, the process limits were determined based on the current semi-finished product properties. Wires for spring production were found to exhibit stress-dependent relaxation behavior. In the area of tool development, the achievable cooling rate for press hardening processes was increased due to additively manufactured cooling channels close to the contour.

The team of the profile and sheet forming department in the area of the remote bending cell and the TSS bending machine.

2.3.1 Preparing the Standardization of the In-Plane Torsion Test

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

The aim of this project was to analyze the fundamental influencing variables of the in-plane torsion test and to use the results to prepare a test specification. For this purpose, the influencing variables were divided into four main areas. First, the influence of the testing machine was investigated, identifying the required machine components and the shape of the clamping for a homogeneous torque transmission. Furthermore, the test conditions were analyzed by considering the required clamping forces and a quasi-static test condition. Here, an analytical approach could be derived and verified which can calculate the maximum strain rate depending on the material behavior, a radius ratio, and the rotational speed. In the area of measurement technology, all influences of specimen, torque, and strain measurements were considered. Finally, the influence of specimen shape and specimen fabrication on the test results was investigated. An adapted specimen shape, which produces a homogeneous stress and strain distribution over a wide test range, was proposed for the standard. In a next step, a proposal for a test specification will be developed based on the project results.

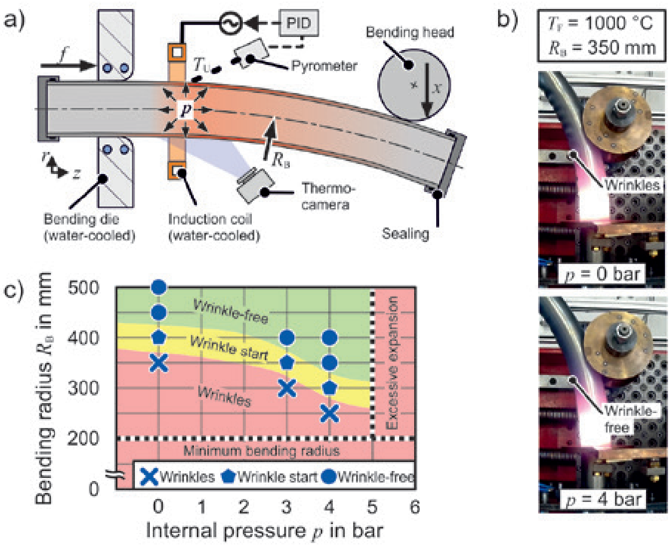


Overview of the four main fields of influences on the test results of the in-plane torsion test

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

Funding	BMWK/ZIM-ZF
Projekt	ZF4101119US9
Contact	Mike Kamaliev M. Sc.
Status	Completed

Cold forming of high-strength, closed profiles is usually associated with pronounced springback and restricted process windows. Common countermeasures are forming at elevated temperatures or stress superposition. Separately, both methods are known from the current state of the art. To combine the potential of these mechanisms, temperature-assisted internal pressure-profile forming (TIP-process) has been developed. In this process, a tube is subjected to a constant internal pressure p, locally heated to forming temperature T_F, and kinematically bent (see Figure a). Taking a ferritic stainless steel (X2CrTiNb18) as an example, with increasing internal pressure p, wrinkling at the inner bend can be minimized (see Figure b). Compared to processes without internal pressure p, forming of smaller bending radii R_B is possible (see Figure c). With heat-treatable steel, a simultaneous adjustment of the mechanical properties is possible, thus realizing the flexible production of high-strength profile components.

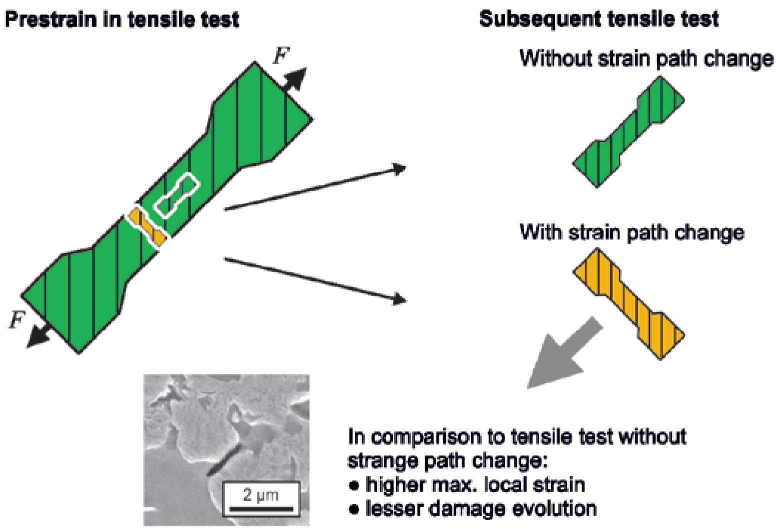


a) Experimental setup, b) Exemplary processes, c) Achieved process window expansion

2.3.3 Damage in Sheet Metal Bending of Lightweight Profiles

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

Damage evolution in the form of voids largely depends on the stress state during forming. The damage evolution during sheet bending of dual-phase steel DP800 can be reduced by compressive stress superposition. This leads to an increase in the performance of bent parts in terms of absorbed impact energy, stiffness, and fatigue strength. In addition to the influence of the stress state, the influence of load and strain path changes on damage evolution is currently being investigated. In the process chain of profile manufacturing a straight profile is produced by roll forming or by air bending and then curved by three-roll push bending or rotary draw bending. With regard to the press hardening process, damage-critical influences in hot sheet forming of 22MnB5 are also identified. Multi-stage tensile tests, among others, are carried out to investigate the strain path changes. Here, strain path changes lead to a lower increase in damage and to a higher elongation at failure compared to monotonous strain paths.

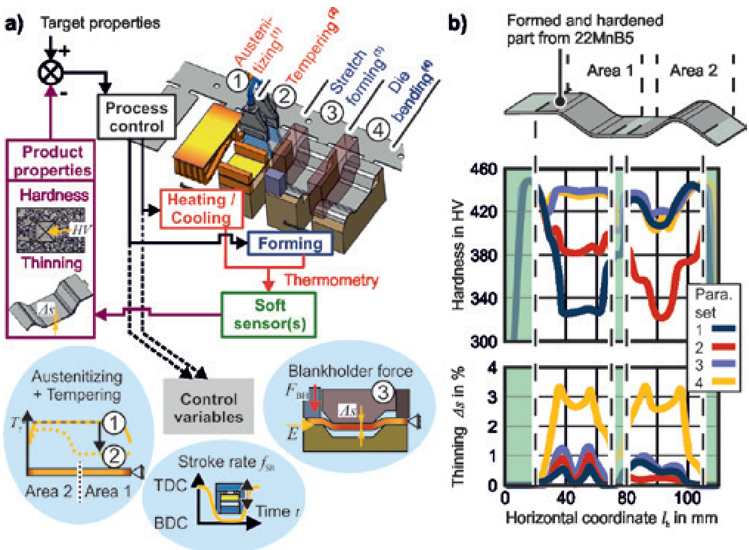


Multi-stage tensile tests on DP800

2.3.4 Property-Controlled Multi-Stage Hot Sheet Metal Forming

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

In order to realize property-controlled multi-stage hot sheet metal forming, it is crucial that the product properties can be set independently by means of suitable degrees of freedom. By integrating induction heating for austenitization, a tempering stage with combined air cooling and resistance heating, and a blankholder with variable force into a progressive die (see Figure a), additional thermal and mechanical control variables and, thus, degrees of freedom are created. Hereby, the hardness and thinning distribution in area 1 and 2 (see Figure b) of the demonstrator component is to be adjusted in a decoupled manner. This approach was verified in a simulation study. Accordingly, in multi-stage hot forming of 22MnB5 sheet material the hardness distribution can be adjusted by choosing the control variables according to parameter sets 1 to 3, while the thinning distribution remains constant. Likewise, the necessary degrees of freedom are given to adjust the hardness at constant thinning (see parameter sets 1 and 4).

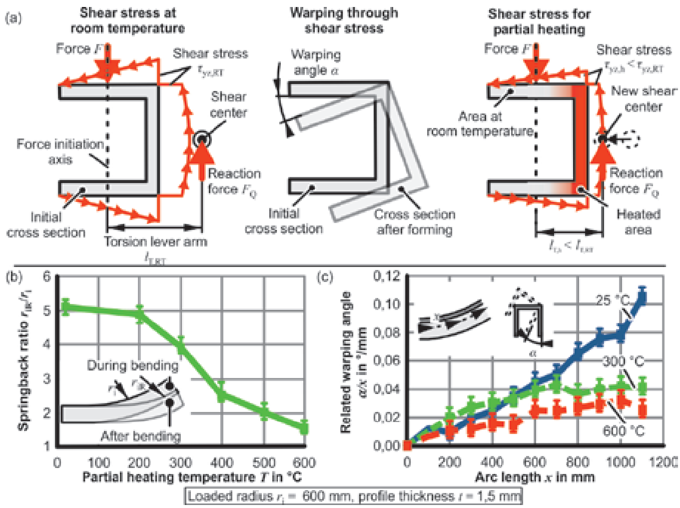


a) Control loop and tooling technology, b) Numerically determined hardness and thinning distribution for different control variable settings

2.3.5 Kinematic Profile Bending with Locally Heated Cross Section

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

The aim of the project was the evaluation of a new method to reduce warping and springback in asymmetric bending of profiles. Through the differing position of the shear center and the force initiation axis in asymmetric bending, torsion is induced in the profile which results in cross-sectional warping. At the same time, the elasticity of the material creates springback. Through selective partial inductive heating of the profile cross section, the maximum of the bending force-induced shear stresses is reduced. This leads to a shift of the shear center position in direction of the force initiation axis, resulting in a shorter torsion lever arm, effectively reducing the acting torsion moment. Springback is reduced at the same time through a global thermal softening of the profile. Lately, the process has been investigated for asymmetric bending of U-profiles consisting of S500MC steel in which a reduction of warping of up to 83% and springback of up to 69% was reached.

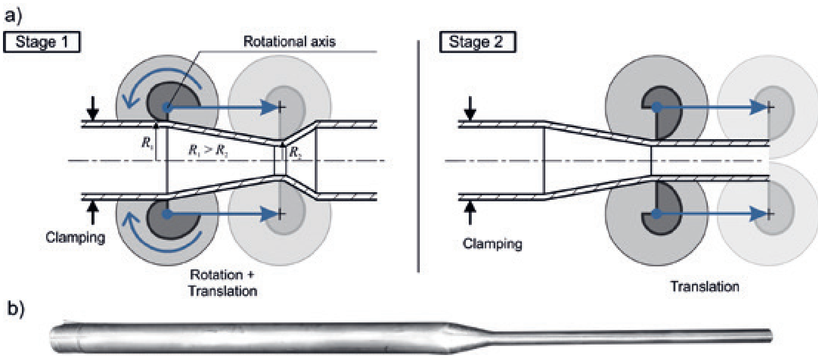


a) Principle of warping, b) springback, and c) warping for bending with partial heating

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

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

The main focus of the project, funded by the BMWK, is on the combined rolling-drawing-process in cooperation with Otto Fuchs KG and MSG Maschinenbau GmbH. Through a combination of rolling and drawing with a non-constant drawing gap, a local change or reduction of the cross-sectional geometry is carried out in this process. This reshaping results in lower material usage in production as well as reduced component weight, which can save CO_2 emissions. Possible areas of application for such load-optimized profiles can be found in various mobility applications. For this reason, the focus is on the investigation of short transition areas, small wall thicknesses, and high-strength aluminum alloys of the 7000 series. In addition to numerical analyses, tests are carried out on a test machine converted for this purpose, and analytical models are developed to predict the final geometry and the process forces.

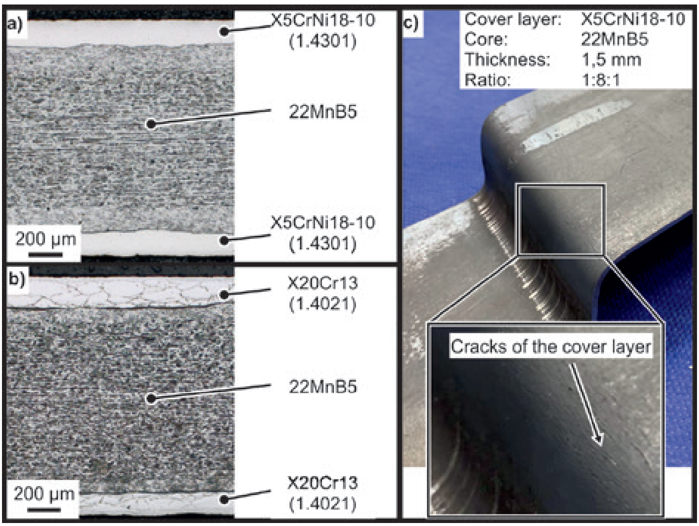


a) Combined roll gradiation process, b) Formed workpiece

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

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

In the DFG collaborative project the formability and applicability of roll-clad Cr-Mn steel composites for press hardening are being investigated together with the IBF of RWTH Aachen University. The aim of the novel material is to reduce CO_2 emissions during press hardening using more efficient heating strategies, such as resistance heating. For this purpose, the common AlSi coating is substituted by stainless steel cover layers as protection against scaling. To investigate the influence of different top layers on the composite properties, a martensitic (1.4021) and an austenitic stainless steel (1.4301) are considered in this project. In the cross-sections (Figure a-b) the formation of a material bond between the core material (22MnB5) and the cover layer is visible. Bending tests confirm that delamination during press hardening can be excluded. However, cracks occur during the production of a hat profile (Figure c), therefore an increase in formability by adjusting the production route is being investigated.

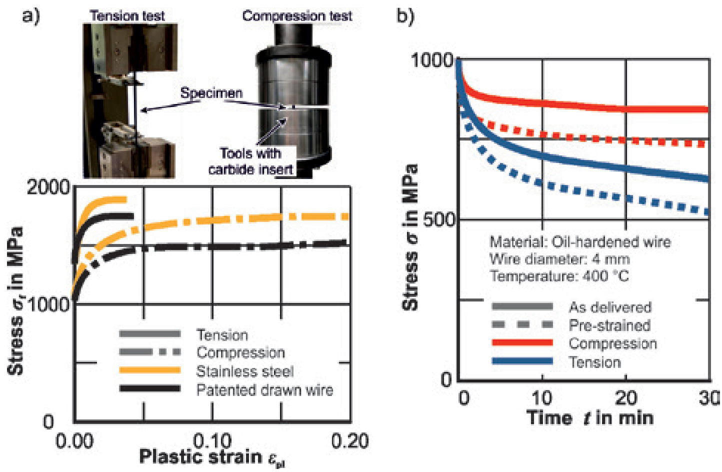


a-b) Micrographs of the composite, c) Press-hardened hat profile

2.3.8 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 multi-stage process consisting of coiling, heat treatment, and pre-setting. The geometry of the spring bodies produced by coiling is changed during heat treatment by the reduction of residual stresses and during pre-setting by plastic deformation. An analytical prediction of the change of the geometry in the heat treatment sub-process requires precise knowledge of the residual stresses. For this purpose, the forming behavior of the materials must be characterized. Investigations show a strongly anisotropic strain hardening behavior of the cold-drawn wires, which is taken into account by material models with kinematic hardening. The flow curves under tensile and compressive loading show differences of up to 15% (see Figure a). In addition to the residual stresses, the stress relief behavior during heat treatment must also be known. Relaxation tests performed on wires show that this behavior depends, among other things, on the material, the stress sign, and the forming history (see Figure b).

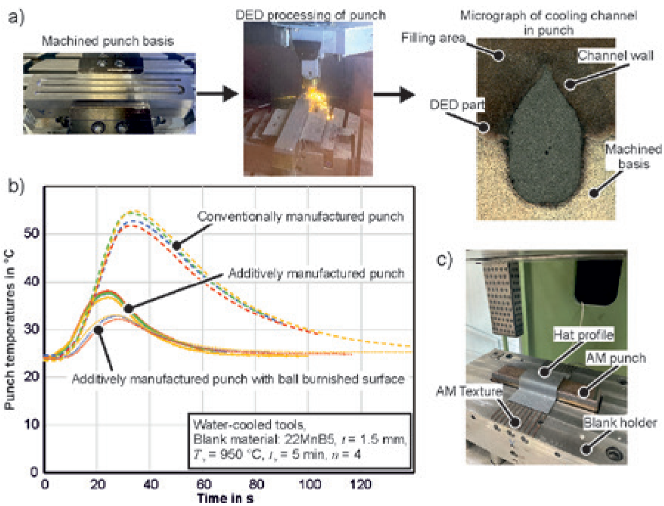


a) Flow curves from tension and compression tests, b) Stress relaxation behavior of oil hardened wire

2.3.9 Functionalization of Additively Manufactured Hot Stamping Tools Using Ball Burnishing

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

For hot stamping tools applied in sheet metal forming, cooling channels, which are usually produced by means of machining processes, are integrated into the tools to increase the parts' strength by quenching. Manufacturing of the hot stamping tools by means of Directed Energy Deposition (DED) enables the channels to be positioned close to the surface. The surface, which is very rough after the DED process, is then leveled by means of ball burnishing. In addition, the DED process allows local textures to be applied to the tool surface. For the testing of a hot stamping tool for the production of a hat profile, a continuous cooling channel groove was milled into a base material. This was closed by means of DED, so that a drop-shaped cooling channel was created in the punch. The cooling channels, which are approx. four times closer to the surface, enable the additively manufactured punch to reduce the punch temperature by up to 40%. By texturing the blank holder, it was possible to reduce the springback by a factor of six due to the more homogeneous temperature distribution in the hat profile.

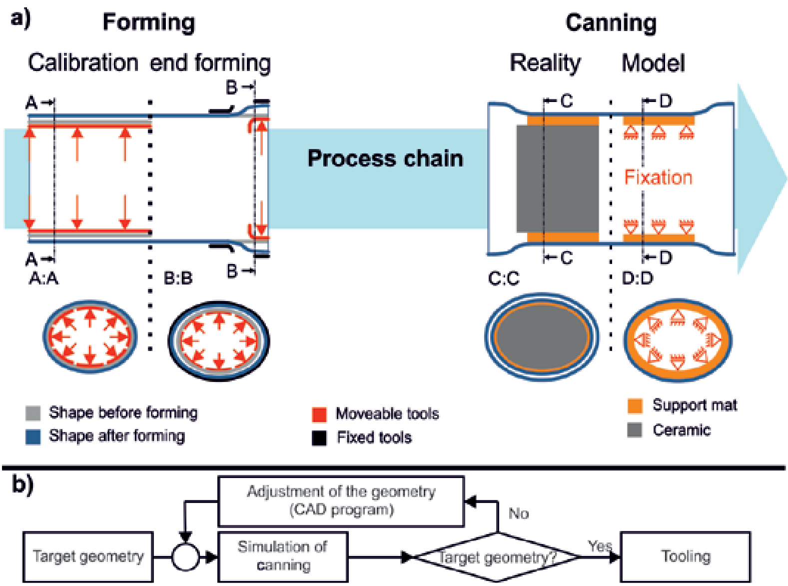


a) Manufacturing route of punch, b) Temperature measurement from: c) Hot stamping setup

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

Funding ReCIMP
Contact Markus Stennei M. Sc.
Status Completed

Modern internal combustion engines have catalytic converters as part of the exhaust system to reduce emissions. In order to realize the steadily increasing requirements for CO_2 emissions in a reduced installation space, more and more non-circular catalysts are manufactured. In this project it has already been shown that the process chain consisting of calibration, expansion, and a canning process (Figure a) can be reproduced with good accuracy using numerical simulation. However, new applications show that for rectangular components the canning process cannot be modeled by a representative pressure. For this reason, the support mat is included in the simulation as a solid. To take the large manufacturing tolerances into account, a software is being developed for the automated setup of a canning process simulation. In combination with a CAD program, this software is used to precisely adjust the deformation caused by filling and to reduce the failure rate of new production lines. The process is shown in Figure b.

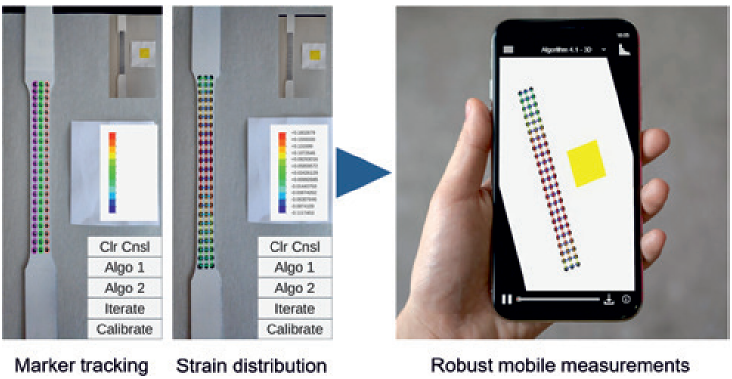


a) Process chain of catalyst, b) Optimization algorithm

2.3.11 Development of an Augmented Reality App for Optical Strain Measurements in Laboratories as Part of the CrossLab Project

Funding TU Dortmund University
Contact Joshua Grodotzki M. Sc.

Owing to the successful participation in the TU-internal competition for the promotion of innovative ideas in the field of digital laboratory teaching, an Augmented Reality app for optical strain measurements via smartphone is currently being developed at the IUL. The app enables students to independently record information about the strain distribution in different materials for which alternatively expensive measuring systems, that are complex to calibrate, would be necessary. Particularly in tensile tests, which are an elementary component of laboratory courses, the strain field measurements instead of previously simple force-displacement curves can help improve the understanding of the processes in the material. To test the robustness of the developed algorithms, synthetic test environments are used in which deviations by the users (e.g. rotation or tilt of the smartphone) are simulated. The orientation of the sample in space is determined using optical markers. Subsequently, the respective image is rotated in space in such a way that the tracked measurement points are located in one plane. From this, the corresponding distances are determined and the strains are derived. The developed app as well as instructions for preparing the test environment (including painting the specimen and illuminating the experiment) will be published upon completion of the project and, thus, will be available to all teachers and learners.

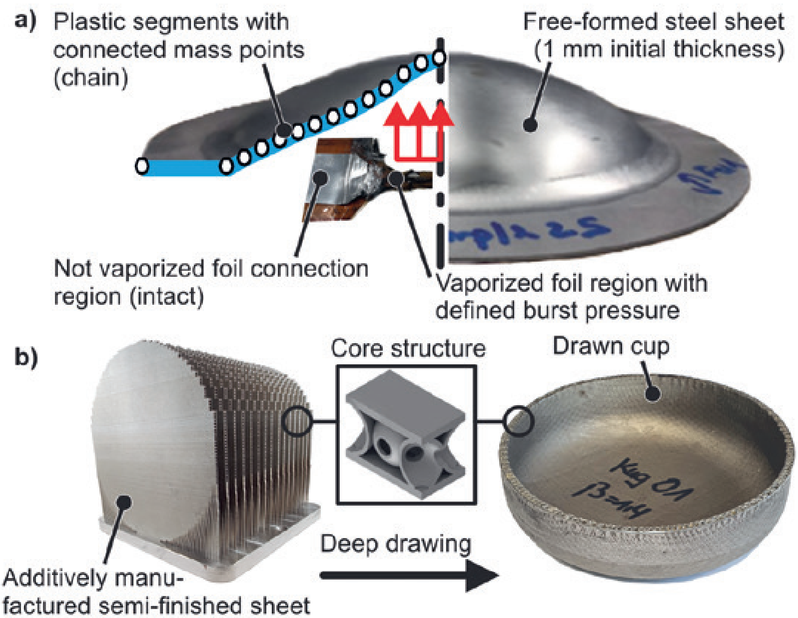


Concept of the mobile strain measurement application

2.4 Department of Non-Conventional Processes

Head Marlon Hahn M. Sc.

In this group, manufacturing processes are investigated and developed whose inherent characteristics offer advantages over conventional forming processes, such as increased forming limits or an increased efficiency. To ensure transferable knowledge, the projects include experimental, numerical, and analytical considerations. The following overarching categorization exists: high-speed forming, incremental forming, joining by forming – also of dissimilar materials –, and the utilization of novel hybrid components (both for tooling as well as semi-finished products). As an example, Figure a illustrates an efficient computational method which only takes a few seconds for the impulsive sheet metal forming by electrically vaporizing foil actuators. The example in Figure b represents the deep drawing of complex additively manufactured semi-finished sandwich structures. The examples demonstrate the diversity and interdisciplinarity of the department. The topics are currently being researched by nine scientific staff members.

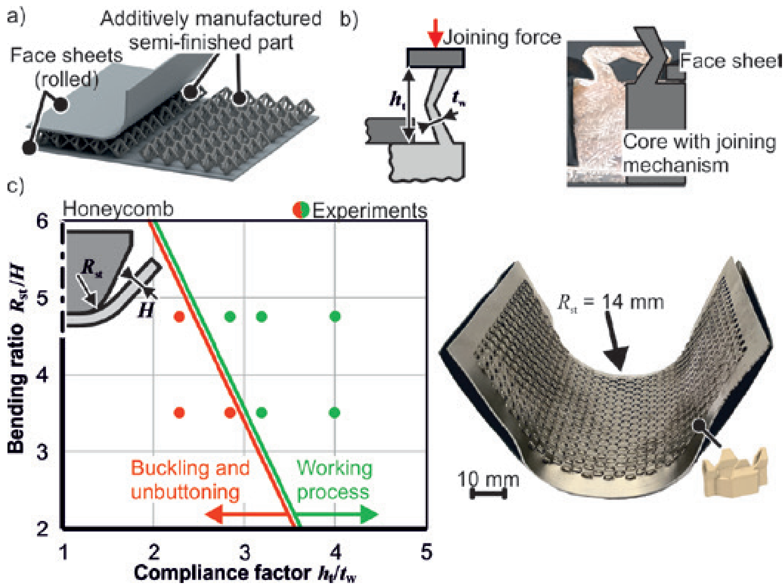


a) Selected topics: a) Vaporizing foil "chain model", b) Deep drawing of sheets with structured cores

2.4.1 Forming of Additively Manufactured Sandwich Sheets with Optimized Core Structures

Funding German Research Foundation (DFG)
Project 317137194
Contact Dr.-Ing. Stephan Rosenthal

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. Form-fit joining elements based on a buckling mechanism are used for the production of large-scale semi-finished sandwich sheets. The investigations show the feasibility of this process as well as the process limits depicted in the figure. The main failure modes are found to be the unbuttoning of the joining partners and the buckling of the face sheets. The compliance of the buckling-based joining elements is responsible for the joint strength. A high compliance requires a good overlap of the cover sheet and ensures a high joint strength.

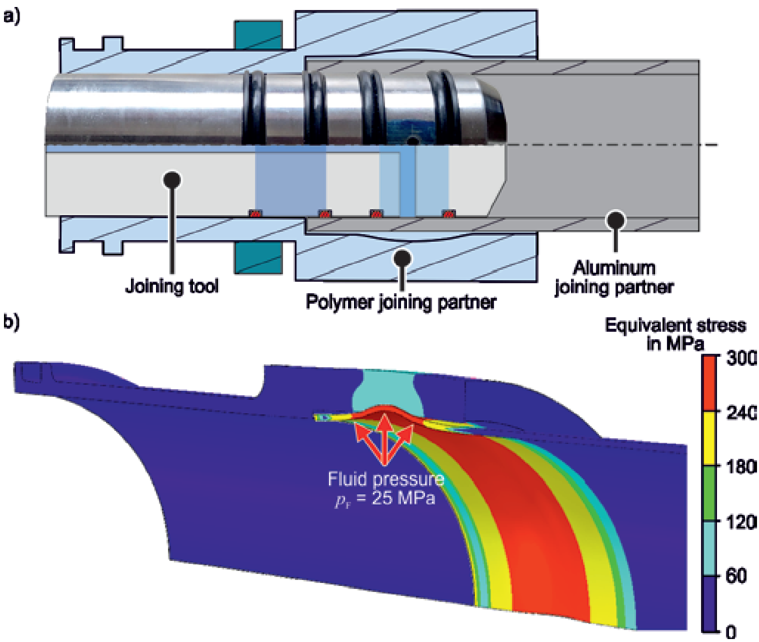


a) Large semi-finished sheet, b) Joining mechanism, c) Process window and bent component

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

Funding BMWK
Project 20W1905C
Contact Florian Weber M. Sc.

In the joint project, which started in July 2020, the IUL, together with PFW Aerospace, Steitz Präzisionstechnik, and Fraunhofer IZFP, investigates joining by forming of metal-polymer components for the use in the aerospace sector. One of the key aspects of the investigation is the varying degree of strain rate sensitivity of the materials to be joined. Highly dynamic electromagnetic and quasi-static hydraulic expansion are used to join aluminum (EN AW-6061 T6) tubes with thermoplastic polyether ether ketone (PEEK) components. In addition to the design and construction of the required joining tools, the focus of the current investigations lies on the numerical design of the joining process and the component geometries (figure). While the influence of viscoelasticity on the expansion process is of interest in the process design, the possibility of an integrated functional test is analyzed in the tool design.

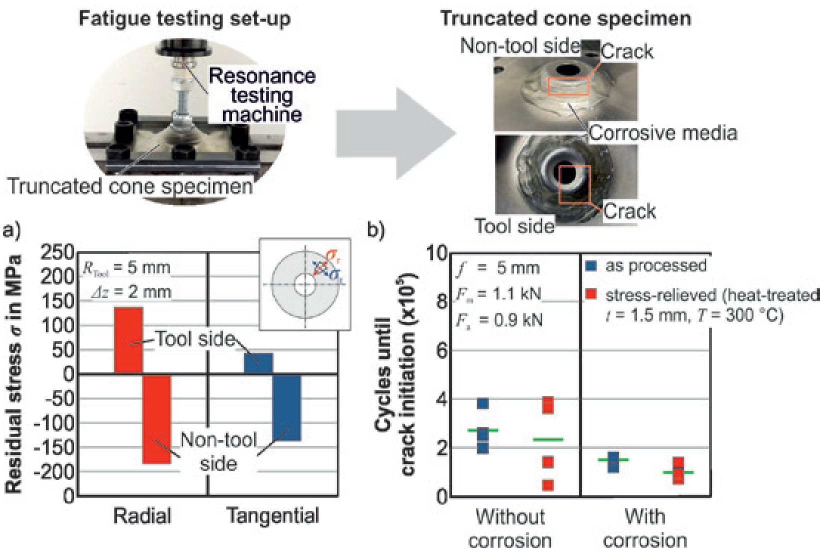


a) Initial situation of joining by hydraulic expansion, b) Numerical process design

2.4.3 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 final third funding period of the DFG priority program SPP 2013 for the targeted use of forming-induced residual stresses in metal components, the project of the IUL investigates the possibility of adjusting the corrosion properties of a component through targeted residual stress induction in cooperation with the Chair of Materials and Surface Engineering of TU Chemnitz. The aim is an improved component performance of cyclically loaded components under corrosive influence. With the incremental sheet metal forming process the near-to-surface residual stresses can be set by adjusting the process parameters. A comparison of the performance of cyclically loaded components shows an influence of the residual stresses on the corrosion effect and the time until failure of the component (figure). A maximization of the performance of cyclically loaded specimens is supposed to be achieved by a numerical prediction model of the structural strength, which takes the initial state of residual stress induced by forming as an input variable into account.

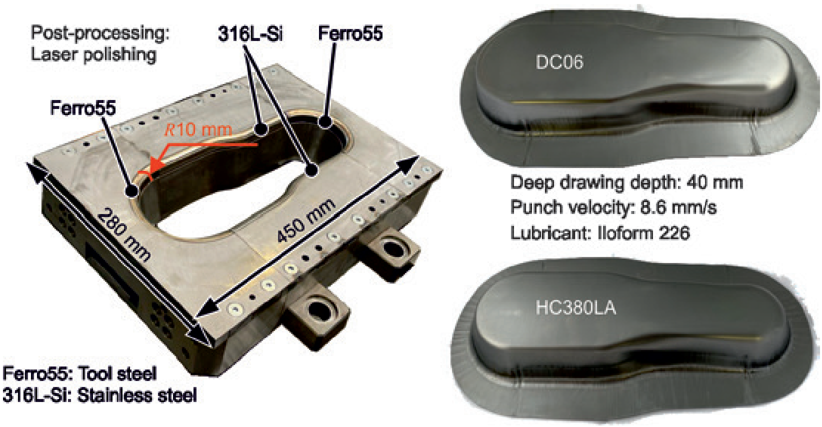


Structural strength analysis with in-situ corrosion

2.4.4 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.
Status	Completed

In this project, the fundamentals of manufacturing hybrid additive laminated tools for sheet metal forming were investigated. A developed semi-analytical model demonstrates the possibility of using low-strength tool sheets. It was shown that a laser metal deposition (LMD) joining step is first required before the remaining filling procedure of the existing stair steps to avoid thermal distortion of the sheets. Laser polishing as a post-processing method reduces the surface hardness of the die, but significantly improves the surface roughness and, most importantly, saves additional tool costs compared to ball burnishing and milling. The knowledge gained was applied to a complex deep drawing geometry (figure). Finally, a systematic economical evaluation of the hybrid process was carried out in comparison with alternative tools, and also with tools produced by LMD and milling only. It was found that the hybrid process is not only more energy efficient, but also faster for the same part weight.

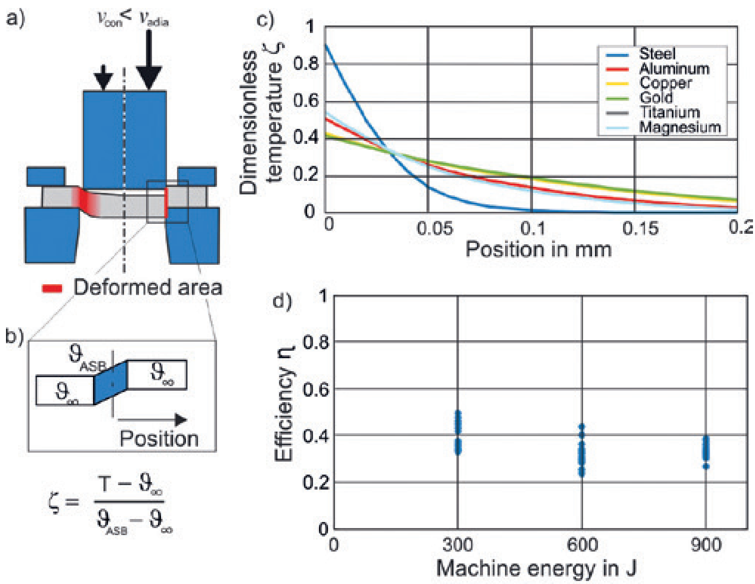


Manufactured hybrid deep drawing tool and parts

2.4.5 Application and Analysis of Adiabatic Blanking

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

In adiabatic blanking the deformation of the material is localized due to the higher process speed compared to conventional blanking (Figure a). Consequently, the heat conduction out of the forming zone is limited and it is also dependent on the thermal boundary conditions (Figure b). For the process duration ($t_{adia} \approx 0{,}2$ ms) a temperature profile and a temperature-induced softening of the material around the forming zone is obtained (Figure c). High resolution over time measurements of acceleration and force enable gathering process-relevant information for the high-speed process, such as strains at material separation and blanking speed. Tool efficiencies (Figure d) and blanking energies can, thus, be determined as a function of the machine energy. This provides the basis for a higher-level comparison of the process, which will be investigated in the scope of the research unit FOR1580 (see chapter 2.4.7). The project is conducted in cooperation with the Institute of Materials Science and Engineering (LWW) at Chemnitz University of Technology.

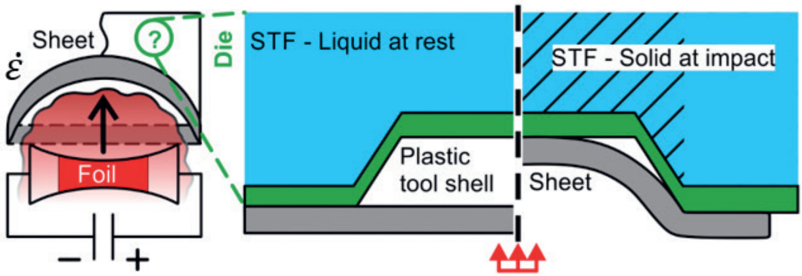


a) Process comparison, b) Thermal boundary condition, c) Temperatures, d) Tool efficiency

2.4.6 Forming by Locally Varying Vaporizing Actuators

Funding	German Research Foundation (DFG)
Project	391967465
Contact	Jan Bechler M. Sc.

The project's continuation started in September 2022. In the first phase, research focused on the basic modeling. In the second phase, the focus lies on increasing the flexibility for low part volumes. This is to be achieved primarily through the use and analysis of a novel die concept in order to reduce the dependence on massive dies that can only be used for certain component geometries. Now, the geometry is defined only by a thin, additively manufactured shell (figure). This shell is backfilled with a shear thickening fluid (STF), which is liquid in its normal state and can thus be easily refilled for other parts. Due to high strain rates during a dynamic workpiece impact, the STF solidifies quasi-instantaneously to support the resulting forces. First experiments demonstrate the functionality. In addition, the damping property of the STF minimizes rebound effects. Further work tasks include the extension of the material spectrum (titanium) and the investigation of springback with regard to pre- and post-processing methods for the semi-finished sheets.

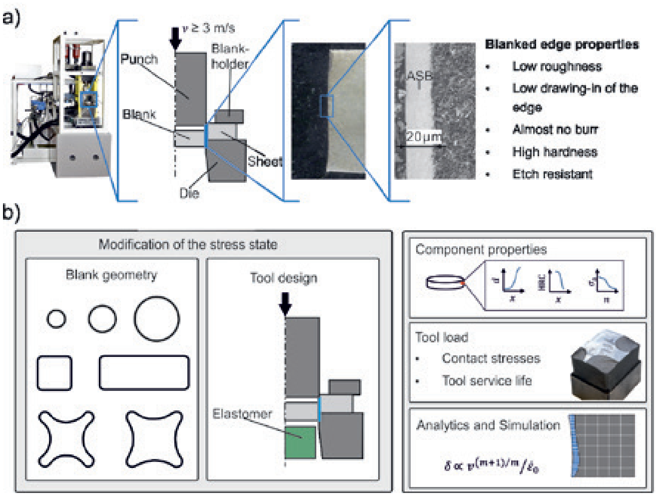


Schematic functioning of the tool concept for flexible high-speed sheet metal forming

2.4.7 Functional Surfaces Through High-Speed Adiabatic Processes: Microstructure, Mechanisms, and Model Development

Funding German Research Foundation (DFG)
Project 460484491 (FOR1580)
Contact Olaf Schrage M. Sc.

The blanked edge produced by high-speed shear cutting (HSSC) (Figure a) shows an increased geometric quality compared to the production by conventional blanking. In addition, adiabatic shear bands (ASB) can be produced within the cutting zone with suitable process parameters and workpiece materials. Compared to the base material, the changed microstructure in the ASB area significantly improves the mechanical and tribological properties. The previous research work on HSSC at the IUL will be continued and intensified in a research network with Chemnitz University of Technology, TU Dortmund University, and Technical University of Munich as well as Fraunhofer IWU (Chemnitz) and Fraunhofer IWM (Freiburg). The overall objective of the research group is a comprehensive model development of the HGSS process, incorporating the microstructural changes associated with the ASB formation under different material and process boundary conditions. At IUL, the targeted adjustment of component properties by modifying the process boundary conditions (Figure b) represents the focus of the research.

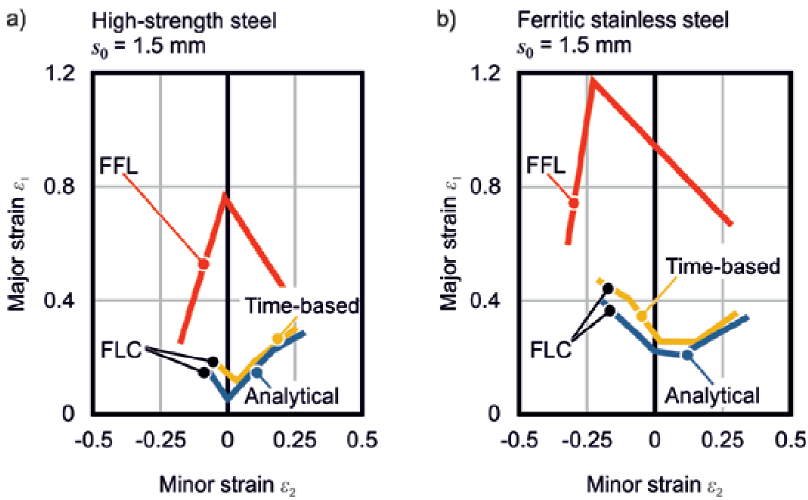


a) Schematic diagram of high-speed shear cutting, b) Focus of investigations

2.4.8 FLC Determination of Ferritic Stainless Steels and Modern Steel Grades

Funding ReCIMP
Contact Jan Bechler M. Sc.

The key element of this project is the identification of a methodology to characterize the formability of ferritic stainless steels and modern steel grades. The fracture forming limit (FFL) and the forming limit curve (FLC) are the main tools to evaluate the global and local formability. The application of a new time-dependent methodology allows a more precise determination of the forming limit curve in comparison to the standard determination. This leads to a more efficient use of the material. A lower boundary of the forming limit curve can also be determined with analytical models for high-strength steels. A statistical adaption of the analytical parameters extends the model for ferritic stainless steels. These analytical models allow a quick estimation of the forming limit for the design of a forming process. The fracture forming limit curve can be determined by the measurement of the fracture thickness and width for the materials and increases the usable forming area.

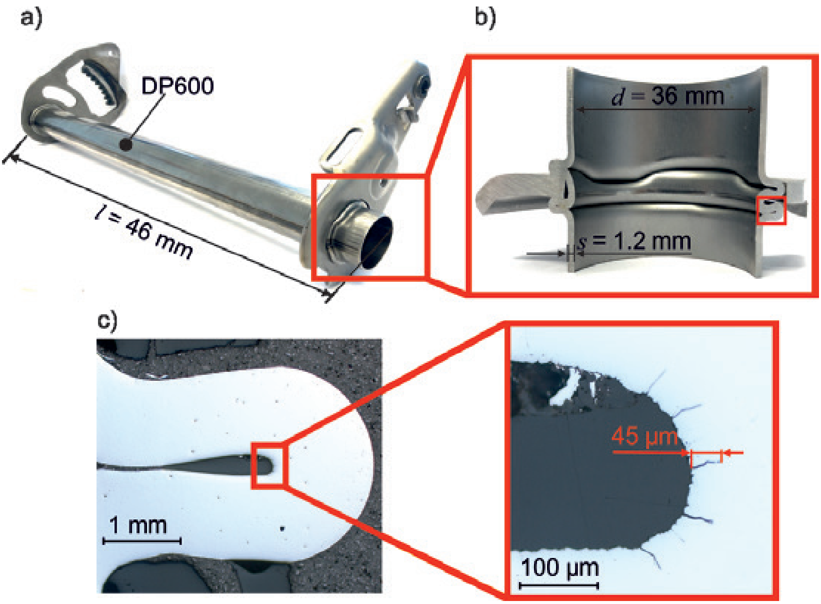


Representative FFL and FLC for a) high-strength steels and b) ferritic stainless steels

2.4.9 Forming-Controlled Fatigue Strength of Tubes

Funding ReCIMP
Contact Jan Bechler M. Sc.

In this group, manufacturing processes are investigated and developed whose inherent characteristics offer advantages over conventional forming processes, such as increased forming limits or an increased efficiency. To ensure transferable knowledge, the projects include experimental, numerical, and analytical considerations. The following overarching categorization exists: high-speed forming, incremental forming, joining by forming – also of dissimilar materials –, and the utilization of novel hybrid components (both for tooling as well as semi-finished products). As an example, Figure a illustrates an efficient computational method which only takes a few seconds for the impulsive sheet metal forming by electrically vaporizing foil actuators. The example in Figure b represents the deep drawing of complex additively manufactured semi-finished sandwich structures. The examples demonstrate the diversity and interdisciplinarity of the department. The topics are currently being researched by nine scientific staff members.

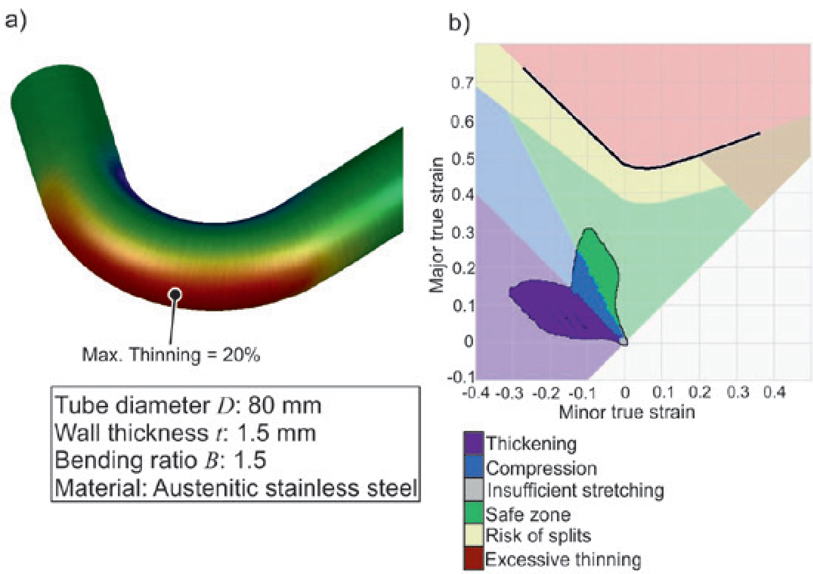


a) Height adjustment system, b) Cross section of the joints, c) Initial cracks at the inner bending radius

2.4.10 Prediction of Wall Thinning during Rotary Draw Bending of Tubes

Funding ReCIMP
Contact Dr.-Ing. Stephan Rosenthal
Status Completed

Austenitic stainless steel offers almost twice the formability of ferritic stainless steel. By contrast, the production of austenitic stainless steels results in CO_2 emissions which are roughly twice as high. The substitution of austenitic stainless steels can thus be a measure to reduce CO_2 emissions in the rotary draw bending of exhaust gas components. In this project, experimental, numerical, and analytical investigations were combined to analyze the thinning behavior of both materials (see Figure a). Based on this analysis, an analytical model was developed to predict wall thinning. Based on this model, as well as on the analysis of the deformation paths (see Figure b), process windows can be derived for the use of ferritic stainless steels in rotary draw bending. The developed process window comprises a large number of different geometric parameter combinations so that the resulting thinning can be predicted during process design.



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

We gratefully acknowledge the funding of our research projects by:

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Further Activities

03

3 Further Activities

3.1 Awards

Prof. Tekkaya receives SME Gold Medal

For more than six decades the non-profit organization SME has honored leading personalities from industry and business whose work has led to decisive breakthroughs and advances in manufacturing technologies, processes, and education. On May 15, 2022, Prof. Tekkaya was awarded the SME Gold Medal at the "SME International Awards Gala" in Detroit. The award recognizes outstanding contributions to manufacturing technology through technical publications and lectures. This year, Prof. Tekkaya is the only European member honored. Since its formation as the membership organization "American Society of Tool Engineers" 90 years ago, the non-profit organization SME has been working to find solutions to the changing challenges of the manufacturing industry with the goal of advancing manufacturing technology and industry through research, networking, and qualification.

Prof. Tekkaya at the award ceremony in Detroit, USA

IUL wins outstanding paper in manufacturing processes at NAMRC 2022

The paper "A control strategy for incremental profile forming" of authors R. Nakahata (The Ohio State University, OSU), S. Seetharaman (OSU), K. Srinivasan (OSU), and A. E. Tekkaya (TU Dortmund University, IUL) won the award for "Outstanding Paper in Manufacturing Processes" at the North American Manufacturing Research Conference (NAMRC) 2022. NAMRC is recognized as North America's preeminent and longest-running international forum for applied research and industrial applications in manufacturing and design. The study discusses the development of a geometry-based online control for the Incremental Profile Forming process (IPF). The IPF process is used to produce tubular parts with varying cross-sections in axial tube direction. However, the geometrical accuracy of the produced parts is yet low. The developed control models is supposed to increase the accuracy of the produced parts through the simultaneous geometry measurement by laser triangulation. Through the achieved results the understanding of the forming process has been increased and the expanded process accuracy shall also increase the attractiveness of the process for industrial application.

3.2 Events

“Impulses and Innovations in Metal Forming” - Celebrations on the occasion of the IUL’s 50th anniversary

Celebrating 50 years of Forming Technology in Dortmund: On September 8 and 9, 2022, the anniversary celebration of the Institute of Forming Technology and Lightweight Components (IUL) took place in Dortmund. Many companions of the institute from Germany and abroad accepted the invitation and took the festivities as an opportunity for a professional and personal exchange.

On the first day of the festivities the technical symposium “Impulses and Innovations in Metal Forming” was dedicated to the future of forming technology. The international audience was able to discover innovations and the latest processes in six exciting presentations in the fields of sheet metal forming, production of forming machines, forming simulations, material characterization, impulse and high-speed forming, and data-driven models in sheet metal forming. The guests had lively discussions after the presentations with the contributing professors Zhigang Wang (Japan), Peter Groche (Germany), Frédéric Barlat (South Korea), A. Erman Tekkaya (IUL), Glenn Daehn (USA), and Dirk Mohr (Switzerland) from international research institutions.

The second day of the event celebrated a half-century of the institute’s history in all its facets. Distinguished guests from the Ministry of Culture and Science of the State of North Rhine-Westphalia, universities, industry, and associations honored the institute’s successes and developments and emphasized the good cooperation over the past decades in their speeches. IUL alumni honored 50 years of the institute’s history by looking back on the beginnings of the institute, which was established in 1972 under the direction of Professor Eberhard von Finckenstein as the Chair of Forming Manufacturing Processes (Lehrstuhl für Umformende Fertigungsverfahren). The chair was founded soon after the founding of Universität Dortmund (later TU Dortmund University). Finally, the speakers illustrated the path to today’s Institute of Forming Technology and Lightweight Components (IUL) under the direction of Professor Matthias Kleiner and Professor A. Erman Tekkaya. Today, the institute is one of the most internationally renowned and largest institutes in its field. It is characterized by broad-based, excellent research and a high level of education for students and young scientists. A special moment was also the tribute to Professor Kleiner on the occasion of his retirement. The attendants of the festivities gave a warm welcome to Gerd von Finckenstein, the son of Professor Eberhard von Finckenstein.

During the ceremony, the institute's staff informed the guests about the latest technological developments in forming technology during guided lab tours and demonstrated processes on the machines in the experimental hall. Another highlight was the bicycle tour starting from the institute to Thyssenkrupp's Rothe Erde site in Dortmund. There, on a guided tour of the plant site, the participants gained insight into the production of large-diameter antifriction bearings and seamless rolled rings. The tour continued through the western city center and past the stadium of Dortmund's famous soccer club BVB 09 back to the IUL.

Photo collage with impressions from the two-day celebration

Institute excursion of the IUL team

The IUL team enjoyed a bicycle tour on August 17, 2022, which was the institute's first excursion since the beginning of the Corona pandemic. The excursion was accompanied by gorgeous weather and the IUL team cycled towards Witten along one of the region's best-known and most popular railway cycle paths, the "Rheinischer Esel". The tour's destination was the company hpc (High Precision Components Witten GmbH). After a warm welcome the group was given a guided tour through the various production halls of the company with interesting insights into the processes at a medium-sized company in the field of production and forming technology. Our thanks to all employees of the company hpc involved! After a little refreshment the group headed back to the IUL where the day was rounded off with a friendly get-together.

The IUL team at the "Rheinischer Esel"

Open Day of TU Dortmund University 2022

Together with the colleagues of the materials test engineering and machining technology, the IUL was again extensively involved in this year's Open Day at TU Dortmund University. For a total of five hours, interested visitors were able to explore the IUL's experimental field and gain insights into the basics as well as current research topics during the guided tours. Machines for bulk forming and additive manufacturing, i.e. the production of modern forming tools, were demonstrated live so that the visitors could get a first-hand impression of forming technology. Afterwards, a blacksmith invited visitors to do it themselves. Using their own muscle power, visitors were able to form a nail into its final shape in the traditional manner, in the style of established craftsmanship. In addition, the guests were offered coffee and cake. Young visitors had the opportunity to design magnetic or attachable buttons, which were then pressed into their final shape in a short sheet metal forming process. This laid the foundation for an increased interest in the field of engineering at an early stage.

Visitors in the IUL experimental hall at the Open Day of TU Dortmund University 2022

Meeting of the IUL Industrial Advisory Board

The IUL Industrial Advisory Board currently consists of 23 industrial companies and research associations. In semi-annual meetings, experiences in the field of forming technology and lightweight components are exchanged. The impulses from industry enable us at the IUL to focus our research work on industry-relevant problems. In return, the participants benefit from the exchange of current research results. On June 3, 2022, the Industry Advisory Board met for the 22nd time and for the first time in-person since the beginning of the corona pandemic. The fact that this had been long awaited by all participants was expressed not least in the high number of participants. Even if in the past years a professional exchange could be maintained by online conferences, it is the personal discussions during coffee and lunch that make up the character of this event. This time, the discussion focused on the topic of "Stress superposition in forming technology". In his talk, Prof. Tekkaya presented some basic principles and gave numerous examples of how stress superposition has a positive effect on forming processes as well as on the resulting components.

The 23rd meeting of the Industrial Advisory Board took place on December 6, 2022. Appropriately for St. Nicholas Day, the participants were welcomed with a "Stutenkerl". After the presentation of the current developments at the IUL, in which Prof. Tekkaya was able to report on some social activities again this time, Dr. Clausmeyer gave a deeper insight into the recently approved sub-project on adiabatic shear cutting within the framework of research group 5380. With an exciting presentation on multifunctional tool coatings for injection moulding, Dipl.-Ing. Marius Fedler from the Kunststoff-Institut für die mittelständische Wirtschaft NRW GmbH gave impulses for further discussions.

Participants of the 22nd meeting of the Industrial Advisory Board of 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:

• Girls*Day 2022 • April 28
• SchnupperUni • August 1-5

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”
- DGM – Member of “Deutsche Gesellschaft für Materialkunde”
- EuraSEM - Council member of the „European Society of Experimental Mechanics“
- FOSTA – Member of the Advisory Board of the “German Steel Federation” (“Forschungsvereinigung Stahlanwendung 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 – Chairman of the Standing Advisory Board of the “International Conference on Technology of Plasticity”
- IDMEC – Member of the ”International Scientific Advisory Council of Institute of Mechanical Engineering“
- JSTP – Member of the “Japan Society for Technology of Plasticity”
- LAETA – Member of the “Associated Laboratory for Energy, Transports and Aerounautics“
- Head of “Research Center for Industrial Metal Processing“ (ReCIMP)
- Member of “DGM-Regionalforum Rhein-Ruhr”
- SME – Member of the “American Society of Manufacting Engineers“
- WGP – Member of the “German Academic Society for Production Engineering” (“Wissenschaftliche Gesellschaft für Produktionstechnik”)

Journals/Editorship

- Deputy Editor, “Elsevier Series in Plasticity of Materials”
- Editor-in-Chief, “Advances in Industrial and Manufacturing Engineering (AIME)” (Elsevier)
- Member of the Advisory Board, “Journal for Economic Factory Operation“ (ZWF) („Zeitschrift für wirtschaftlichen Fabrikbetrieb“)
- 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”

In Scientific Committees

- AiF – German Federation of Industrial Research Associations („Arbeitsgemeinschaft industrieller Forschungsvereinigung “Otto von Guericke” e. V.“)
- ANR – French National Research Agency
- CIRP – International Academy for Production Engineering
- DFG – German Research Foundation
- ESF College of Expert Reviewers
- ICFG – International Cold Forging Group
- KIT – Karlsruhe Institute of Technology

- MIT – Massachusetts Institute of Technology, USA
- The Ohio State University, USA
- University of Duisburg-Essen, Germany
- Unversity of New Hampshire, USA
- University of Waterloo, Canada

For Journals

- Acta Materialia
- Additive Manufacturing
- 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
- Engineering Fracture Mechanics
- Energy Reports
- Engineering Research ("Forschung im Ingenieurswesen")
- Engineering with Computers
- 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
- European Academy of Sciences and Arts
- German Academy of Natural Scientists Leopoldina
- Indian National Science Academy
- Swiss Academy of Engineering Sciences

Advisory Boards

- Advisory Committee Japan Science and Technology Agency (JST) Tokyo
- Board of Trustees, Max Planck-Institute of Molecular Cell Biology and Genetics, Dresden
- Member of the Supervisory Board Futurium gGmbH
- Member of International Advisory Board of Moonshot R&D at Japan Science and Technology Agency (JST) Tokyo
- STS Council and Board – STS-Forum Science and Technology in Society, Japan

University Advisory Boards

- Board of Trustees, Julius Maximilian-University Würzburg
- Board of Trustees, TU Berlin
- Board of Trustees, Paris Lodron Universität Salzburg
- International Advisory Board Faculty of Engineering, Twente University
- Scientific Advisory Board BTU Cottbus-Senftenberg

Foundation Advisory Boards

- Advisory Board, Werner Siemens-Stiftung, Switzerland
- Board of Trustees, Deutsche Telekom Foundation

Professional Chairs

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

Consultant and Advisory Board

- Member of the Jury for the “Deutscher Innovationspreis”
- Member of the Jury of the Georg von Holtzbrinck Prize for Science Journalism
- Tang Prize International Advisory Board, Taipei

Cooperation Advisory Boards

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

International Exchange

04

4 International Exchange

Prof. Frédéric Barlat

Prof. Frédéric Barlat from the "Graduate Institute of Ferrous Technology" of Pohang University of Science and Technology in South Korea visited the IUL from September 1 to 22. The internationally renowned expert for anisotropic plasticity discussed with Prof. Tekkaya and the interested staff the current research at the institute. Here, he contributed to the research work in the area of modeling anisotropy and the Bauschinger effect. At RWTH Aachen University, he held a hybrid presentation on the influence of hydrostatic stresses on the plastic behavior of high-strength steels to the TRR 188 scientists. In the subsequent discussions with the TRR 188 members, he showed great interest in the new findings from the area of his dissertation topic: ductile damage.

Prof. Frédéric Barlat

Dr. Abhijit Brahme and Dr. Waqas Muhammad

Dr. Till Clausmeyer and Dr. Waqas Muhammad in front of a testing machine

The visits of Dr. Waqas Muhammad (October 5-17) and Dr. Abhijit Brahme (November 23 until December 8) deepened the Institute's collaboration with the Computational Mechanics Research Group at the University of Waterloo in Canada towards the end of 2022. The IUL and the group of Prof. Kaan Inal (Mercator Fellow in SFB/CRC 188) collaborate on the topics of modelling and characterisation of damage in forming technology. The intensive collaboration is reflected in two jointly supervised Master's theses, a conference paper and an article in an SCI journal on the prediction of void area fraction with neural networks based on microstructure data. Dr. Muhammad presented his work on predicting the mechanical behaviour of aluminium alloys using machine learning. Dr. Brahme presented a very fast approach

Dr. Abhijit Brahme and Jan Gerlach at IUL's Christmas party

developed in Waterloo for calculating material behaviour using crystal plasticity to the CRC 188 contributors during his visit to Aachen.

Visit of Prof. Yoshinori Yoshida at the IUL

On December 8 and 9, 2022, Prof. Yoshinori Yoshida from Gifu University in Japan and his two students Mr. Takashi Matsunaga and Mr. Kaito Amakusa were guests at the IUL. Prof. Yoshida is the director and coordinator of the student exchange program "G-CADET". The aim of this program presented at the IUL is to expand the international cooperation in engineering sciences. We are very pleased that, after a break due to Corona, we will be able to welcome Japanese students in Dortmund again next year and that German students will be able to start their journey to Japan. In addition to the lecture by Prof. Yoshida, Mr. Matsunaga gave a lecture entitled "Automatic identification of hot forging parameters; heat transfer coefficient and friction" and Mr. Amakusa presented his research results on "Optimization of process condition for powder bed fusion additive manufacturing".

Presentation on the G-CADET program

International Exchange

04

Technical Equipment

05

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

- Equibiaxial compression testing machine, self-built at IUL
- 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, RIO1074-8-00-3 by Rio
- Laser surface velocimeter for non-contact velocity measurement,
  LSV-200 bei Polytec
- 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, 38DL PLus by Olympus
- X-ray diffractometer for measuring residual stresses, Xstress 3000 by Stresstech

Miscellaneous

- Autonomous mobile robot, LD-90 by Omron
- 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
- High-temperature chamber furnaces, up to 1200° C and 160 l volume, N60/65 HA, N120/85 HA and N161 by Nabertherm
- Hydraulic power units and pressure intensifiers up to 4000 bar (3x)
- Hydrostatic roller burnishing tools with and without couplings for atomatic tool change, 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
- Power source for resistance welding, 500 kW, Genius HWI 436WA by Pro-Con / Harms & Wende
- 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 2022 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 2022 which have added to our joint success.

Industriebeirat des IUL | IUL Industrial Advisory Board

Das Gremium des Industriebeirates vermittelte auch im Jahr 2022 wichtige Impulse hinsichtlich des industriellen Forschungsbedarfes. An dieser Stelle möchten wir uns für diese wertvolle Zusammenarbeit bedanken.

In 2022, 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.

- Dr. Denise Beitelschmidt, Zwick GmbH & Co. KG
- 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
- Dr. Gerhard Hammann, TRUMPF Werkzeugmaschinen GmbH & Co. KG
- Dr. Jens Heidenreich, PHOENIX FEINBAU GmbH & Co. KG
- 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
- Dr. Roald Lingbeek, Autoliv Inc.
- Hans Mulder, Tata Steel Research & Development Product Application Centre
- Dr. Ingo Neubauer, simufact engineering GmbH
- Franz-Bernd Pauli, Franz Pauli GmbH & Co. KG
- Rainer Salomon, Forschungsvereinigung Stahlanwendung e. V. (FOSTA)
- 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
- Dr. Andres Weinrich, Verband der Deutschen Federnindustrie e. V. (VDFI)

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
- Fraunhofer-Institut für Werkstoffmechanik, Chemnitz
- Fraunhofer-Institut für Werkzeugmaschinen und Umformtechnik, Chemnitz
- Fraunhofer-Institut für Werkstoffmechanik, Freiburg
- Gemeinschaftslabor für Elektronenmikroskopie, Rheinisch-Westfälische Technische Hochschule Aachen
- Institut für Angewandte Materialien – Werkstoffkunde, Karlsruher Institut für Technologie (KIT)
- Institut für Aufbereitungsmaschinen und Recyclingsystemtechnik, Technische Universität Bergakademie Freiberg
- 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 Leichtbau und Kunststofftechnik, Technische Universität Dresden
- 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 Werkstoffwissenschaft, Technische Universität Dresden
- Institut für Werkzeugmaschinen und Betriebswissenschaften, Technische Universität München
- Institut für Werkzeugmaschinen und Fabrikbetrieb, Technische Universität Berlin
- Laboratorium für Werkstoff- und Fügetechnik, Universität Paderborn
- Lehrgebiet Konstruktions- und Fertigungstechnik, Hochschule Hamm-Lippstadt
- Lehrstuhl für Automatisierungs- und Regelungstechnik, Christian-Albrechts-Universität zu Kiel
- 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 Werkstoff- und Oberflächentechnik, 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, Yanagido, 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
- AUDI AG
- AutoForm Engineering Deutschland GmbH
- Autoliv Inc.
- Baoshan Iron & Steel Co. Ltd.
- Benteler International AG
- Bilstein GmbH & Co. KG
- BMW AG
- BÖHLER-UDDEHOLM Deutschland GmbH
- borit Leichtbau-Technik GmbH
- Brand KG
- CARL BECHEM GMBH
- CENIT AG
- Centroplast Engineering Plastics GmbH
- C-TEC Constellium Technology Center
- Daimler AG
- data M Sheet Metal Solutions GmbH
- Deutsche Edelstahlwerke Specialty Steel GmbH & Co. KG
- DYNAmore GmbH
- ElringKlinger AG
- Erichsen GmbH & Co. KG
- F. W. Brökelmann Aluminiumwerk GmbH & Co. KG
- Festo SE & Co. KG
- FLORA Wilh. Förster GmbH & Co. KG
- Forvia Faurecia
- 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
- GKN Driveline Deutschland 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

- Ingenieurbüro Peter Baumgart
- 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
- Novelis Deutschland 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
- simufact engineering gmbh
- 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
- TK Oberfläche GmbH
- TM Lasertechnik GmbH
- transfluid Maschinenbau GmbH
- transvalor S.A.
- Trimet Aluminium SE
- TRUMPF Hüttinger GmbH + Co. KG
- TRUMPF Werkzeugmaschinen GmbH + Co. KG
- Uddeholms AB
- Viessmann Werke GmbH & Co. KG
- voestalpine AG
- voestalpine High Performance Metals Deutschland GmbH
- Vossloh AG
- wefa Westdeutsche Farben GmbH
- Welser Profile Deutschland GmbH
- Weseralu GmbH & Co. KG
- 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.
- I²FG – 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]

Ali, Md Ammar
Tekkaya, A. E.; Selvaggio, A.
Implementierung und Bewertung eines Verschweißkriteriums zur Vorhersage der Schweißnahtqualität beim direkten Strangpressen von spänebasierten Pressbolzen
Implementation and Evaluation of a Weld Criteria to Predict the Weld Quality During Direct Hot Extrusion of Chip Based Billets

Amarendra, Amar Kumar
Tekkaya, A. E.; Kamaliev, M.
Mikrostrukturelle Entwicklung durch Warmumformung von hochfesten Aluminiumlegierungen
Microstructural Evolution Through Hot Die Forming of High Strength Aluminium

Bechler, Jan
Tekkaya, A. E.; Stiebert, F.
Analyse des Kerbschlagverhaltens von tiefgezogenen Bauteilen bei tiefen Temperaturen
Analysis of the Impact Behavior of Deep Drawn Components at Low Temperatures

Bilgic, Muhammed
Tekkaya, A. E.; Schowtjak, A.
Simulation von Umformprozessen mittels neuronaler Netze
Simulation of Forming Processes Using Neural Networks

Borek, Martin
Tekkaya, A. E.; Maaß, F.
Experimentelle und numerische Eigenspannungsanalyse für die kombinierte zug- und druckspannungsüberlagerte inkrementelle Blechumformung
Experimental and Numerical Residual Stress Analysis of Combined Tensile and Compressive Stress-Superposed Incremental Forming

Flesch, Jan
Tekkaya, A. E.; Kamaliev, M.
Prozessrealisierung der isothermen Warmumformung mittels Innenhochdruck
Process Realization of Isothermal Hot Forming With Internal Pressure

Göppert, Pascal
Tekkaya, A. E.; Gebhard, J.
Herstellung aufschäumbarer Halbzeuge mittels Spänestrangpressen
Production of Foamable Semi-Finished Profiles by Chip Extrusion

Hmeidan, Mohamed
Tekkaya, A. E.; Lennemann, P.
Lastpfadbeeinflussung beim Biegen von V-Profilen
Influencing the Strain Path in Bending of a V Section

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

Huddar, Gomatesh
Tekkaya, A. E.; Hoenen, N.
Experimentelle und numerische Untersuchung eines kombinierten Walz- und Ziehprozesses für Rohre
Experimental and Numerical Study of Combined Rolling and Drawing Process of Tubes

Koppka, Lena
Tekkaya, A. E.; Gerlach, J.
Modellierung der Schadensentwicklung mittels Deep Learning mit Anwendung auf die Metallumformung
Modelling of Damage Evolution Using Deep Learning With Application to Metal Forming

Lu, Yang
Tekkaya, A. E., Weber, F.
Elektromagnetisches Fügen von Metall-Polymer-Verbindungen
Electromagnetic Joining of Metal-Polymer-Joints

Marín Velásquez, Gabriel
Tekkaya, A. E.; Komodromos, A.
Untersuchung eines mittels Laserpulverauftragsschweißens hergestellten Presshärtewerkzeugs mit oberflächennahen Kühlkanälen
Investigation of a Hot Stamping Tool With Near-Surface Cooling Channels Manufactured by Directed Energy Deposition

Ogunsolu, Oluseyi
Tekkaya, A. E.; Goyal, S.
Optimierung von Stützstrukturen zur Vermeidung der Plastifizierung von Hybridspulen bei elektromagnetischer Umformung
Optimization of Support Structures for Prevention of Plasticization of Hybrid Coils in Electromagnetic Forming

Schmidt, Lukas
Tekkaya, A. E.; Martschin, J.
Regelungsorientierte Berechnung des Kontaktdrucks beim mehrstufigen Presshärten im Folgeverbundwerkzeug abhängig von der Blechdickenverteilung
Control-Oriented Calculation of the Contact Pressure During Multi-Stage Press Hardening in the Progressive Die Depending on the Sheet Thickness Distribution

Schrage, Olaf
Tekkaya, A. E.; Seetharaman, S. (The Ohio State University, USA)
Analytische und rechnergestützte Modellierung der Reaktion von zylindrischen Schalen auf radiales Eindrücken
Analytical and Computational Modeling of the Response of Cylindrical Shells to Radial Indentation

Schulz, Oliver
Tekkaya, A. E.; Stiebert, F.
Untersuchung und Erweiterung des ebenen Torsionsversuchs mit radialer Zugspannungsüberlagung
Investigation and Extension of the In-Plane Torsion Test With Radial Tensile Stress Superposition

Yu, Wei
Tekkaya, A. E.; Kamaliev, M.
Bestimmung von Fließkurven durch den Hot-Tube-Bulge-Test
mit Regelung der Dehnrate
Determination of Strain Rate Controlled Flow Curves Using the Isothermal Hot Tube Bulge Test

Abgeschlossene Bachelorarbeiten | Completed Bachelor of Science Theses

Bechler, Niklas
Tekkaya, A. E.; Rosenthal, S.
Formschlüssiges Fügen zur Herstellung von Sandwichblechen mit additiv gefertigtem Kern
Joining by Forming to Produce Sandwich Sheets With Additively Manufactured Core Structures

Becirevic, Emina
Tekkaya, A. E.; Stiebert, F.
Herstellung und Charakterisierung von ultradünnen, feinkörnigen Folien aus 1.4404 für Bipolarplatten
Production and Characterization of Ultra-Thin, Fine-Grained Foils Made of 1.4404 for Bipolar Plates

Deng, Chenrui
Tekkaya, A. E.; Stennei, M.
Einfluss der Erwärmungsstrategie auf die Austenitisierungstemperatur bei einem martensitischen Edelstahl
Influence of the Heating Strategy on the Austenitizing Temperature for a Martensitic Stainless Steel

Dimas Zekri, Fiona
Tekkaya, A. E.; Martschin, J.
Untersuchung der Herstellung von Exzenterschneckenrotoren mit der inkrementellen Profilumformung
Analysis of the Production of Eccentric Screw Rotors by Using the Incremental Profile Forming Process

Harnisch, Philipp
Tekkaya, A. E.; Martschin, J.
Charakterisierung des Einflusses der thermomechanischen Historie beim mehrstufigen Presshärten von 22MnB5 auf die Fließkurve
A Characterization of the Influence of the Thermomechanical History in Multi-Stage Press Hardening of 22MnB5 on the Flow Curve

Heideck, Philipp
Tekkaya, A. E.; Grodotzki, J.
Entwicklung eines Fachlabors zur additiven Fertigung in der Umformtechnik
Development of a PBL Laboratory for Additive Manufacturing in Forming Technology

Hövener, Maximilian
Tekkaya, A. E.; Wernicke, S.
Entwicklung einer Berechnungsvorlage zur universellen Auslegung von Wärmeüberträgern für die Blechmassiv-Warmumformung
Development of a Calculation Template for the Universal Design of Heat Exchangers in Plate Forging

Horstmann, Christopher
Tekkaya, A. E.; Maaß, F.
Experimentelle Untersuchungen zur Separierung des Eigenspannungseinflusses
Experimental Analysis for Separation of the Influence of Residual Stresses

Inoglu, Oguzhan
Tekkaya, A. E.; Rethmann, P.
Berücksichtigung der Umformhistorie gezogener Drähte durch kinematische Verfestigung bei der Simulation des Federwindens
Simulation of Spring Coiling With Consideration of the Forming History of Drawn Wires by the Use of Kinematic Hardening

Kaup, David
Tekkaya, A. E.; Kamaliev, M.
Definition von Prozessgrenzen bei der spannungsüberlagerten Hochtemperatur-Profilumformung
Definition of Process Limits for Stress-Superposed High Temperature Profile Forming

Kratzel, Sebastian
Tekkaya, A. E.; Gerlach, J.
Modellierung des Kerbschlagbiegeversuches von fließgepressten Bauteilen unter Berücksichtigung umforminduzierter Schädigung
Modeling of the Notched Bar Impact Test of Extruded Components Under Consideration of Deformation-Induced Damage

Neukirchen, Felix
Tekkaya, A. E.; Stennei, M.
Ursachenanalyse für vereinzeltes Rissaufkommen bei der mehrstufigen, umformtechnischen Bauteilherstellung
Causal Analysis of Occasional Crack Occurance in Multi-Stage, Forming Component Manufacturing

Ocakli, Mehmet-Kasim
Tekkaya, A. E.; Dardaei Joghan, H.
Hybride additive Fertigung einer laminierten Werkzeuggeometrie mit Freiformflächen
Hybrid Additive Manufacturing of a Laminated Tool With Freeform Surfaces

Özümer, Ishak
Tekkaya, A. E.; Stennei, M.
Einfluss der Temperatur auf die Dehnratensensitivität eines martensitischen und austenitischen Edelstahls
Effect of Temperature on the Strain Rate Sensitivity of Martensitic and Austenitic Stainless Steel

Schütze, Julius
Tekkaya, A. E.; Kamaliev, M.
Hot Tube Bulge Test – Beeinflussung von Dehnpfad und Grenzformänderung
Hot Tube Bulge Test – Influencing Strain Path and Forming Limits

Stiller, Leon
Tekkaya, A. E.; Selvaggio, A.
Numerische und experimentelle Identifikation der Einflussfaktoren auf die Qualität stranggepresster Profile aus Aluminiumrezyklat-Pressbolzen
Numerical and Experimental Identification of Factors Influencing the Quality of Extruded Profiles Based on Aluminum Recyclate Billets

Turck, Janis
Tekkaya, A. E.; Gebhard, J.
Untersuchung des Einflusses der Geometrie eines stationären Ventils beim kontinuierlichen Strangpressen
Investigation of the Influence of the Geometry of a Stationary Valve During Continuous Extrusion

Abgeschlossene Projektarbeiten | Completed Project Theses

Aina, Ayotomiwa
Tekkaya, A. E.; Weber, F.
Prozessdesign zum Verbinden von Metall- und Thermoplastrohren durch elektromagnetische Expansion
Process Design for Joining Metal and Thermoplastic Tubes by Electromagnetic Expansion

Aydin, Baris; Eyican, Ilkan
Tekkaya, A. E.; Upadhya, S.
Vorrichtungskonstruktion zur Niederdruck-Hydroumformung
Fixture Design for Low Pressure Hydroforming

Bogawat, Pritish Sandeep
Tekkaya, A. E.; Selvaggio, A.
Automatisierung des Lochaufweiterungsversuches mithilfe der Fotogrammetrie
Automation of Hole Expansion Test With the Help of Computer Vision Techniques

Boumaaza, Youssef
Tekkaya, A. E.; Rethmann, P.
Untersuchung des Fließverhaltens von Federstahldraht mit dem Torsionsversuch
Investigation of the Plastic Behavior of Spring Steel Wires With the Torsion Test

Braun, Matthias
Tekkaya, A. E.; Rethmann, P.
Numerische Simulation des Federwindens
Numerical Simulation of Helical Spring Coiling

Coen, Michael
Tekkaya, A. E.; Goyal, S.
Untersuchung von additiv gefertigten Stahlstützstrukturen auf Kupferspulen für elektromagnetische Blechumformung
Investigation of Additively Manufactured Steel Side Supports on Copper Coils for Electromagnetic Sheet Forming

Dieckheuer, Tim
Tekkaya, A. E.; Dardaei Joghan, H.
Klassifizierung von Tiefziehwerkzeugen für die produktionstechnische Bewertung der hybriden additiven Schichtlaminatfertigung
Classification of Deep Drawing Tools for the Production Engineering Evaluation of Hybrid Additive Layer Laminate Manufacturing

Dimas Zekri, Fiona
Tekkaya, A. E.; Martschin, J.
Entwicklung eines Herstellungsverfahrens für Verdränger-pumpen-Rotoren aus Rohr-Halbzeugen durch innovative Umformverfahren
Development of a Manufacturing Process for Positive Displacement Pump Rotors From Tubular Semi-Finished Products Using Innovative Forming Processes

Drehband, Eduard
Tekkaya, A. E.; Upadhya, S.
Reduzierung der Rückfederung beim Profilbiegen mittels Spannungsüberlagerung durch elektromagnetische Kraft
Reduction of Springback During Profile Bending by Means of Stress Superposition Through Electromagnetic Force

Elsayed, Awab
Tekkaya, A. E.; Goyal, S.
Untersuchung des Proximity-Effekts bei der Verwendung von Mehrwindungsspulen beim elektromagnetischen Umformen
The Study of Proximity Effect Using Multiple Coils in Electromagnetic Forming

Göppert, Pascal
Tekkaya, A. E.; Kolpak, F.
Parameteranalyse beim Festwalzen gehärteter Wellen mit verschiedenen Werkzeugkinematiken
Parameter Analysis During Roller Burnishing of Shafts With Different Tool Kinematics

Heideck, Philipp
Tekkaya, A. E.; Rosenthal, S.
Simulative Entwicklung einer topologieoptimierten Einheitszelle
Development of a Topology-Optimized Unit Cell

Horstmann, Christopher
Tekkaya, A. E.; Gebhard, J.
Numerische und analytische Untersuchung eines stationä-ren Ventils beim kontinuierlichen Strangpressen
Numerical and Analytical Investigation of a Stationary Valve in Continuous Extrusion

Kadoglu, Arda
Tekkaya, A. E.; Schmitz, F.
Konstruktion eines Werkzeugs für die Kompaktierung von Aluminiumspänen mittels Hochgeschwindigkeit
Design of a Tool for High-Speed Compaction of Aluminum Chips

Keyk, Simon
Tekkaya, A. E.; Rosenthal, S.
Kompensation der Blechausdünnung beim Kragenziehen
Compensation of Thinning in Collar Forming

Kopp, Justin
Tekkaya, A. E.; Ghattamaneni, M.
Vorhersage der Wandstärkenabnahme beim Rotationszug-biegen durch numerische und analytische Modellierung
Prediction of Wall Thickness Reduction in Rotational Tensile Bending by Numerical and Analytical Modeling

Piecuch, Mario; Polus, Gero
Tekkaya, A. E.; Grodotzki, J.
Vergleich verschiedener Niederhalterkonzepte für Tiefziehsimulationen
Comparison of Different Concepts for Blank Holders in Deep Drawing Simulations

Preuer, Fabian
Tekkaya, A. E.; Hoffmann, E.
Kinematisches Profilbiegen mit partieller Erwärmung von U-Profilen
Kinematic Profile Bending of U-Profiles With Partial Heating

Saha, Sarbhanu
Tekkaya, A. E.; Stiebert, F.
Untersuchung der Prozessgrenze der Faltenbildung im ebenen Torsionsversuch
Study of Wrinkling Limit for In-Plane Torsion Test

Sapre, Aditya
Tekkaya, A. E.; Weber, F.
Analyse der Zeitabhängigkeit des Passfugendrucks beim Innenhochdruckfügen von Aluminium-Polycarbonat-Verbindungen
Analysis of the Time-Dependency of the Interference Pressure in Joining by Hydraulic Expansion of Aluminum Polycarbonate Joints

Schütze, Julian; Sultani, Mielad
Tekkaya, A. E.; Stiebert, F.
Konzeption und Konstruktion eines Drehwinkelsensors für den Ebenen Torsionsversuch
Design and Construction of a Rotary Angle Sensor for the In-Plane Torsion Test

Tumbrink, Sven
Tekkaya, A. E.; Wernicke, S.
Analyse des Stanzrest-Einsparpotenzials und Konzeption eines Transfersystems zur Reduzierung der Stanzreste in Folgeverbundprozessen
Analysis of the Potential for Cutting Waste and Design of a Transfer System for Reducing Cutting Waste in Downstream Composite Processes

Turck, Janis
Tekkaya, A. E.; Ghattamaneni, M.
Vorhersage der Wandstärkenabnahme beim Rotationszugbiegen durch automatisierte numerische Modellierung
Prediction of Wall Thickness Reduction in Rotational Tensile Bending by Automated Numerical Modeling

Ausgewählte Veröffentlichungen und Vorträge | Selected Publications and Lectures

08

Zeitschriftenbeiträge | For SCI-Journals

Coppieters, S., Traphöner, H., Stiebert, F., Balan, T., Kuwabara, T., Tekkaya, A. E., 2022. Large Strain Flow Curve Identification for Sheet Metal. Journal of Materials Processing Technology 308, DOI: 10.1016/j.jmatprotec.2022.117725.

Cwiekala, N., Traphöner, H., Haupt, P., Clausmeyer, T., Tekkaya, A. E, 2022. Analytical Model of the In-Plane Torsion Test. Acta Mechanica 233 (2), pp. 641-663.

Dardaei Joghan, H., Hahn, M., Sehrt, J. T., Tekkaya, A. E., 2022. Hybrid Additive Manufacturing of Metal Laminated Forming Tools. CIRP Annals 71 (1), pp. 225-228.

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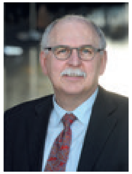

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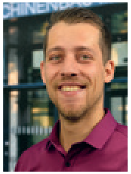

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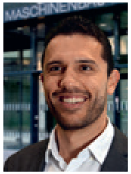

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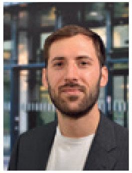

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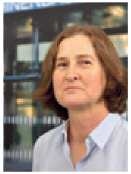

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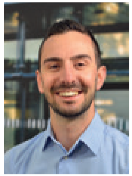

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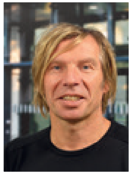

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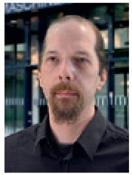

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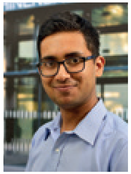

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