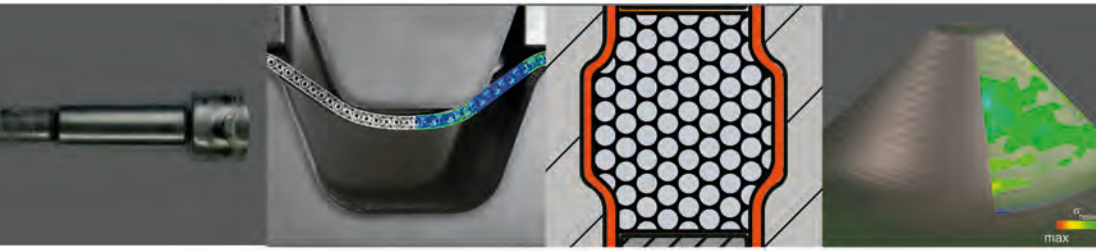

Institute of
Forming Technology and
Lightweight Components

Activity Report

20

technische universität
dortmund

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Imprint

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Preface

The year 2020 will be remembered as a special one for a long time because of the corona virus pandemic. The primary goal was and still is to reliably ensure teaching and supervision for students in consistent quality, to continue research work at the institute without major restrictions or interruptions, and to fulfill our commitments to cooperation partners. At the same time, it is necessary to reduce social contacts in order to prevent the virus from spreading. The protection measures to prevent infections, which have been developed as fast as possible, guarantee that all teaching and research work in the institute's test field could be continued after an adjustment period. The IUL team works both from home and on campus. All lectures, practical exercises, and examinations are performed entirely in digital form and we also successfully conducted five digital PhD exams this year.

Our team has to face special challenges: The employees establish new structures while working from home and they work under difficult conditions in the experimental hall. Innovative concepts for digital teaching were realized within a very short time. The IUL benefited from its expertise from the project "ELLI" ("Excellent Teaching and Learning in Engineering Science"). Since 2011, the IUL has been contributing to research on engineering education – also focussing on the digitization of teaching. Even before the pandemic, the results obtained on engineering didactics were implemented in teaching at the IUL and technologies for the digital transfer of knowledge such as remote labs and virtual worlds were established in the courses. This helped tremendously when managing the short-term adaptation to online courses.
The DFG's evaluation of the Collaborative Research Center TRR 188 also took place digitally for the first time. We are grateful and proud that the German Research Foundation decided to continue its funding. For the second funding period Professor Erman Tekkaya will, according to schedule, hand over the center's management to Professor Gerhard Hirt from the IBF at RWTH Aachen University until the end of 2024. Other institutions involved in the second funding period are the "Max-Planck-Institut für Eisenforschung" in Düsseldorf and the Institute for Applied Materials – Section "Materials and Biomechanics" at KIT in Karlsruhe.

2021 will also be a challenging year for us. Yet, in view of the tasks we have already mastered together, we are looking forward with confidence and anticipation to the year 2021 in which we will also make up for the conferences that could not be held due to last year's special circumstances. We would be pleased to welcome you at the International Conference on High Speed Forming 2021 (ICHSF) or at the 8th Tube and Profile Bending Conference (DORP).

Up-to-date information on our conferences and the IUL can be found at **www.iul.eu** at all times.

We very much hope to meet our international colleagues in person again soon and to be able to welcome them at the IUL. We would like to thank all partners of the institute for their support and the entire IUL team for its great commitment during these demanding times.

A. Erman Tekkaya

Matthias Kleiner

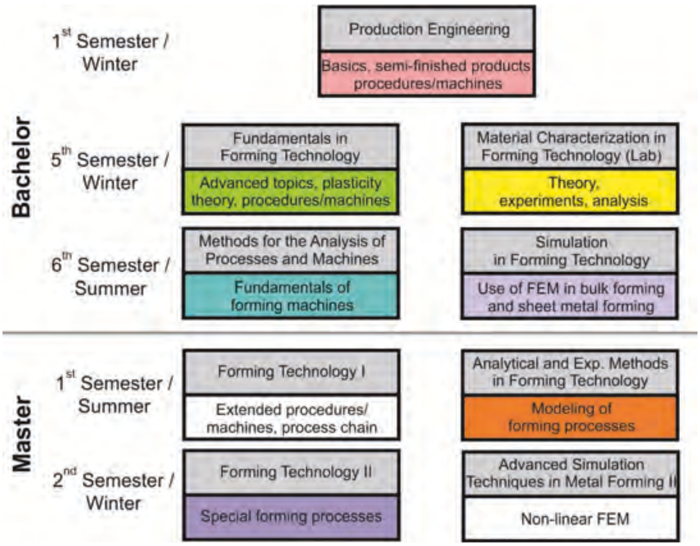
Education

01

1 Education

1.1 Offered Courses

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



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

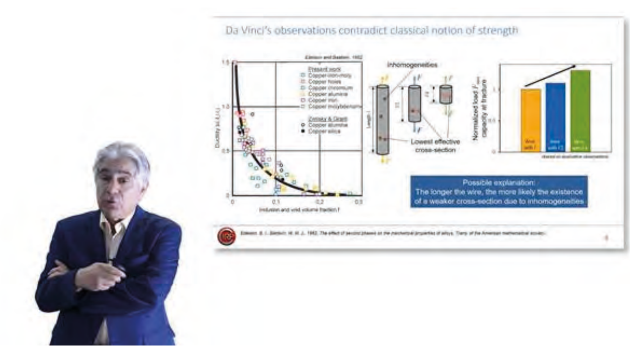
Other courses offered by the institute in 2020 were:

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

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

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

Due to the worldwide COVID-19 pandemic and the corresponding access restrictions at TU Dortmund University, the IUL found itself constrained to shift all lectures of summer semester 2020 to virtual teaching methods. The lectures were offered by video recordings. Weekly digital discussion sessions ensured the interaction between students and lecturer. Due to the persistent hazardous situation, the IUL will continue its digital education in the winter semester 2020/2021.



Example of a video-recorded lecture during the digital semester at the IUL

In 2020, the following guest lecturers have contributed to the course offer at the IUL:

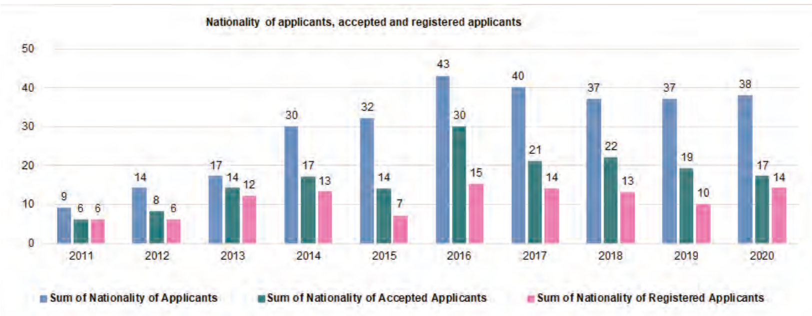
- Prof. J. Hirsch, Hydro Aluminium Rolled Products
- Prof. K. Roll, formerly Daimler AG Sindelfingen
- Prof. J. Sehrt, Ruhr-Universität Bochum
- Dr. G. Georgiadis, Volkswagen AG

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

1.2 Master of Science in Manufacturing Technology (MMT)

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

The English-taught, four-semester study program 'Master of Science in Manufacturing Technology', which started in 2011, was again of much interest to international students regarding the start of studies in winter semester 2020/21. 48 carefully selected and excellent students out of around 900 applicants from 38 nations have been admitted to the MMT program. Within the scope of the cooperation with the Turkish-German University in Istanbul, organized by the German Academic Exchange Service (German: DAAD), three students from Turkey started their MMT studies.



Diversity of nationalities of applicants, accepted and registered applicants

In order to further increase the diversity of the MMT program, the coordination team analyzed the countries of origin of the students and, on this basis, took steps to inform more students from other countries about the study program.

In this context, newsletters were send out, webinars were offered and ads were placed in cooperation with the DAAD in order to draw attention to the program and the application period. Due to the Covid-19 pandemic, the EAIE conference, which the coordination team has attended regularly in previous years, had to be held digitally this year. In video sessions, discussions, and virtual "campfires", more than 1,500 participants were able to exchange ideas on a strategy development in the international affairs sector.

The MMT online application portal has qualitatively improved in cooperation with the IT & Media Center of TU Dortmund University. Hence, the application

procedure for the applicants as well as the processing of the applicant's data and the subsequent selection of the students to be admitted have become even more convenient and efficient.
The global pandemic has also had a major impact on the start of studies in 2020/21. As official authorities and institutions were closed for weeks, it was impossible for the majority of the selected applicants to travel to Dortmund for the beginning of the winter semester. As a result, the coordination team decided, in consultation with the individual chairs, to organize this semester's MMT lectures fully digital.

In order to give the students taking up their studies digitally from their home countries the best possible start at the Faculty of Mechanical Engineering, the MMT coordination team organized a virtual Welcome Week with various activities for the new batch of students. The kick-off event was Professor Tekkaya's welcome of the new students by video conference as head of the study program. The students also had the opportunity to make first contacts with each other. The next day, the chairs involved in the MMT introduced themselves to the students with short presentations and videos. The students' technical interest was immediately awakened, resulting in a lively exchange between students and chair representatives. During the subsequent digital tour of the IUL lab, the new MMT class was given an insight into the practical part of the study program. Here, too, one could clearly feel the technical interest and the anticipation of their arrival at TU Dortmund University. On day three of the Welcome Week the MMT coordination team organized a workshop on living and studying in Dortmund. During this workshop, the German higher education system was explained to the students in detail and useful hints and tricks were given. In the Q&A session that followed, the new MMT students had the opportunity to ask questions about studying and living in Germany. The lively exchange via video and chat made clear how much the students had already networked during the last days. At the weekend, both the new cohort and the older MMT students had the opportunity to participate in an intercultural training that focused on networking with each other and expanding their intercultural competences.

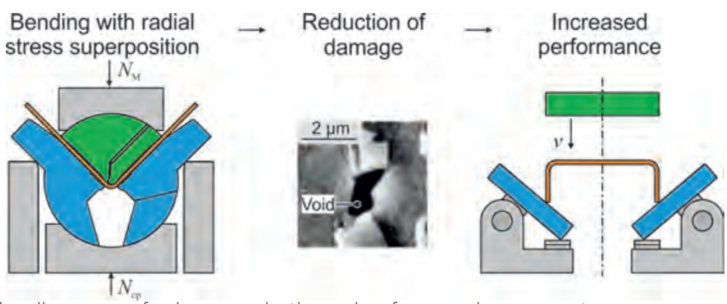
For further information, please visit: **www.mmt.mb.tu-dortmund.de.**

1.3 Doctoral Theses

Meya, Rickmer	Damage-Controlled Sheet Metal Bending by Means of Compressive Stress Superposition
Original title	Schädigungskontrolliertes Blechbiegen mittels Druckspannungsüberlagerung
Series	Dortmunder Umformtechnik, Volume 108
Publisher	Shaker Verlag, 2020
Oral exam	May 14, 2020
Advisor	Prof. Dr.-Ing. A. E. Tekkaya
Co-examiner	Prof. Dr.-Ing. W. Volk (Technical University of Munich)

In current product design of bent sheet metal components often only the properties of the virgin material are included. In some cases the deformation-induced strain hardening and residual stresses are also taken into account. Damage induced by the forming process is not considered. As a result of the unknown influence of damage on the product performance, the manufactured components are often oversized. Therefore, this work shows for the first time which influence damage has on the performance of bent components.
To influence damage, the load path must be changed during plastic deformation. For this purpose, a stress superposition is necessary. Since the conventional processes are not able to apply predictable compressive stresses, a new bending process has been developed. The so-called bending with radial stress superposition can apply adjustable stress superposition during the process and leads to reduced void area fractions while maintaining the geometry of the product.

This works shows that forming-induced damage has a decisive influence on the crash behavior, the cyclic properties, and the stiffness of bent components. Due to the known influences of damage on the performance, it can already be included in the product design process as a product property.

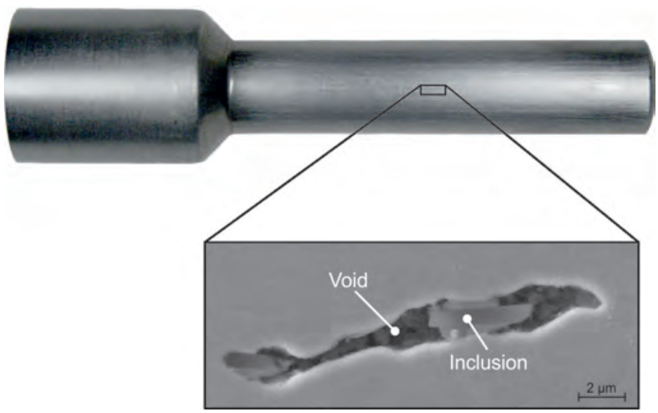


New bending process for damage reduction and performance improvement

Hering, Oliver	Damage in Cold Forging: Evolution, Impact, and Control
Original title	Schädigung in der Kaltmassivumformung: Entwicklung, Auswirkungen und Kontrolle
Series	Dortmunder Umformtechnik, Volume 109
Publisher	Shaker Verlag, 2020
Oral exam	May 25, 2020
Advisor	Prof. Dr.-Ing. A. E. Tekkaya
Co-examiner	Prof. Dr.-Ing. S. Münstermann (RWTH Aachen University)

The load paths occurring during forward rod extrusion are numerically determined in this thesis and described using triaxiality and Lode-angle-parameter. Forward rod extrusion was identified as an ideal method to determine the relationships between the load path, damage, and performance as the hydrostatic pressure is strongly dependent on the process parameters along the central axis of the extruded components as well as known homogeneous strains and negligible residual stresses after component ejection and sample extraction exist.

The influence of the load paths on the development of ductile damage is investigated experimentally using scanning electron microscopy and density measurements. Ultimately, the influence of damage on the resulting performance is determined. Notched bar impact tests, fatigue tests, and measurements of the Young's modulus and static strength are carried out for this purpose. With the exception of static strength, increased damage leads to a decrease in performance.

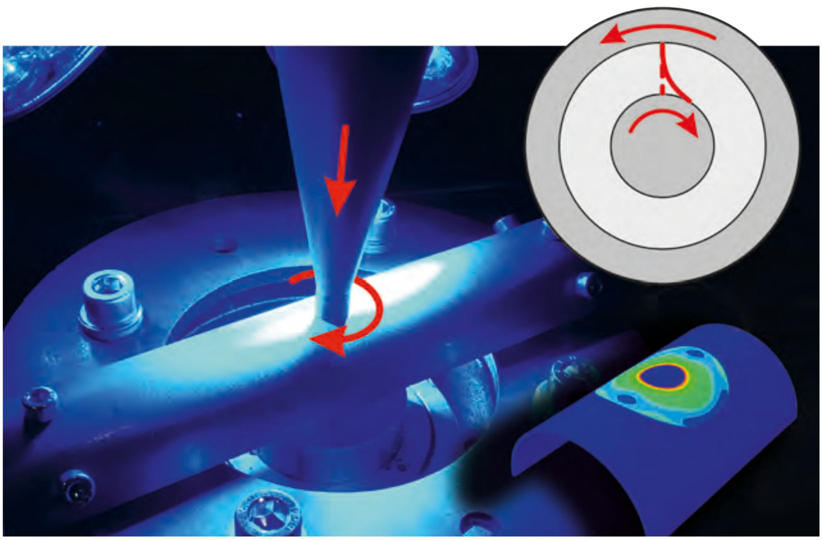


Void in an extruded part

Traphöner, Heinrich	Extension of the Application Limits of the In-Plane Torsion Test
Original title	Erweiterung der Anwendungsgrenzen des ebenen Torsionsversuchs
Series	Dortmunder Umformtechnik, Volume 110
Publisher	Shaker Verlag, 2020
Oral exam	October 8, 2020
Advisor	Prof. Dr.-Ing. A. E. Tekkaya
Co-examiner	Prof. Dr.-Ing. D. Mohr (ETH Zurich)

Due to its advantageous properties, the in-plane torsion test is increasingly used for the characterization of sheet metal materials. These advantages are the ideal simple shear stress state until fracture, the material characterization without edge effects, and the resulting determination of flow curves up to very high equivalent strains.

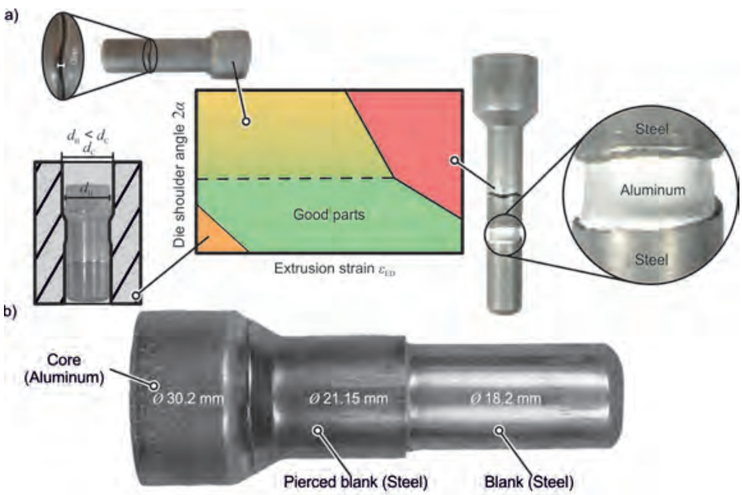
The aim of the work is to extend the application limits of the in-plane torsion test. For this purpose, all components and influences involved in the test and evaluation are analyzed. These are the strain measurement technology that has to be used for the measurement of very large shear strains, the shape of the specimen, which offers additional opportunities for the process design, and the clamping, which in particular influences the process limits. Finally, the application of the in-plane torsion test for the characterization of thin sheets and curved parts is investigated.



In-plane torsion test on tubes

Napierala, Oliver	Combined Deep Drawing and Cold Forging – Draw Forging Analysis, Component Properties and Potentials
Original title	Tiefzieh-Verbundfließpressen – Analyse, Bauteileigenschaften und Potentiale
Series	Dortmunder Umformtechnik, Volume 111
Publisher	Shaker Verlag, 2020
Oral exam	October 23, 2020
Advisor	Prof. Dr.-Ing. A. E. Tekkaya
Co-examiner	Prof. Dr.-Ing. habil. Dipl.-Math. B. Awiszus (Chemnitz University of Technology)

Draw-forging enables the manufacturing of composite shafts from a core and a sheet metal semi-finished product on the surface by a combination of deep-drawing and extrusion. In numerical and experimental investigations the process failures "crack of the blank", "gap between blank" and "core, and insufficient forming of the component head" were analyzed and a process window was determined (see Figure a). An analytical model describes the punch force curve with a deviation < 16%. A large number of process potentials were identified from the results of the basic research and implemented technologically. For example, the process "expanding-draw-forging", which had been applied for a patent within the scope of this work, allows each individual shoulder of a shaft to be covered with different materials that meet the requirements of the shoulder surface (see Figure b).

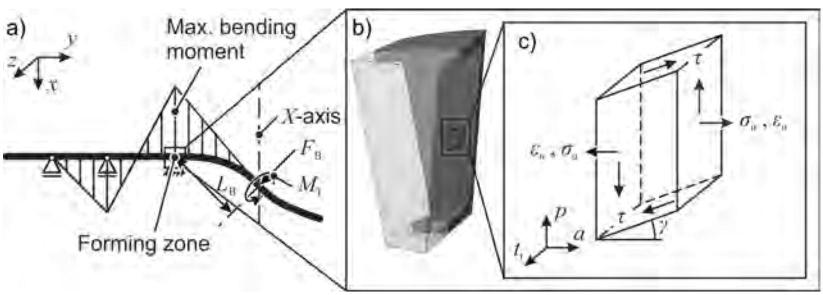


a) Process window, b) Expanding-draw-forging – Double-stepped composite shaft

Staupendahl, Daniel	3D Profile Bending with Five Controlled Degrees of Freedom
Series	Dortmunder Umformtechnik,
Publisher	Shaker Verlag, 2021
Oral exam	December 4, 2020
Advisor	Prof. Dr.-Ing. A. E. Tekkaya
Co-examiner	Prof. Dr.-Ing. B. Engel (University of Siegen)

Kinematic bending of tubes and profiles to three-dimensional (3D) contours offers the potential of coping with current demands for natural aesthetic design and high flexibility. In order to generate a comprehensive understanding of the mechanics of 3D bending, first, the geometrical characteristics of 3D-shaped profiles are analyzed. Subsequently, the controlled degrees of freedom (cDOFs) which process kinematics need in order to produce 3D shapes are derived. This groundwork is used to set up a 5-cDOF profile bending process with integrated force and torque sensors and to develop an efficient contact-based contour sensor.

A curved elastic model is created which is able to accurately model in-plane springback and the interaction of torque and bending force components. During the analysis of the plastic profile behavior, equations are set up that describe the reciprocal effects of axial and shear stress. They are used to calculate the bending force and torque acting on a profile during 3D bending. Finally, the geometric, elastic, and plastic process description is merged into a comprehensive process model.



a) Simplified supported beam model of the 3D bending process, b) Segment of the profile, c) Element of a profile segment with the simplified stress state uniaxial stress + shear stress

Research

02

2 Research

The research activities of the Institute of Forming Technology and Lightweight Components comprise the development of new forming processes and process chains as well as the extension of existing production processes. The objectives are physically sound process descriptions, the configuration and improvement of component properties, and a holistic approach of the process efficiency. Methodological key aspects are material characterization and simulation methods. The fundamental research results are transferred to industrial practice. This process is often accompanied by industrial partners.

35 scientists, supported by 11 technicians and administrative staff members and approximately 50 student assistants, work on the institute's research projects. Especially when it comes to interdisciplinary research issues, the projects are often pursued with national and international partners. The participation in two "Collaborative Research Centers", TRR 188 (spokesperson) and TRR 73 (local spokesperson), and in the two "Priority Programs", SPP 2013 and SPP 2183, express these intensive networking efforts. Besides the three departments "Bulk Metal Forming", "Profile and Sheet Metal Forming", and "Non-Conventional Processes", the institute structure covers four inter-divisional units (see figure): "Research Center for Industrial Metal Processing" (ReCIMP), "Research Group on Additive Technology" (ReGAT), "Excellent Teaching and Learning in Engineering Science" (ELLI 2), and "Research Group Applied Mechanics". In the following, the department-specific research objectives and research projects are presented.

Institute structure

2.1 Research Groups and Centers

2.1.1 Collaborative Research Center Transregio 188 – Damage Controlled Forming Processes

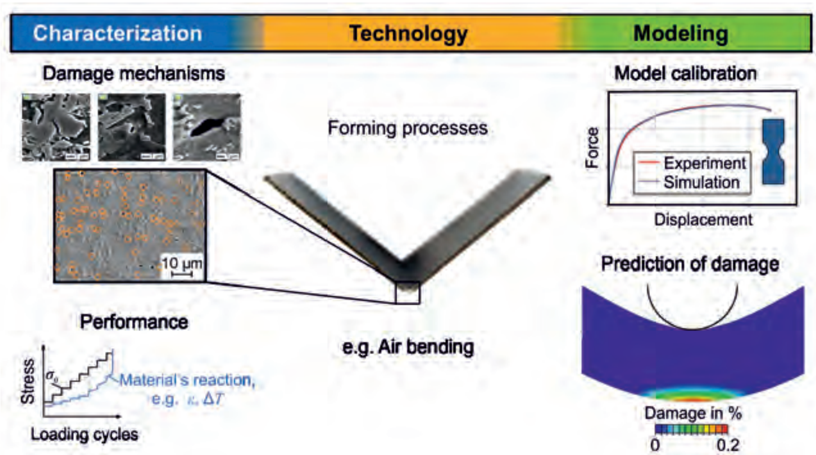
Funding	German Research Foundation (DFG)
Project-ID	CRC 188/1-2020
Spokesperson	Prof. Dr.-Ing. A. Erman Tekkaya
Managing Director	Dr.-Ing. Frauke Maevus

The research hypothesis of the Collaborative Research Center TRR 188 is that the damage caused by the forming process can be controlled and that the damage significantly influences the performance of the components. Accordingly, the overall goal of TRR 188 is to understand the mechanisms of material damage during forming to quantitatively predict the evolution of damage and to adjust damage states with regard to component performance. The guiding principle of TRR 188 "Damage is not a failure" means that ductile damage in forming technology is not only a measure of the distance to the failure limit ("formability"), but also has a decisive influence on the performance in the application ("usability"). Thus, the damage is a product property that is influenced by the forming technology used in component production.

The first phase of the Collaborative Research Center TRR 188, which started in 2017, ends this year. Therefore, we look back on years full of results and events, on the one hand, and, on the other hand, expectantly to the future of this project. The application for approval of the second phase with a renewed term of four years was submitted in July. In September, the first virtual assessment of a collaborative research center with the participation of the IUL took place. The German Research Foundation (DFG) has decided to continue funding the CRC/TRR188. Thus, research on the paradigm shift in forming technology can be continued until the end of 2024.

Scientists from TU Dortmund University (the spokesman university) and RWTH Aachen University carry out research in multiple subprojects. In Dortmund, the Institute of Forming Technology and Lightweight Components (IUL), the Institute of Mechanics (IM), and the Department of Materials Test Engineering (WPT) from the Faculty of Mechanical Engineering and the Chair of Structural Mechanics (BM) from the Faculty of Architecture and Civil Engineering are involved. At RWTH Aachen University, the Institute of Metal Forming (IBF), the Steel Institute (IEHK), and the Institute for Physical Metallurgy and Materials Physics (IMM) from the Faculty of Georesources and Materials Engineering as well as the Laboratory for Machine Tools and Production Engineering (WZL) from the Faculty of Mechanical Engineering and the Central Facility for Electron Microscopy (GFE) are part of TRR 188. Moreover, there is the Chair of Mechanical Design and Manufacturing at BTU Cottbus-Senftenberg and the non-university institute Max-Planck-Institut für Eisenforschung GmbH (MPIE) in Dusseldorf.

In the first funding period fundamental forming processes were investigated with regard to damage development and the resulting performance. For this purpose, an interdisciplinary consortium was formed, which is divided into the project areas characterization, technology, and modeling (see figure).



Project areas of the TRR 188

In project area A (Technology) damage in the forming process was controlled by adjusting the hydrostatic pressure via process parameters and modifications. Furthermore, it was shown that the damage significantly influences the performance. In project area B (Characterization) efficient methods for quantifying the damage and characterizing the damage mechanisms were developed using samples from project area A. In project area C (Modeling) damage modeling approaches from the micro- to the macroscale were developed and validated using experimental data from project areas A and B. The scientific service project prepared the developed damage models for finite element (FE) simulations and provided software tools for process simulation and parameter identification.

In this research center an interdisciplinary team has grown together, which has learned to speak a common language. Besides the regular meetings, the work on central cross-cutting issues in the four working groups “Efficient damage characterization”, “Performance”, “Validation”, and “Damage definition” contributed to this.

Despite these successes, some questions already mentioned in the first phase’s proposal, but also new open questions remain for the possible second funding period. Potential topics include the consideration of more complex component geometries and process sequences, the variation of the Lode angle parameter, and temperature-assisted forming or heat treatment.

Not only because of the proposal phase and the upcoming assessment, five plenary meetings were held this year, four of which were virtual. In March, the second industrial colloquium took place in Aachen. Nearly 70 national and international participants were provided insights into the latest developments in the field of damage-controlled forming processes in 13 lectures and an accompanying poster exhibition. Due to the corona virus, the lectures of the second industrial colloquium were also available online. The focus of the conference was on the characterization as well as the multiscale modeling of damage evolution.

In collaboration with the international researchers Pierre-Olivier Bouchard, Stefania Bruschi, and Cem Tasan, A. Erman Tekkaya as main author published the keynote paper “Damage in Metal Forming” in the CIRP Annals. In addition, 10 papers of TRR 188 were published in a special issue of “Production Engineering” on the topic “Damage Controlled Forming Processes”.

2.1.2 ReCIMP – Research Center for Industrial Metal Processing

Head Sebastian Wernicke M. Sc.

The cooperation with the international automotive supplier Faurecia, which has been established more than seven years ago, was successfully continued in 2020. In the Research Center for Industrial Metal Processing (ReCIMP) the IUL cooperates with Faurecia's divisions Automotive Seating and Clean Mobility in various projects in the field of innovative metal forming processes. The superordinate objective of each project is to improve and deepen the basic knowledge about the processes and process chains under investigation. In addition, there is a focus on the identification and investigation of new scientific directions of research in the field of manufacturing technology. Cooperation with other industrial companies and research institutions to build up a competence network is a welcome side effect.

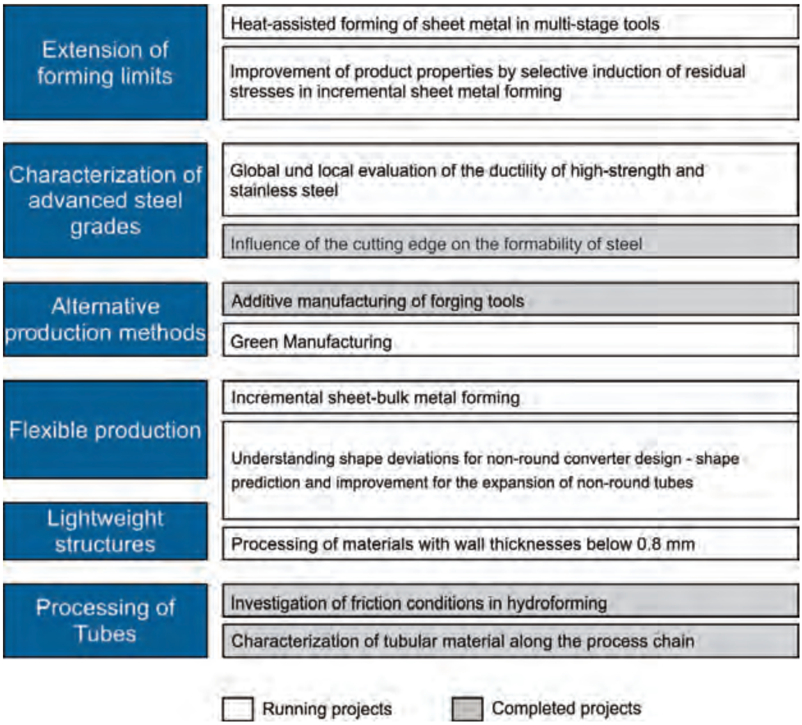
Structurally, the individual ReCIMP projects are assigned to the following six priority areas:

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

The project work is performed by scientists from the various IUL departments on a subject-specific basis. The Advisory Board of ReCIMP regularly discusses the progress of the individual projects as well as the overall strategy of the research center. The following figure gives an overview of the projects carried out in 2020.

The researchers are supported by a large number of student assistants and students preparing project or final theses in the projects. Since the establishment of the research center, far more than 60 students have been involved in ReCIMP projects; for several current scientific employees of the IUL, a thesis in ReCIMP was the first step towards their scientific career. In 2020 alone, six project, bachelor, and master theses were written in the research center.

The cooperation is particularly effective when the research topics initially dealt with within the research center lead to fundamental questions and research fields for externally funded projects – this has already happened several times in the past years.



Research projects worked on in 2020

In the field of characterizing modern steel grades, the investigations on the evaluation of global and local ductility were continued in 2020. Depending on the manufacturing process chain, one of the two properties is more important than the other. However, there are also cases in which a balanced relationship between global and local formability is of interest. The measurement of the parameters requires new approaches and was investigated in the project "Ductility analysis of high-strength steels and stainless steels" of various steel grades for applications in the areas of "seating technology" and "exhaust tract".

Animated by the raising political effort towards the reduction of C02-emissions, ReCIMP initiated a new project in 2020 focussing on the emissions in metal forming process chains. The first steps of the project "Green Manufacturing" are the identification of political and industrial efforts and developments. With two exemplary metal forming process chains, the project goal is to analyze the emissions of sub-processes and to determine the corresponding CO_2 saving-potential. Current investigations concentrate on an analytical approach for the prediction of CO_2-emissions for the future process design.

In 2020, the project "Processing of materials with wall thicknesses below 0.8 mm" focusses on structured sheet material. The numerical process design for the structured sheets requires knowledge about the forming limits of this material. Therefore, the work in this project addresses the determination of forming-limit-diagrams (FLC) of such structured sheets. The measurement of the local strain during conventional material characterization is identified to be the major challenge in this project (chapter 2.4.12). Due to the structure of the sheets, the crack-initiation happens to occur non-reproducibly and is, thus, usually beyond the range of the optical strain measurement. Consequently, the FLC-determination is not feasible for all observed sheet structures. Moreover, the FLC-determination is limited to only a few strain states.

Beside sheet materials, ReCIMP also considers the forming of tube materials. Emphasis is to be put on non-round tubes as their impact, for example in exhaust systems, increases due to limitations in the assembly space. In the project "Understanding shape deviations for non-round converter design – shape prediction and improvement for the expansion of non-round tubes" a numerical model of the forming process was developed and validated in 2020. The current investigations deal with the subsequent canning process (chapter 2.2.9). With this canning processes the preformed tubes become a component of the exhaust system. During the canning process a sensitive monolith is surrounded by a soft-material and inserted into the preformed tube. This leads to an undesired deformation of the oval tubes. Therefore, the progressive investigation incorporates the numerical implementation of the canning process. Numerical modeling of this process will support the improvement of final shape deviations as well as the load distribution on the sensitive monolith. The numerical consideration of the soft material, which surrounds the monolith, appears to be the most challenging task of further investigations.

2.1.3 ReGAT – Research Group on Additive Technology

Contact Stephan Rosenthal, M. Sc.
Dr.-Ing. Dipl.-Wirt.-Ing. Ramona Hölker-Jäger (on parental leave)

The working group "Research Group on Additive Technology" (ReGAT) deals with the combination of forming technology and additive manufacturing. The working group pursues the goal of using the flexibility and design freedom of additive manufacturing processes in an advantageous way for forming technology. Current research deals with the development of additively manufactured semi-finished products for further processing as well as the use of additive manufacturing processes for tool production or as part of the forming-production chain.

The IUL has two additive manufacturing machines for metallic materials. On the one hand, a 5-axis milling machine with integrated laser-powder-deposition capabilities combining additive manufacturing and milling-post-processing. In this way, tools for forming technology can be produced in a single clamping, which saves time, money, and material and it also offers the possibility of functional integration. Stainless steel and tool steel can be processed, or even hybrid material concepts can be produced by material mixing. As part of a research project, the milling machine was enhanced to include the option of integrated incremental sheet forming. Thus, it is possible to combine three manufacturing processes (forming, additive manufacturing, subtractive manufacturing) in one set-up and to manufacture specific components for specific applications. Current research work to be mentioned in the context of the Lasertec 65 3D investigates new types of tool concepts for forming technology. Strategies are developed to reduce the stair step effect in tools made of laminated sheet metal (see chapter 2.4.3). This is done by means of a combination of additive manufacturing and post-processing employing surface roller burnishing. This means that even complex tools can be manufactured quickly and cost-effectively. Another basic project deals with the functionalization of additively manufactured press hardening tools by means of roller burnishing, including internal cooling channels (see chapter 2.3.7). Additively manufactured tools are reworked using forming technology in order to level the tool surfaces in a targeted manner and to influence the material properties locally (strength, heat transfer coefficients).

The second additive manufacturing machine uses Selective Laser Melting (SLM). This process enables the production of highly functional metallic components in the powder bed with filigree geometry details. Current research in this area focuses on the design of semi-finished sandwich products with optimized core structures for forming technology (see chapter 2.4.1). By a subsequent forming operation of the semi-finished products, the productivity of the process chain can be increased.

Machines for metallic powder-based additive manufacturing at the IUL

2.1.4 Research for Engineering Education – ELLI 2

ELLI 2 – Excellent Teaching and Learning in Engineering Science

Funding	BMBF/DLR
Project	01 PL 16082 C
Project director	Prof. Dr.-Ing. A. Erman Tekkaya
Contact	Joshua Grodotzki M. Sc. Dipl.-Inf. Alessandro Selvaggio Siddharth Upadhya M. Sc. Oleksandr Mogylenko M. Sc.
Status	Completed

Teaching and learning, the main focus of the ELLI 2 project in the field of engineering sciences, was affected by the pandemic like hardly any other aspect of university life. The media was filled with reports of closed schools and universities as well as the struggle of these institutions to continue teaching despite a total lockdown. Closed campuses and school buildings forced a rapid digitization of the entire teaching process. In most cases, the teachers were neither trained to do this nor were they equipped with the proper technology. Hence, the quality of teaching suffered noticeably in many cases, especially at the beginning of the lockdown.

Preparing higher engineering education for the shift to digital teaching was one of the crucial aspects of the ELLI 2 collaborative project. Research from the previous years in the fields of teaching technology and methodology came in handy during this critical time. The entire field of digital teaching got a huge push forward, with many aspects here to stay. Since 2011 (ELLI: 2011-2016, ELLI 2: 2016-2020), TU Dortmund University, RWTH Aachen University, and RUB Ruhr-Universität Bochum have joined forces in this project, which is funded by the Federal Ministry of Education and Research as part of the Teaching Quality Pact. Combining excellent technologies with the best didactical methods is the key to the success of this project. The project consists of four core areas:

- Remote labs and virtual learning environments
- Globalization
- Student Life Cycle
- Entrepreneurship

A strategically important tool of the ELLI 2 project in this year was the workshop series Proper Digital Teaching. This workshop series was initiated proactively two years ago by the ELLI 2 team in Dortmund – way before the acute necessity posed by the pandemic. The goal of the workshop is to prepare the educators of the department of mechanical engineering at TU Dortmund University for a successful transition to digital teaching using appropriate digital tools and methods alike. In each workshop technological as well as engineering education-related aspects were presented. Once it was clear that the summer semester at TU Dortmund University would be a fully digital semester, the frequency of workshops was ramped up – of course using virtual meetings – in order to support the teachers during these unprecedented times. Owing to the engagement of all teachers and with the support of these workshops, the department of mechanical engineering can look back at a very successful semester. Everyone is well prepared for the winter semester, which will be held completely online as well.

Especially for all the laboratory courses, which traditionally take place during the winter semester, the research work from the last years focusing on remote laboratories is of high value now. That is because the best way for students and teachers to remain safe and healthy is to not get in physical contact with one another. Remote laboratories are the method of choice so that the students neither face a delay in their study program nor miss out lab courses entirely. To this end, the students can use the remote laboratories in the field of material characterization, tube bending, and additive manufacturing. The latter was enhanced by a post-processing chamber, so that the students can reconstruct the entire process chain on their own while following all safety regulations.

The current stage of the remote tube bending lab allows for the direct measurement of springback using augmented reality tools. The students can perform this measurement on their own by accessing the newly developed tool through the webpage of the laboratory. Owing to the flexible design, the tool works independently of the initially defined parameters by the students. Hence, the explorative nature of the learning process is maintained, since the students can measure arbitrary geometries. A demonstration video of the rotary draw bending remote laboratory can be accessed by following the QR code on the right.

The current developments and research outcomes are frequently published. At this year's International Conference on Remote Engineering and Virtual Instrumentation (REV) in Athens, GA, USA, the conference attendees could try many of the ELLI developments hands-on. They could experiment with the tele-operative testing cell for material characterization directly from the plenary hall. Mr. Upadhya's paper on the ongoing developments of the additive manufacturing remote lab was awarded the Best Short Paper Award at the conference. The newly developed open-source user and content management platform HALO (German abbreviation for house of laboratories) was presented to the public for the first time. This platform will host all remote laboratories of the ELLI project and will also be accessible to other educators around the world. This QR code links you to the landing page of the platform.

Towards the end of the ELLI 2 project, a new homepage was conceptualized and developed in which all products that have been developed during ELLI and ELLI 2 will be archived and made accessible to the public. In this context, the term product comprises every technology and methods which has been investigated for its beneficial impact on engineering education. The list contains mobile applications, remote laboratories, software but also concepts for lectures, workshops, and seminars. The name of the page is BEETBox – Best Practices in Engineering Education Toolbox. All partners involved in the ELLI project from Aachen, Bochum, and Dortmund will include their products in this toolbox. Hence, long after the project is finished, all information will still be available to the public. As the HALO platform, the BEETBox, which can be accessed through the QR code below, is designed to be a hub for impulses and discussions centered on engineering education. Therefore, a lot of material will be available for download on the respective product pages. On each of these product pages all relevant information is given in written form as well as in the form of a short video.

The entire ELLI team wishes you lots of inspiration browsing through the products! In addition to the BEETbox, the ELLI team will publish a book on its 8 years of research at the wbv Verlag with the title "Lehren und Lernen in den Ingenieurwissenschaften: innovativ, digital, international".

2.1.5 Research Group Applied Mechanics

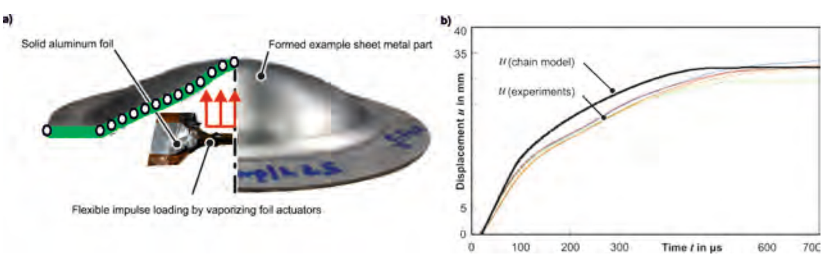
Contact Dr.-Ing. Till Clausmeyer

The Research Group Applied Mechanics concentrates on the competences of the Institute of Forming Technology and Lightweight Components in the fields of analytical approaches, material characterization, material modeling, and simulation for forming applications. The researchers working in these fields discuss these topics, e.g. during information sessions on mechanical and microstructural characterization methods at IUL. They support each other in related research questions. Fundamental research topics of the former Department of Applied Mechanics in Forming Technologies are addressed in the new research group since June 1. The development and application of the aforementioned methods is conducted for the forming technologies available at IUL: bulk, sheet and profile forming as well as non-conventional forming methods. The purchases of a 10 kN Erichsen UNIMAT Basic 054 tensile test machine, a servo-hydraulic Walter + Bai testing machine, and a Coxem EM-30 PLUS scanning electron microcope strengthen the competences of the research group.

Presentation of the current CIRP paper of IUL during the virtual CIRP video paper sessions

The methods supported by the research group play an important role regarding the grants acquired by IUL in 2020: DFG projects on adiabatic blanking and the analysis of continuous hot extrusion by means of similtude theory as well as an AiF project on the manufacturing of springs with the help of plasticity theory. Expertise in plasticity theory and damage mechanics are central for the research in the collaborative research center CRC 188 “Damage controlled forming processes”, in particular newly developed methods for parameter identification. The researchers present the methodological studies of the research group in scientific journals, patents, and presentation at conferences. Presenting at conferences provides the researchers with important feedback from colleagues, e.g. of the CIRP community. Dr. Till Clausmeyer explained a new analytical approach to decribe high-speed blanking processes at the CIRP video paper sessions. The width of shear bands in this process can be predicted with respect to the material properties.Important journal articles include a new testing method to determine forming limit curves at high strain rates (> 1000 /s) by Dr. Koray Demir and co-authors, new methods for the determination of yield curves under shear for large strains (> 2.5) by Dr. Traphöner, and an efficient method to predict the geometry during high-speed forming processes by Marlon Hahn and Prof. Erman Tekkaya. The developed method relies on elementary assumptions to decribe the dynamical forming of sheet metals, e.g. with vaporizing foils. Sheets are formed by mechanical impulses. The approach predicts the geometry with good accuracy and is approximately 10.000 times faster than a detailed modeling with complex finite-element simulations, even though it is based on simplifying assumptions. Felix Kolpak, Dr. Oliver Hering, and Prof. Erman Tekkaya invented a device for the material testing in biaxial conmpression. The patent for this invention, which enables a determination of yield curves of metallic specimens under compression from two sides, is pending. The knowledge of such flow curves is important for bulk metal forming.

The researchers in the research group could contribute to virtual conferences even though there were travel restrictions due to the coronavirus pandemic. Prof. Erman Tekkaya and Dr. Till Clausmeyer organised a minisymposium on topics related to damage control in forming processes for the first virtual international forming conference ESAFORM 2020. Several participants of IUL provided presentations and discussed with other participants at a webinar on the identification of material parameters under large strain. The webinar was organized by the Belgian company OCAS and the Belgian university KU Leuven. The collaboration of the Department of Bulk Metal Forming, researchers in the research group Applied Mechanics, and the Japanese steel manufacturer KOBE Steel and its employee Yasuhisa Taki could be continued sussessfully, even though there were temporary restrictions on the use of the lab and the metallography lab.



a) Principal sketch of forming with vaporizing foils and b) Comparison of chain model and measurements

2.2 Department of Bulk Metal Forming

Head Dr.-Ing. Oliver Hering

The focus of the department of bulk metal forming lies on the investigation of the processes hot extrusion and cold forging. Fundamental issues as well as innovative processes and process variants are investigated. Basically, the influence of the Bauschinger effect occurring during load reversal as well as the influence of forming-induced damage on the performance of cold forged components is investigated. For the application in sheet-bulk metal forming, the occurrence of cross-hardening in sheet metals with orthogonal strain path changes is investigated. For the prediction of the damage evolution, methods for parameter identification based on experimental microstructure investigations are developed.

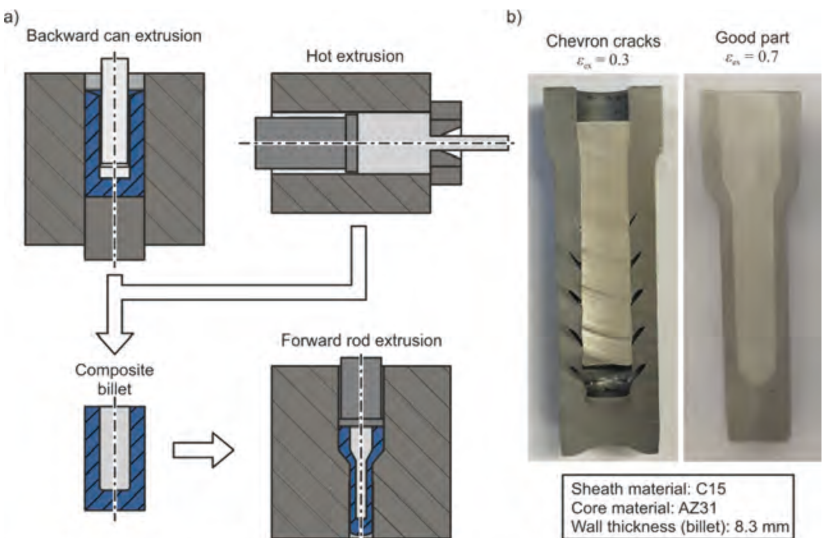
The process development aims at lightweight-oriented process designs. The processes composite cold forging and combined deep drawing and cold forging allow for lightweight and load-adapted components to be realized. A research focus in extrusion is the grading of the mechanical properties over the profile cross-section for the production of battery boxes.

Members of the department of bulk metal forming

2.2.1 Composite Cold Forging of Cold Forged Semi-Finished Parts

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

Forward rod extrusion of composite billets consisting of a light metal core and a steel cup allow for the production of lightweight gear shafts while losing only small amounts of torsional and bending stiffness in comparison to a steel-only shaft. The steel sheath of the composite billet is produced by backward can extrusion. To further increase the lightweight potential compared to aluminum cores, magnesium is used instead. To this end, C15 steel cups with three different wall thicknesses are produced, into which hot extruded round AZ 31 magnesium profiles with corresponding diameters are inserted. Subsequently, the hybrid billets are formed into composite shafts by forward rod extrusion (see Figure a). The high hydrostatic pressure during this forming process enables the magnesium to be formed at room temperature and up to large strains. The process is limited by the occurrence of chevron cracks when using low extrusion strains (see Figure b) and by upsetting of the shafts during ejection for high extrusion strains.

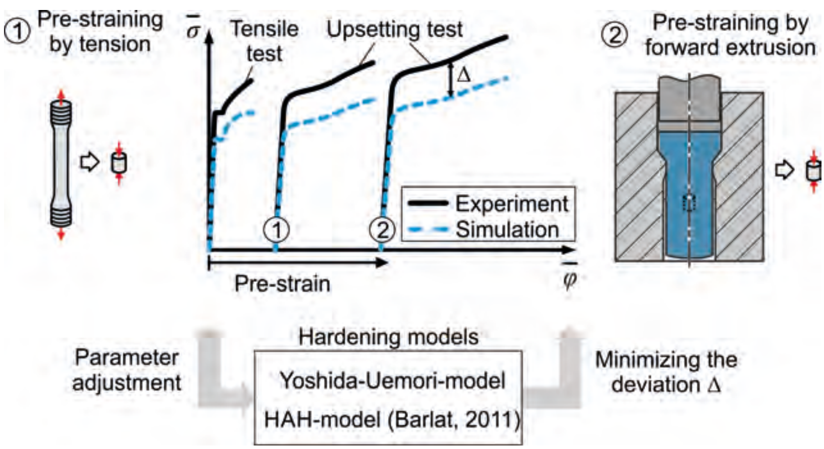


a) Process flow, b) Longitudinal cross section view of investigated specimens

2.2.2 Influence of the Multiaxial Bauschinger Effect in Cold Forging

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

In the DFG-funded project new methods were developed that allow the characterization of anisotropic hardening effects exhibited at large strains (see figure). By using and modifying the kinematic work hardening model according to Yoshida and Uemori (2002), all anisotropic hardening effects exhibited by the case-hardening steel 16MnCrS5 could be captured with high accuracy over the entire relevant strain range. By using the model, the prediction quality of component properties (hardening and residual stresses) could be improved significantly by means of FEM simulation of forward rod extrusion.
In the area of cold bulk forming, multi-stage or combined forming processes are frequently used to produce complex, highly stressed parts. Thus, certain material regions are sometimes formed multiple times. If a load reversal occurs locally, this can trigger anisotropic hardening phenomena. It is expected that the use of the model in multi-stage process chains will also reveal an influence on process forces and tool loads.

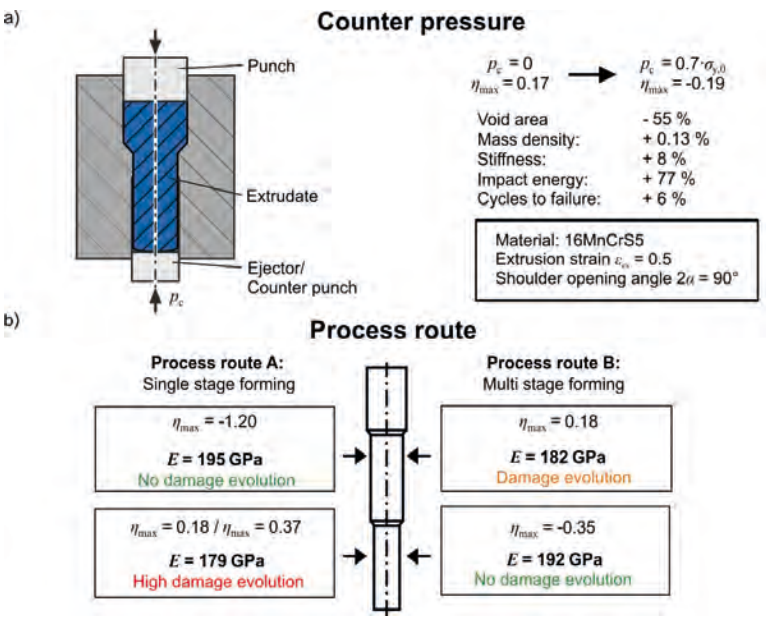


Characterization and modeling of anisotropic hardening at large strains

2.2.3 Influencing the Evolution of Damage in Cold Extrusion

Funding	German Research Foundation (DFG)
Project	CRC/TRR 188 • Subproject A02
Contact	Dr.-Ing. Oliver Hering

Damage in terms of microscopic voids influences the performance of cold extruded components. It has already been shown that the influence of geometric parameters, such as extrusion strain or shoulder opening angle, on the load path leads to a change in the microscopically measurable damage. The separated influence of damage on the performance of the components was determined by means of measurements of the stiffness E, impact energy, and the number of cycles to failure in fatigue tests. Damage evolution is reduced by systematic stress superposition using a counter punch in forward rod extrusion without changing the geometry of the produced component (see Figure a). Furthermore, shafts with multiple stages and varying process routes are investigated. The occurring counter pressure p_c reduces the triaxiality η during forming, resulting in a reduced damage evolution and, thus, improved product properties. By changing the process route, the damage distribution can be affected locally (see Figure b).

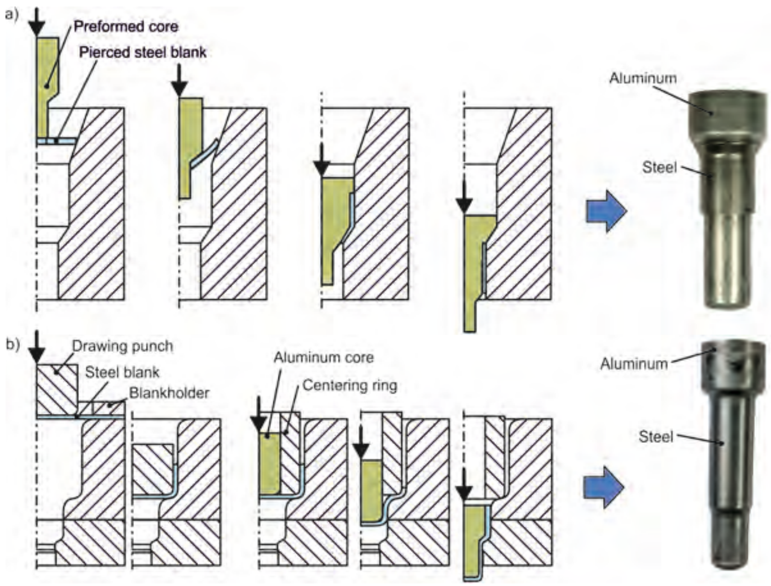


Impact of counter pressure and process route on damage evolution and resulting product performance

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

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

The combination of deep drawing and cold forging, the so-called draw-forging process, enables the production of composite components consisting of an aluminum core and a steel shell. In this way, the advantages of different materials, such as the low weight of aluminum and the high strength of steels, can be brought together appropriately. In the research project the product range of draw forging is extended by the process variants draw-forging with a pierced blank (see Figure a) and direct successive draw-forging (see Figure b). In the first variant, perforated circular blanks are used to cover any section of a shaft. In the second process variant, the metal blank is deep-drawn in several steps and then extruded together with the aluminum core. The drawing ratio and the coated length can be increased significantly by successive deep drawing. Both process variants were successfully carried out experimentally and first limits for the sheet metal geometries and process parameters were identified.

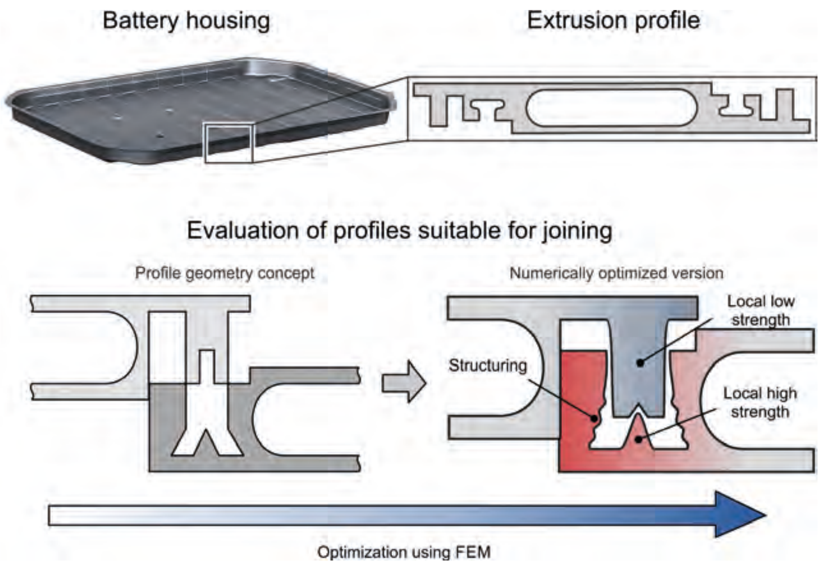


a) Draw-forging with pierced blank, b) Direct successive draw-forging

2.2.5 Linear Joining of Profiles with Increased Sealing Requirements

Funding AiF/Stifterverband Metalle
Project 21048 N
Contact André Schulze M. Sc.

In cooperation with the Laboratory of Materials and Joining technology (LWF) at Paderborn University, this project investigates the development and implementation of a novel extrusion concept for the production of profiles with increased sealing requirements for battery housings. Especially in the context of electromobility, the impermeability of assemblies is of fundamental importance. The solution to achieve these goals involves a simulation-supported development of profile geometry, the setting of extrusion parameters, and local cooling strategies to produce profiles with ideal properties for a downstream, optimized joining process (see figure). The joining process is to be realized by forming technology, ideally on the basis of a press stroke. After the development of corresponding profiles, the resulting impermeability of the linear joints will be investigated and the results will be evaluated in the context of the manufacturing and joining process. Initial investigations are concerned with the profile design by identifying structures suitable for joining.



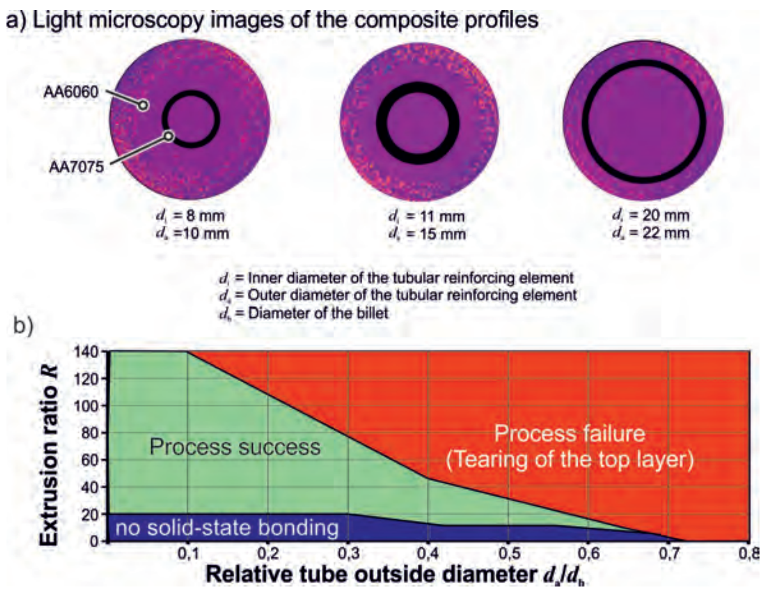
Design and development of extrusion profiles suitable for joining

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

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

The aim of the project is the development of a process route consisting of composite hot extrusion with tubular reinforcing elements and subsequent cold forging to produce flange-shaped components. While the extrusion process is carried out at the IUL, the Institute of Metal Forming (IFU) in Stuttgart is responsible for further processing of the semi-finished products by means of lateral extrusion.

Initially, hybrid profiles were extruded from the combination of AA6060 as matrix material and AA7075 as reinforcing element. Figure a shows the cross sections of extruded semi-finished products utilizing reinforcing tubes with different initial inner and outer diameters d_i and d_a. A process window was determined numerically which shows the process success with regard to the extrusion ratio and the relative tube outside diameter (see Figure b). Process errors occur at high values of these parameters. Low values reduce the weld-quality so that the desired solid-state bonding does not occur.

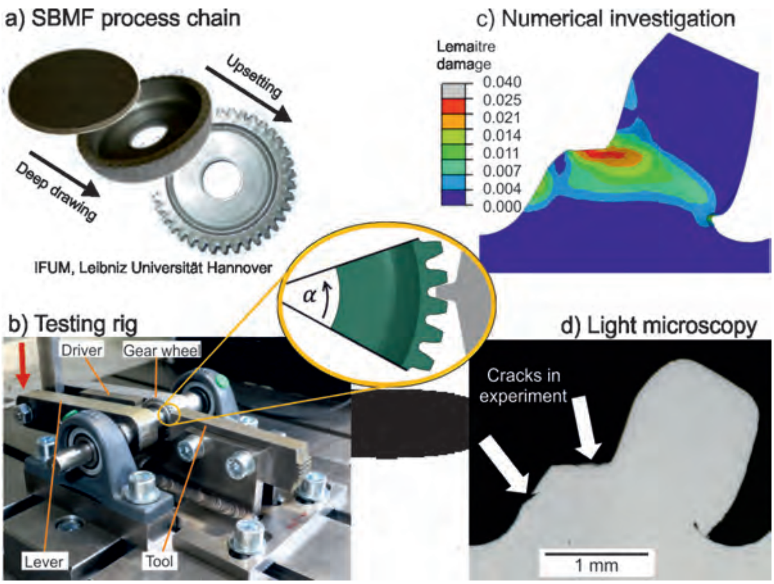


a) Light microscopy images of three composite profiles, b) Process window of AA6060 – AA7075

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

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

Sheet-Bulk Metal Forming (SBMF) enables the near-net-shape production of components directly from sheet metal. The extent to which an increased strain rate, e.g. in case of sudden overload, has an influence on failure in service was investigated on a gear wheel manufactured by BMU (see Figure a). To this end, a test rig was developed by the Institute for Materials Science (IW) at Leibniz Universität Hannover to test the strength of the gearing at peripheral speeds of 0.012 mm/s and 25 mm/s (see Figure b). Numerically, the plastic behavior was represented with the Johnson-Cook approach and the damage development with a criterion according to Lemaitre. The numerical and microscopic investigations have shown that, regardless of the speed, the component fails at the same position and in the same way (see Figures c and d). At increased speed, however, the damage in the component is about 25% higher, although the plastic strains are almost identical.



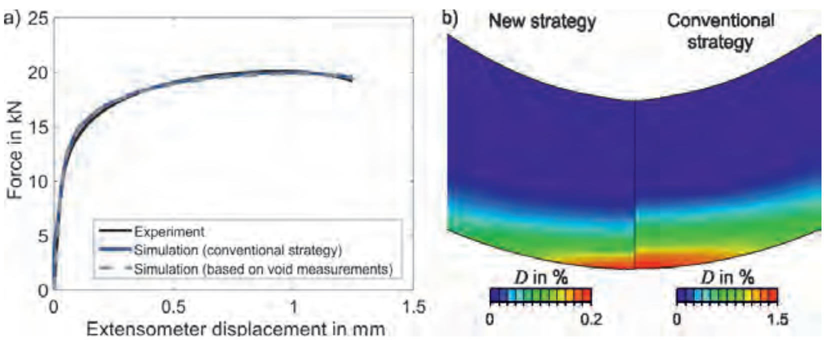
a) Gear wheel, b) Test rig for gear wheel, c) Simulation result, d) Microscopic investigation

2.2.8 Model Integration for Process Simulation

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

Numerical simulations are used in order to optimally design forming processes in the CRC/TRR 188. The prediction of damage in the sense of void fractions is of special importance for the product performance. In order to predict the damage realistically, a methodology for model calibration has been developed based on experimentally measured void fractions. While a similar procedure for the Gurson-Tvergaard-Needleman-model is already established, this strategy has been extended to be generally applicable.

The figure depicts the simulation results with the Lemaitre model for a classical parameter identification process compared to the newly developed strategy. While there is barely any difference between those curves (see Figure a), there are large differences in the void evolution D of an air bending process (see Figure b). The results for the strategy based on void measurements depict the experimental data well, whereas there are large differences for the conventional strategy.

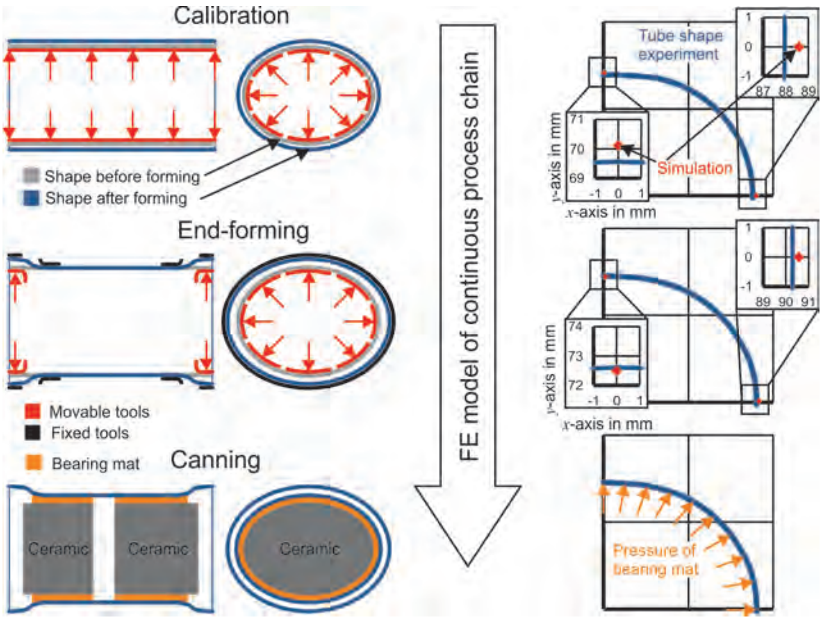


a) Results of the parameter identification process, b) Validation in terms of air bending

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

Funding ReCIMP
Contact Dr.-Ing. Till Clausmeyer

Exhaust systems for automobiles are facing increased requirements on utilization of assembly space. Consequently, the demand for non-round tubes increases. To comply with the required shape tolerances of complex non-round-tubes, a finite-element model of the forming process chain was created. A challenge was to adequately consider unknown or variable process parameters in the simulation. The chosen approach enabled the prediction of shape deviation within the required tolerance for different shapes (see figure). The subsequent filling process (canning) is currently being considered. Only this filling process turns the formed tubes into an exhaust component. In this process a stiff ceramic is encased in a soft bearing mat and inserted into the tube. This results in an undesired deviation of the shape of the pipe component. Currently, various approaches are being investigated to numerically map the filling process. The aim is to predict the further change in shape caused by canning as well as the load on the sensitive inner component.



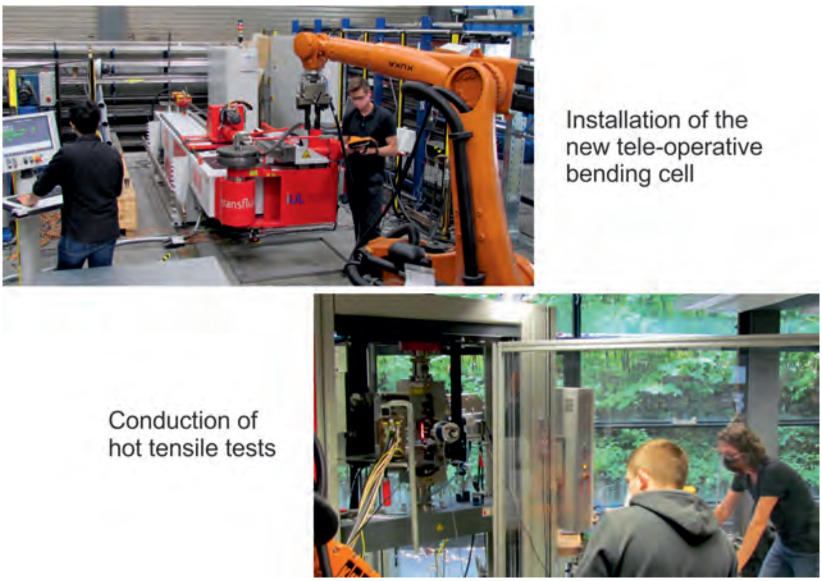
Continuous prediction of the shape during the canning process chain

2.3 Department of Profile and Sheet Metal Forming

Head Dr.-Ing. Rickmer Meya

The department primarily focuses on the development of new processes for the forming of profiles, tubes, and sheets as well as on the research of fundamentals for known forming processes and on the characterization of materials at elevated temperatures and strains (see picture).

This year, for example, active media-based profile forming and simultaneous kinematic bending in a continuous process using a graded temperature field was developed as a new process. In the field of fundamental research, the influence of forming-induced damage on the performance of bent components is revealed. Further investigations deal with temperature-assisted forming for improved process and product properties. Here, the focus is on controlling product properties in hot stamping and by the use of additively manufactured press hardening tools as well as profile bending with partial heating. Furthermore, a conventional rotary draw bending machine was prepared as a tele-operative test laboratory for the application in teaching (see figure).

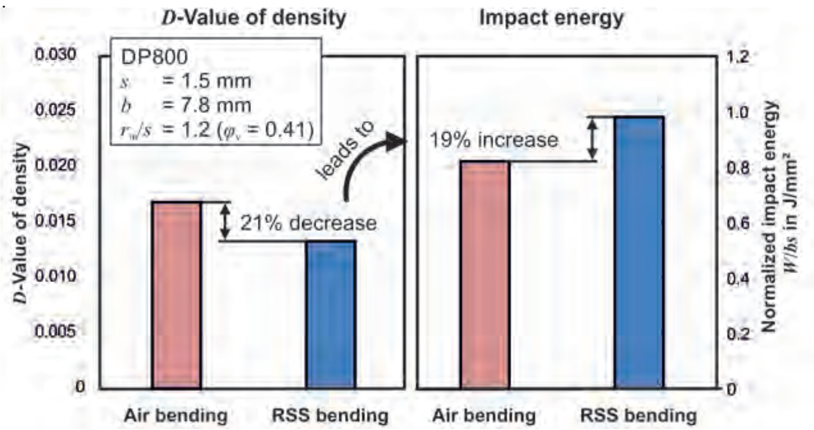


The pictures show the rotary draw bending machine lab and the conduction of a hot tensile test.

2.3.1 Damage in Sheet Metal Bending of Lightweight Profiles

Funding	German Research Foundation (DFG)
Project	CRC/TRR 188 • Subproject A05
Contact	Dr.-Ing. Rickmer Meya

Bent parts made of high-strength steel materials are often produced by processes such as air or die bending. The stress state and, thus, the damage is only slightly influenced by conventional process parameters during air bending so that the so-called RSS bending was developed. This process is able to superpose compressive stresses in the forming zone in a controlled manner. Thus, damage can be reduced. The hypothesis that damage control based on the modification of the hydrostatic stress state can significantly increase the performance of bent parts in terms of absorbed impact energy, stiffness, and fatigue strength has been confirmed. To determine the notched impact strength of bent sheets, a modified specimen with a groove has been developed which generates a stress concentration directly in the forming zone. Due to the stress superposition during RSS bending and the resulting reduced damage, the absorbed impact energy is increased by up to 19% (see figure).

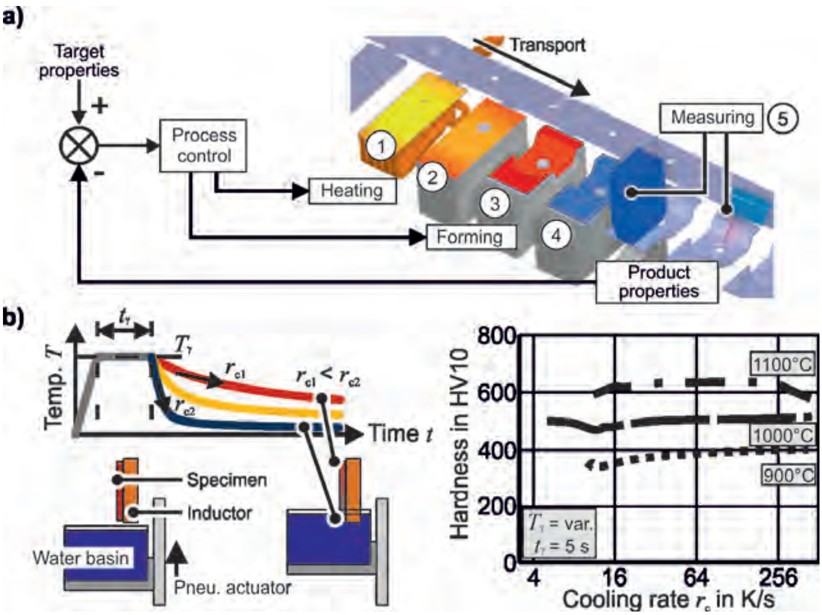


Influence of different bending methods on damage and performance

2.3.2 Property-Controlled Multi-Stage Hot Sheet Metal Forming

Funding	German Research Foundation (DFG)
Project	424334660 (SPP2183)
Contact	Juri Martschin M. Sc.

To enable a robust and versatile production, a method for the manufacturing of complex sheet metal components using a controlled, multi-stage, heat-assisted forming process is being developed in this project. In the closed-loop demonstrator process (see Figure a) a sheet metal blank is first rapidly heated and then formed and quenched in three stages in a progressive die. Finally, essential product properties are measured and fed back to the process control. The press hardening steel X46Cr13 is used to carry out a heat treatment during the forming process. The setting of the product properties – such as the hardness – takes place within the process control by adjusting the heating parameters as well as the number of strokes per minute and ram curve of the press. Quenching tests are carried out to determine the sensitivity of the selected material to the heating parameters (see Figure b). Hardness measurements show that the product hardness can be set by varying the austenitizing temperature T_γ.

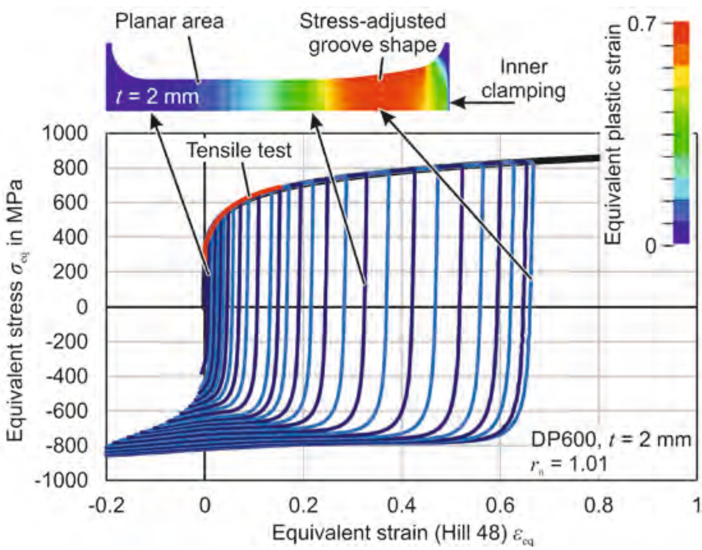


a) Demonstration process in the progressive die, b) Quenching test and hardness results

2.3.3 Novel In-Plane Torsion Specimen for the Characterization of Damage and Hardening

Funding	German Research Foundation (DFG)
Project	327544970
Contact	Dr.-Ing. Heinrich Traphöner
Status	Completed

One advantage of the in-plane torsion test is the efficient characterization of the kinematic hardening by evaluating the specimen at different radii. For planar specimens, however, the strain that can be achieved before the reverse of load is limited by the influence of the inner clamping. Specimens with a groove achieve significantly higher strains, but can only be evaluated in a limited area of the groove. For this reason, a sample is developed that combines the advantages of both specimen shapes. The figure shows the numerical simulation of a groove which has been extended by a planar area. The equivalent strain decreases with increasing distance from the inner clamping. With this new specimen shape it is possible to characterize both very high pre-strains and very low pre-strains on a single specimen. The figure shows the cyclic stress-strain curves for a high-strength DP600 steel of 2 mm sheet thickness with pre-strains between 0 and 0.7, which was determined on a single specimen and with a single experiment.

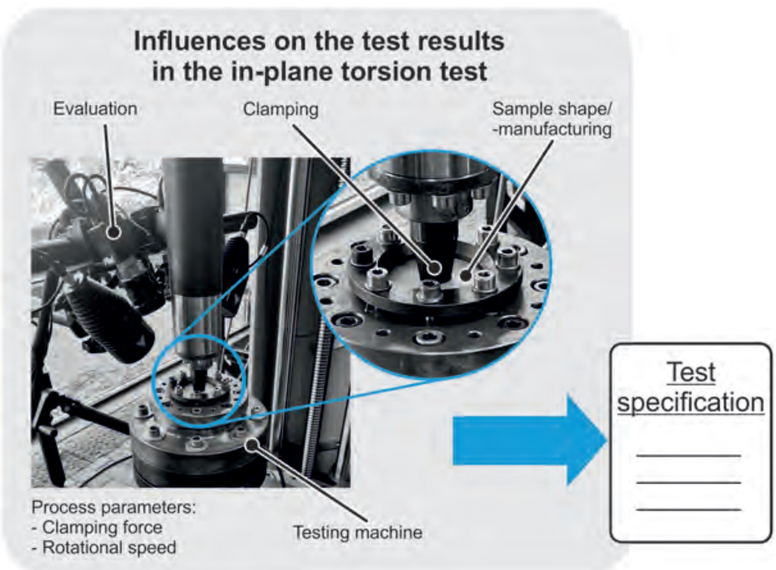


Numerical simulation and cyclic flow curves for an in-plane torsion test with a planar groove root

2.3.4 Preparing the Standardization of the In-Plane Torsion Test

Funding	AiF/FOSTA
Project	21137 N/P1320
Contact	Fabian Stiebert M. Sc.

The in-plane torsion test (IPTT) is a material characterization method which can determine flow curves under pure shearing up to high degrees of deformation. In order to enable a broader industrial use of the IPTT, a standardization of the test procedure needs to be established and a test specification has to be prepared. For this purpose, the influence of different process parameters as well as the influence of the sample manufacturing and sample geometry on the test results will be investigated. Based on these results, suitable test conditions for a standardized test procedure will be defined. By an analytical examination of smooth clamping surfaces it can be shown that when using the same clamping force an annular clamping surface can increase the transmittable torque compared to a full clamping surface. However, due to the machine-related limitation of the clamping force, this torque is not sufficient to test materials up to high strains without slipping. For this reason, different clamping surface geometries are examined in a further step with regard to their suitability.

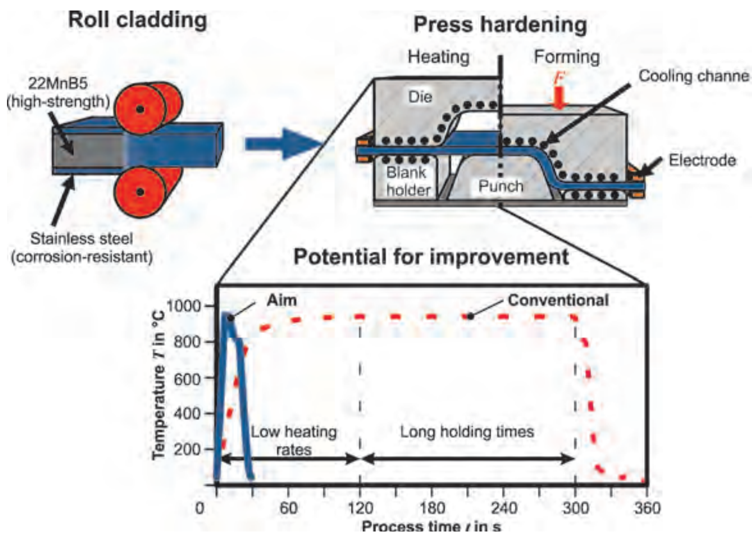


Test setup and influences on the results of the in-plane torsion test

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

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

Press hardening is used for the production of high-strength components which are, for example, installed in safety-relevant areas of the automobile. Due to the high process temperatures, coated sheets must be used as a protection against oxidation. However, the coatings are not resistant to high temperatures, so diffusion layers must be formed. These require low heating rates and long holding times. To reduce the process time, the extent to which the coatings can be replaced by stainless steel cover plates is being investigated in cooperation with the IBF of RWTH Aachen University. An austenitic (1.4301) and a martensitic stainless steel (1.4021) are being investigated as top layer and the boron-manganese steel 22MnB5 as core material. In the next step, these plates will be materially bonded at the IBF during the rolling process (roll cladding). The variation of the materials and their layer thickness ratios enables the production of load-adapted lightweight components. The roll clad semi-finished products are subsequently evaluated in terms of forming technology at the IUL.

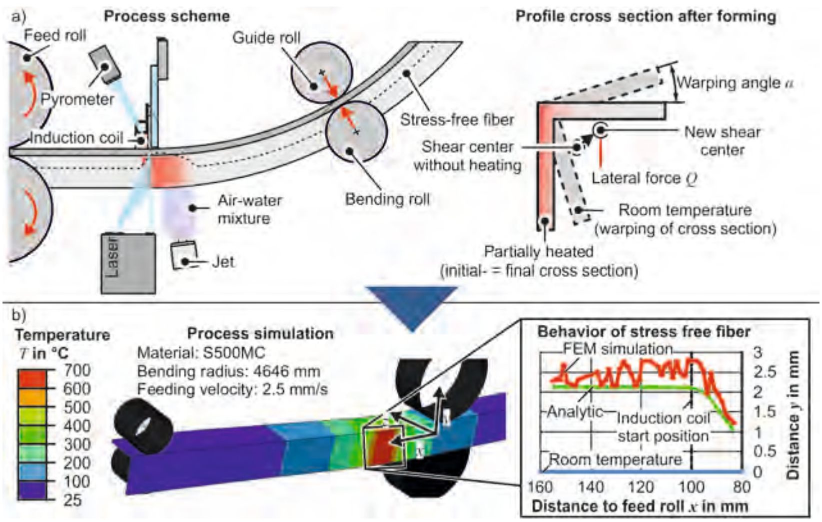


Potential for improvement in press hardening by using roll-clad semi-finished products

2.3.6 Kinematic Profile Bending with Partial Cross-Sectional Heating

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

In this project the suitability of partial heating of asymmetric profiles for the reduction of geometrical deviations in bending processes is examined. In conventional bending of asymmetric profiles a deviation of the shear center position from the bending plane leads to warping in the cross section. To avoid the effect of warping, L-profiles are partially heated through induction and quenched using an air-water mixture after the bending process. Consequently, the position of the stress-free fiber and the position of the shear center changes due to thermal softening in one of the profile areas (see Figure a). For the geometrical result the forming temperature as well as the selection of the heated area is relevant. The first research objective is to find a temperature of the heated area which negates the warping entirely while not influencing the material properties. To quantify the influence of temperature on the stress free fiber, numerical and analytical methods are used (see Figure b).

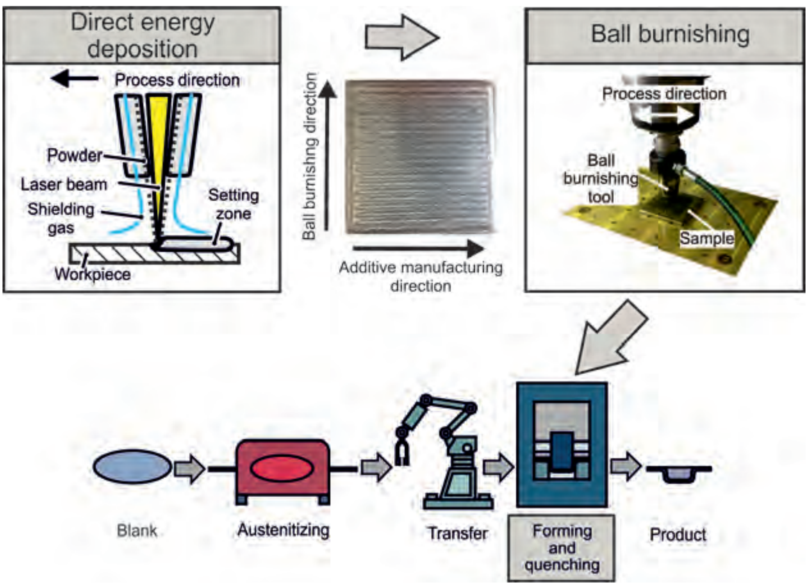


a) Process principle, b) Analytical and numerical results for stress-free fiber

2.3.7 Functionalization of Additively Manufactured Hot Stamping Tools Using Ball Burnishing

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

Hot stamping is used in sheet metal forming in order to use the increased forming capacity due to high temperatures and the increase in strength due to quenching. For this purpose, cooling channels, which are usually produced using machining processes, are integrated into the tools. Within the scope of the project the development of additively manufactured hot stamping tools by means of direct energy deposition is intended to enable the channels to be positioned as close as possible to the surface. This avoids local overheating of the tool. Since direct energy deposition creates a very rough, wavy surface, post-processing is necessary. This is done by means of incremental ball burnishing (see figure). Here, the tool surfaces can be adjusted locally. In this way, a targeted influence on the heat transfer and the material flow during hot stamping is to be achieved. Initial studies of ball burnishing additively manufactured surfaces show that the high roughness can be reduced by up to 75%, depending on the hardness of the tool steel powder.

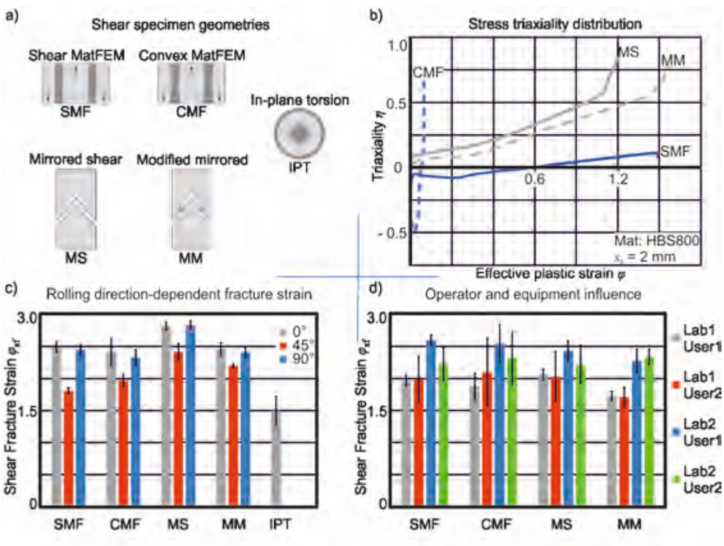


Process steps for additively manufactured and ball-burnished hot stamping tools

2.3.8 Characterization of Fracture Resistance of Optimized Ferritic and Bainitic Steel Grades with Special Focus on Shear Loading

Funding ReCIMP
Contact Dr.-Ing. Rickmer Meya

Car seat components are often subjected to shear loads. Based on the anisotropy of the material and the type of shear test, a high deviation is observed in the shear fracture strain. With the aim to understand this deviation, the shear fracture resistance of a ferritic (S700MC) and a bainitic (HBS800) steel is determined using five different specimen geometries (see Figure a), while also considering their rolling direction. Additionally, numerical stress triaxiality investigations for four of these geometries show that, apart from the IPT specimen, the SMF specimen was the only geometry showing an almost ideal shear behavior during the test ($\eta=L=0$) (see Figure b). Experimentally, it is determined that HBS800 shows high anisotropy with the fracture strain being lower in the diagonal direction compared to the longitudinal (see Figure c). Up next, investigations to correlate the results with the triaxiality variance as well as a validation using an industry part are planned. Further, the influence of the equipment as well as the operator on the results has been analyzed (see Figure d).

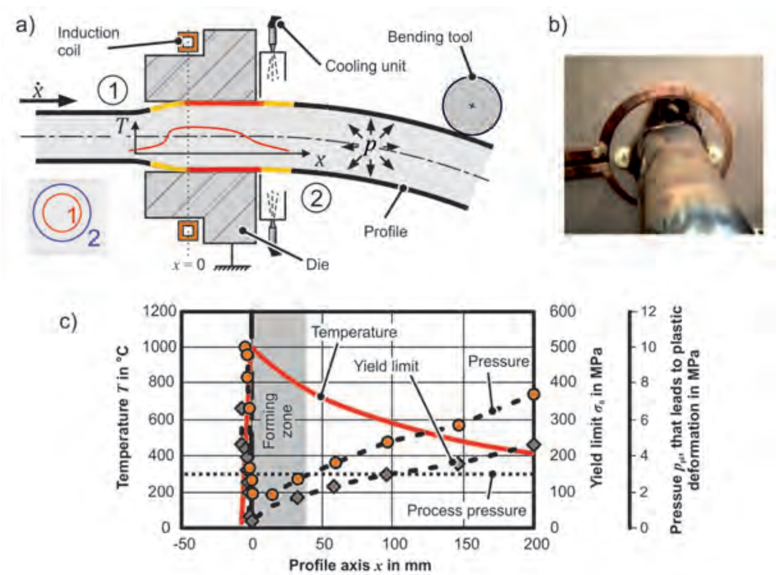


a) Tested geometries, b) Triaxiality distribution, Influence of c) Anisotropy and d) Test conditions

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

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

The production of thin-walled, load-adapted, and cuved profiles has a high potential for safety-relevant structures in automotive applications. Currently, there is no process enabling all these aspects in one manufacturing step. In cooperation with the company HoDforming, the temperature-assisted internal-pressure profile-forming (TIP process) is being investigated for this purpose (see Figure a). A profile is subjected to internal pressure and pushed through a forming die. By inductive heating of the semi-finished product, the yield point of the material is reduced locally so that the internal pressure expands the profile in this area. A cooling unit is used to achieve variable thermal treatment along the longitudinal axis, while the profile is formed by a bending tool. The feasibility of the process has already been proven experimentally (see Figure b). Analytical and empirical approaches enable the establishment of a process window with regard to temperature, flow behavior, and the pressure required for plastic expansion (see Figure c).



a) Process principle, b) Experimental implementation and c) A process window for the expansion

2.4 Department of Non-Conventional Processes

Head Marlon Hahn M. Sc.

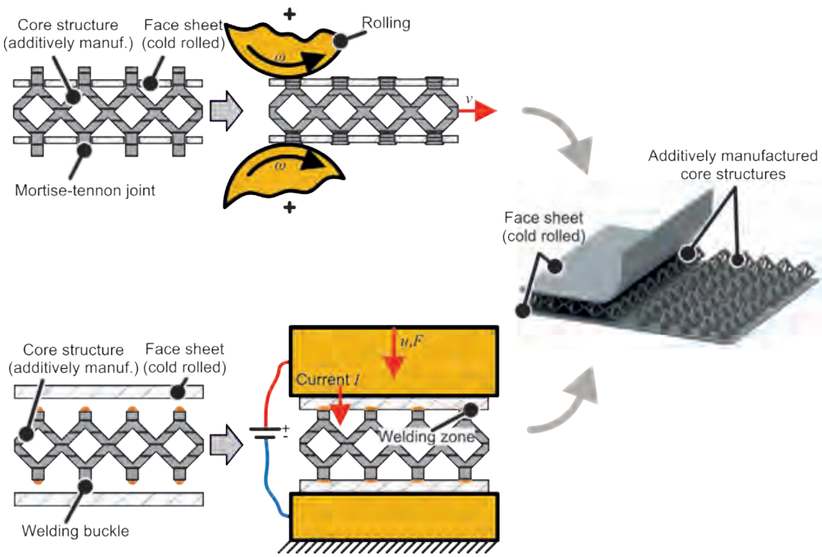
This research department focuses on technologies that offer advantages over traditional forming operations, such as extended forming limits or an increased production flexibility. These processes are either very new or challenges regarding a wide industrial adoption still exist and should be overcome. Current projects deal, for example, with different high speed processes, joining of hybrid material systems by forming, targeted enhancement of a part's fatigue strength through adjusted incremental forming as well as with novel applications of additive manufacturing, like the improvement of the prototyping technology of layer-laminated deep drawing tools or the forming of innovative three-dimensional high performance structures (cf. figure background). Within all these research projects, both numerical and analytical methods as well as up-to-date experimental measuring techniques are employed to facilitate a fundamental process understanding. This way, further potentials and scientific questions can be identified. The team consists of eight researchers at present (see figure).

Animated image of the department during the pandemic

2.4.1 Forming of Additively Manufactured Sandwich Sheets with Optimized Core Structures

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

In cooperation with the Institute for Product Engineering of the University of Duisburg-Essen additively manufactured sandwich sheet composites with core structures optimized for forming are developed. The semi-finished core structures must withstand a forming operation without losing their structural integrity. The aim of the second funding period is the production and characterization of large-area semi-finished sandwich products. This is intended to overcome the currently prevailing space restrictions for additively manufactured components. In order to manufacture the semi-finished products, suitable joining methods (material- or form-fit; see figure) for connecting the additively manufactured core and the rolled top layer must be developed and tested. To further increase the formability of the semi-finished products, a new type of highly ductile TWIP steel is to be qualified as part of the project. To further increase performance, the structures will also be adapted by means of topology optimization.

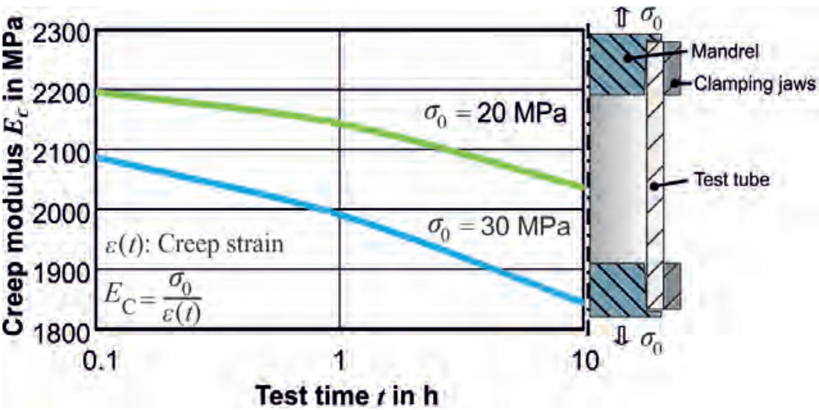


Concept for joining and manufacturing large-area semi-finished sandwich products

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

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

The research in this project is designed as a collaborative joint project with the partners PFW Aerospace, Steitz Präzisionstechnik, and Fraunhofer IZFP. Within the scope of the IUL subproject the use of contactless joining by forming processes for hybrid metal-thermoplastic force- and form-fit connections in aerospace applications is investigated. Joining by die-less hydroforming as well as electromagnetic joining by expansion is taken into consideration, including a possible integration of corresponding non-destructive testing methods. Besides the significantly different material behavior of the joining partners, the specific requirements of the aerospace industry pose fundamental challenges for the novel joints to be developed. These are, for example, the prevention of a kerosene leakage and the necessity of a well-defined electrical conductance of the joint in the event of a lightning strike. Current investigations focus on the time-dependent material characterization of the different joining partners.

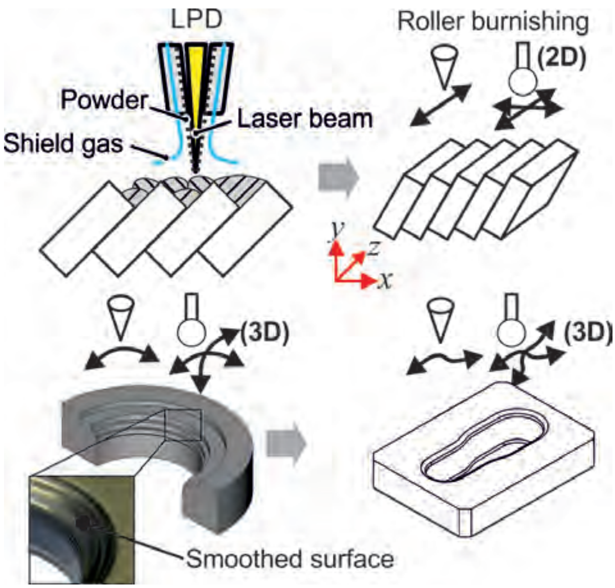


Creep behavior of polycarbonate determined by tensile tube test

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

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

The aim of the project is to develop a resource-efficient process chain for the flexible manufacturing of dies for deep drawing processes. The corresponding high-volume base body of the die is manufactured in a fast and cost-efficient way from varying single sheet metal layers. The occurring 'stair steps', which always result from the layering of the sheets, are to be filled subsequently by laser powder deposition (LPD) and, eventually, the active die areas are to be smoothed through roller burnishing employing different strategies. In this context, the weld seam as well as the bonding quality to the sheets has to be characterized thoroughly. An analytical description is supposed to ease the design process for the layer-laminated tool. The fundamentals developed are transferred to drawing tools of different complexities and examined in forming tests with regard to the achievable component quality and wear development. Finally, a technological, economic, and energetic evaluation is carried out.

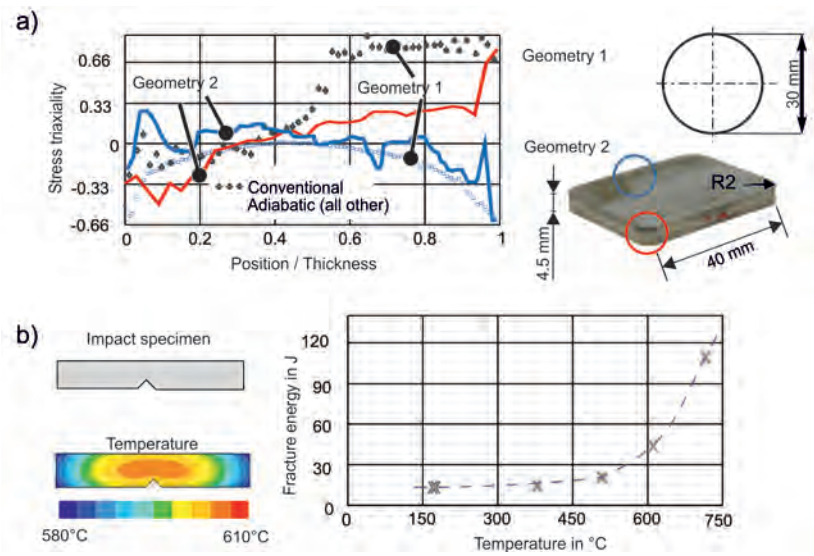


Process chain of manufacturing a hybrid deep drawing tool

2.4.4 Application and Analysis of Adiabatic Blanking

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

Due to its high local rate of deformation ($\dot{\varepsilon} \geq 10^4\ s^{-1}$) and short process time ($t < 2$ ms), adiabatic blanking exhibits temperature-induced softening. This localizes the plastic strain and leads to a compression-shear stress in the cutting gap. Compared to the conventional blanking process, this results in a high blanking quality and the formation of adiabatic shear bands (dynamic recrystallization). Depending on the blanking geometry (see Figure a), this stress state can also alter in adiabatic blanking. By adapting the boundary conditions, a homogeneous loading is to be achieved over the circumference. For this purpose, simulative predictions of local effects are required for which existing methods are continuously extended. For example, the determination of the onset of failure is improved by new temperature-dependent failure criteria, which are determined by dynamic characterization tests (see Figure b). The project is conducted in cooperation with the Institute of Materials Science and Engineering (LWW) at Chemnitz University of Technology.

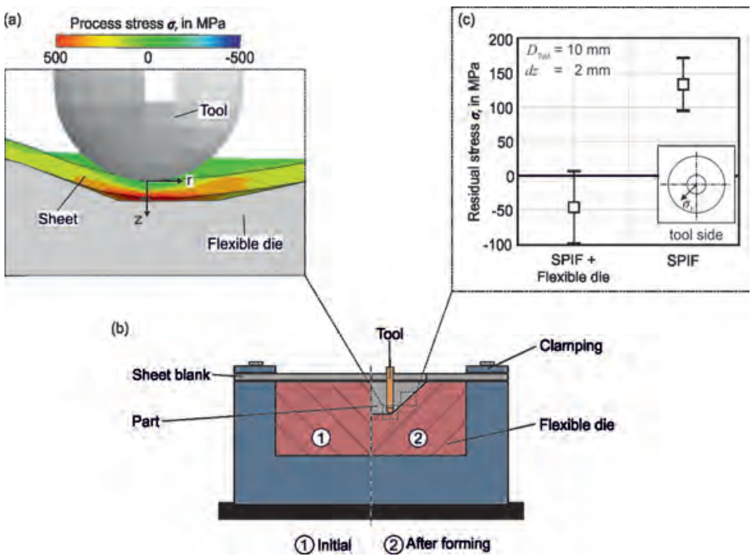


a) Stress state during the process, b) Modeling of temperature-dependent failure

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

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

The aim of the second funding period of the priority program is to improve metal component properties through forming-induced residual stresses. In collaboration with the department of Metallic Materials of TU Berlin University the Single Point Incremental Forming (SPIF) process is analyzed with regard to the targeted adjustment of residual stresses. The potential of influencing the residual stresses in a specific way through the forming process was proven in the previous funding period. Based on a numerical process model (see Figure a), a SPIF process enhancement using a flexible polyurethane die is established (see Figure b). This process enhancement even enables an introduction of compressive residual stresses at the tool side of the component (see Figure c). Eventually, the fatigue strength of cyclic loaded components is to be increased through the targeted SPIF-introduction of residual stresses. The research also considers the influence of disturbance values on the residual stress generation.

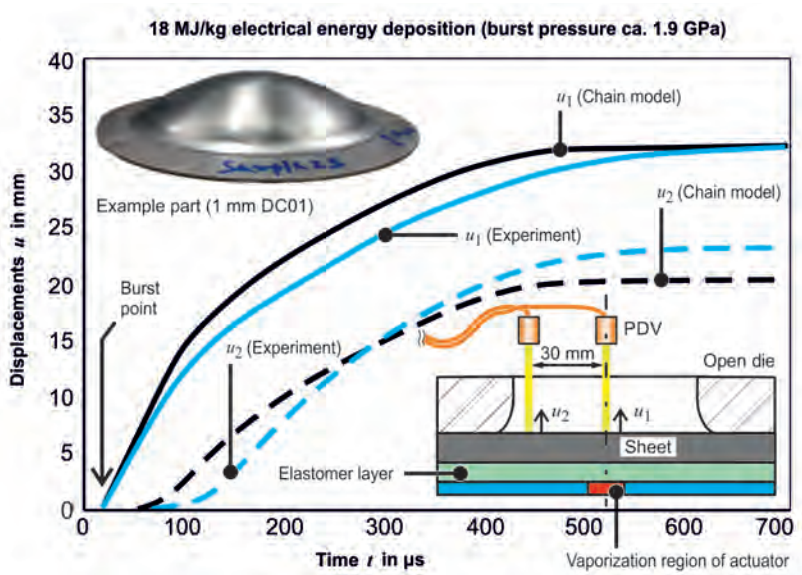


a) Numerical process model, b) Process set-up, c) XRD measurement results

2.4.6 Forming by Locally Varying Vaporizing Actuators

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

Discharging a capacitor bank over an Al foil leads to the foil's rapid vaporization (called vaporizing actuator) so that the resulting pressure – depending on the actuator placement – can be used for a locally flexible sheet metal forming operation. Aiming at a predictive process design, a two-step approach for the establishment of a multi-physical modeling exists. The electrical energy deposition until the so-called burst point was already investigated numerically as well as analytically. The burst energy density corresponds to a certain impulse pressure, by which the strain rate-dependent forming is modeled in the second step. Regarding a spatially complete simulation, a meshless method is considered for the expanding foil actuator. Yet, in a simplified code the sheet blank has first been expressed as a "plastically connected mass chain" (chain model in figure), loaded by a pre-defined impulse over the vaporization region of the actuator. Measurements employing Photon Doppler Velocimetry (PDV) validate the inertia-caused dynamics of the forming history (see figure).

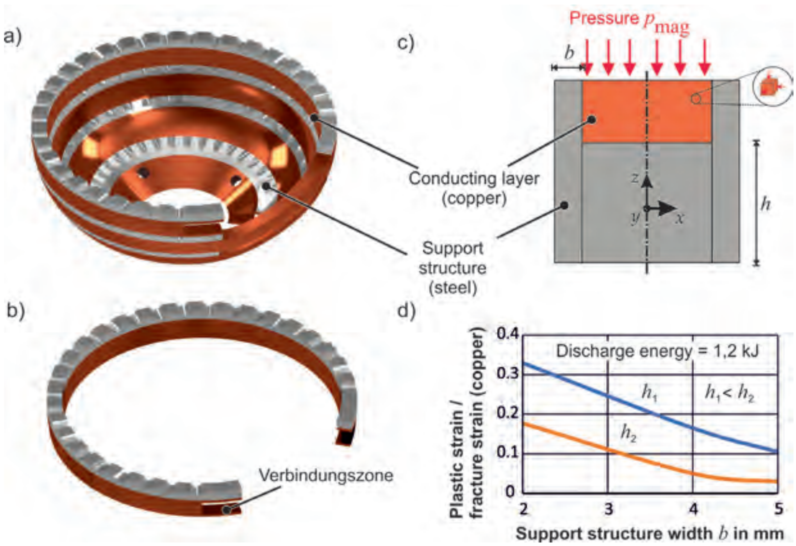


Exemplary comparison between experiment and simplified forming model

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

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

In collaboration with the Institute of Machine Tools and Factory Management of TU Berlin the final funding period of the project is conducted with the objective of developing hybrid (multi-metallic) additively manufactured coils for the process design for electromagnetic forming. The current focus of research at the IUL is on the development of a hybrid coil for the reduction of the achievable corner radius of deep-drawn parts (see Figures a, b). Due to the complicated geometry of the hybrid coil, an assembly-based solution is proposed which provides additional flexibility to the coil use. Moreover, the prevention of plastic deformation of the coils is investigated with the introduction of steel support structures. By the help of side supports, a hydrostatic pressure in the coil is applied, minimizing undesired plastic deformation (see Figures c, d). Validated numerical and analytical analyses facilitate the design procedure of the novel hybrid coils for the ensuing experimental realization.

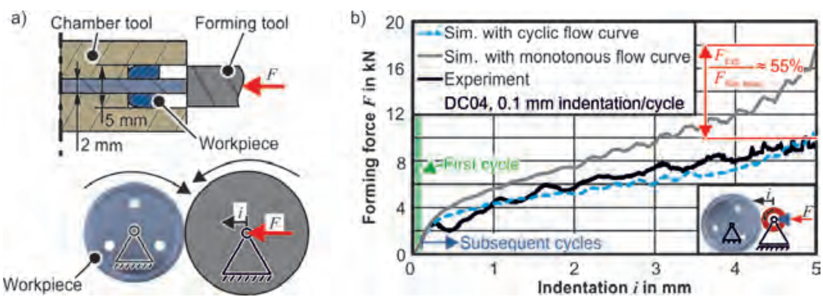


a) Assembly-based coil, b) Corresponding ring element, c) Coil cross section, d) Deformation analysis

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

Funding	German Research Foundation (DFG)
Project	CRC/TR 73 • Subproject A4
Contact	Sebastian Wernicke M. Sc.

The main objective is the manufacturing of geometrically complex components from sheets with integrated functional elements by incremental forming. After adjusting the load capacity by thickening of the edge (see Figure a) the calibration of functional elements follows. As a fundamental question, it has to be investigated whether the strain paths resulting from different process strategies are usable for a targeted manipulation of the mechanical product properties. Numerical investigations of the iSBMF processes present cyclic load changes. Measurements of the resulting hardness reveal that iSBMF is not able to transform the strain hardening potential of the material observed in material characterization with monotonous loading. The consideration of cyclic strain hardening by a simplified modeling approach increases the quality of the force prediction by 55% compared to utilizing flow curves determined during monotonous loading (see Figure b). Therefore, taking kinematic hardening into account is identified to be essential for the numerical process design of iSBMF.

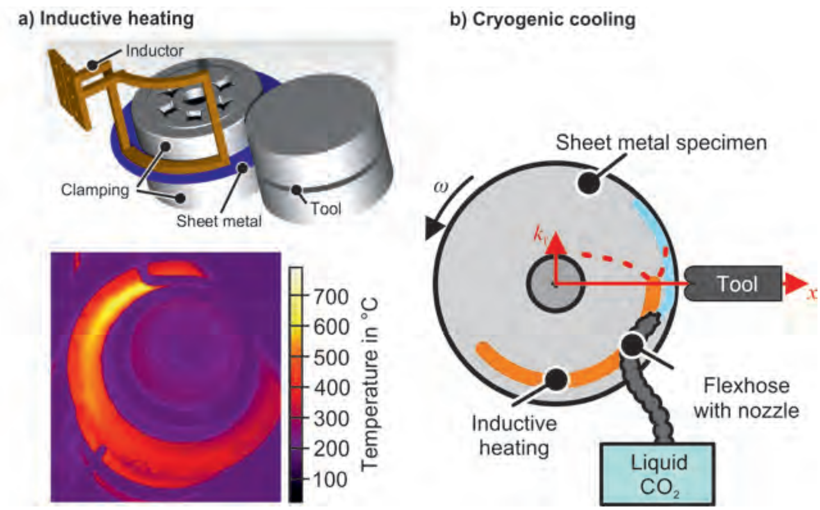


a) Schematic of experimental setup, b) Resulting forming force comparison

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

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

A challenge of incremental sheet bulk metal forming is to achieve a uniform edge thickness distribution from the sheet edge to the center of the sheet. By means of thermally graded forming, the flow stress needs to be reduced locally in order to be able to influence the axial material flow in a targeted manner. With this strategy a homogenization of the thickened sheet height shall be achieved. The transfer project is being carried out in cooperation with the industrial partners Winkelmann Powertrain Components GmbH, Thyssenkrupp Hohenlimburg GmbH, Faurecia Seatings GmbH, and Voestalpine High Performance Metals Germany GmbH. Investigations intending to identify suitable process control strategies have shown that inductive heating is a promising approach for setting a sharp temperature gradient. In addition to the thermal grading, cryogenic cooling with temperatures down to -80°C is planned to be used. Thus, a further change of the yield stress in the outer boundary region of the sheet should be achieved.

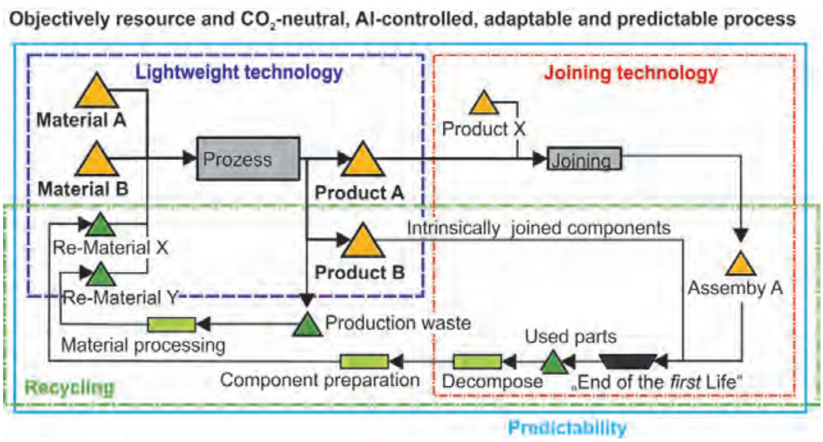


a) Inductive heating with thermographic image, b) Possible cryogenic cooling setup

2.4.10 Forming Technologies for Metallic and Hybrid Lightweight Structures for the Use in Electromobility

Funding	BMBF/PTKA • Promotion Platform FOREL 2
Project	02P16Z011
Contact	Fabian Schmitz M. Sc.
Status	Completed

The partners within this coordination project of the University of Dresden, Bergakademie Freiberg, University of Paderborn, University of Munich, and TU Dortmund University dealt with topics on future mobility, particularly regarding numerical predictive ability and lightweight construction. The project focused on the further development of existing processes as well as the identification of new fields of research for specific problems and fields of application of electric mobility. On the basis of expert interviews and studies an interdisciplinary guide was created in the last phase of the project, which is divided into four sections (see Figure: joining technology, numerical predictability, recycling, lightweight technology). It corresponds to the final milestone of the project and shows a vision for the specialized fields involved for the year 2030+, derives a roadmap for the next 10 years, and provides specific recommendations for funding and guidance to achieve the vision.

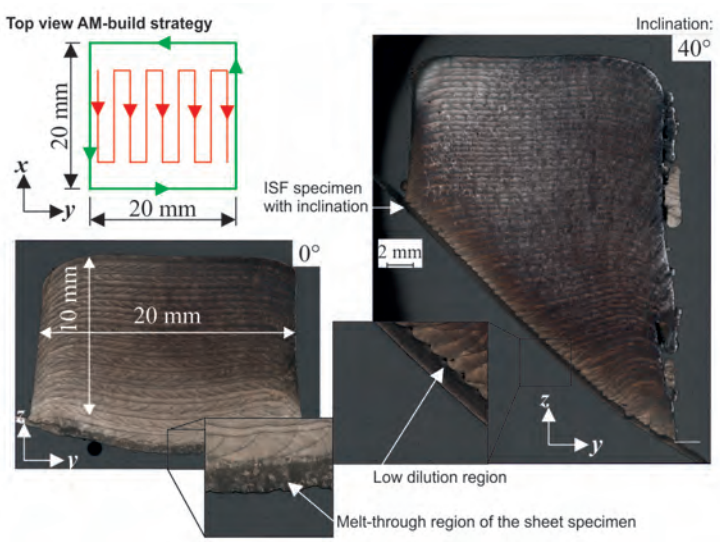


Material flow of a production chain as well as thematic allocation of the FOREL guide

2.4.11 Process Combination of Incremental Sheet Forming and Laser Powder Deposition for Lightweight Manufacturing

Funding	German Research Foundation (DFG)
Project	385276922
Contact	Marlon Hahn M. Sc.
Status	Completed

The aim of this project was the analysis of the process combination of incremental sheet forming (ISF) and additive manufacturing (AM) in the form of laser metal deposition (LMD) with respect to their fundamental interactions. The investigations focused on the effects of ISF having an influence on the application of functional additive elements. The incrementally formed sheet metal served as thin substrate for the ensuing LMD process. Besides a process window for the additive material deposition itself, including corresponding path strategies, the influence of the ISF step-down incrementation and inclination angle on the qualitiy of the additive deposition was analyzed (see figure). In this context, despite some inherent restictions, the process combination appeared to be relatively robust with regard to the abovementioned variations. Furthermore, the bonding strength between the deposited material and the sheet substrate was tested under tensile and torsional loading and failure always occurred in the thin sheet instead of in the welded region.

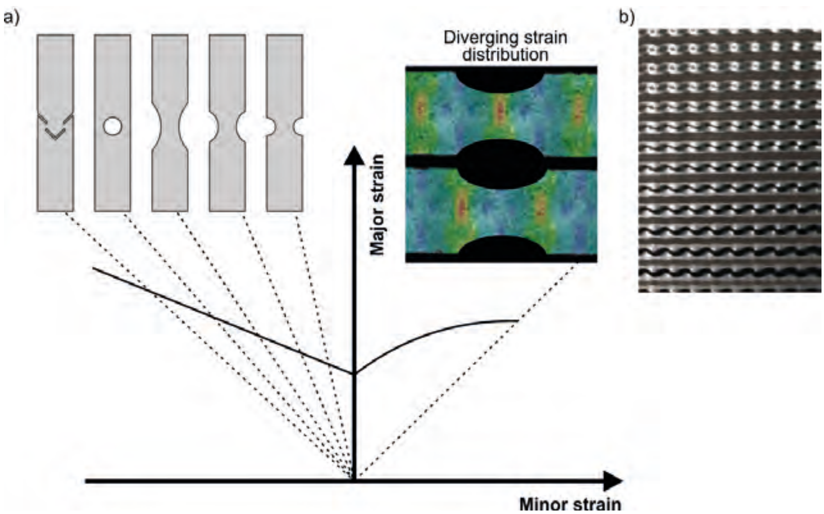


AM-deposited material and dilution with (40°) and without (0°) inclination from ISF

2.4.12 Crash Forming of Structured Sheets with Wall Thicknesses Less Than 0.8 mm

Funding	ReCIMP
Contact	Florian Weber M. Sc.

The introduction of defined three-dimensional structures into sheet forming has several advantages compared to flat sheets. The increase in heat transfer due to an expansion of the surface, an improved moment of inertia as well as the decrease in noise and the possibility of shock absorbency can be mentioned exemplarily. Within the scope of this ReCIMP project the application of structured ferritic chromium steel sheets for exhaust system insulation is investigated. To ensure a robust manufacturing process, the deep drawing of the sheets is analyzed numerically. Therefore, the experimental determination of the forming limit is necessary (see Figure a). Besides the Nakazima test, the principal strains are determined by tensile tests with grooved specimens. Due to the inhomogeneity of the three-dimensional structure (see Figure b), the strain distribution depends on the rolling direction of the sheets as well as the positioning of the grooves. This leads to a scattering in the forming limit diagram.



a) FLC determination via tensile tests and optical strain measurement. b) Example of a structured sheet

2.5 Patents

2.5.1 Granted Patents

Title	Device and method for producing non-porous profiles from separation residues by means of extrusion
Application number	EP2809461
Patent holder	TU Dortmund University
Status	Granted July 29, 2020
Inventors	A. E. Tekkaya • V. Güley

Title	Process for the production of thermoplastic fiber-metal laminate components by means of forming processes and correspondingly produced fiber-metal laminate components
Application number	DE102014001132
Patent holder	Karlsruhe Institute of Technology TU Dortmund University
Status	Granted September 3, 2020
Inventors	A. E. Tekkaya • N. Ben Khalifa • A. Güner T. Mennecart • A. Rösner • K. André • F. Henning

2.5.2 Published Patents

Title	Device and method for the conduction of compression tests on specimens to characterize materials as well as corresponding test specimens
File number	DE102019001442 A1
Patent holder	TU Dortmund University
Status	Filed September 3, 2020
Inventors	F. Kolpak • O. Hering • A. E. Tekkaya

Title	Method and device for producing profiled cross-sections from metals and plastics by means of extrusion molding and extrusion
File number	PCT/DE2019/000058
Patent holder	TU Dortmund University
Status	Filed September 10, 2020
Inventors	J. Gebhard • A. E. Tekkaya • M. Stommel N. Ben Khalifa • T. Kloppenborg • A. Schulze C. Dahnke • F. Günther

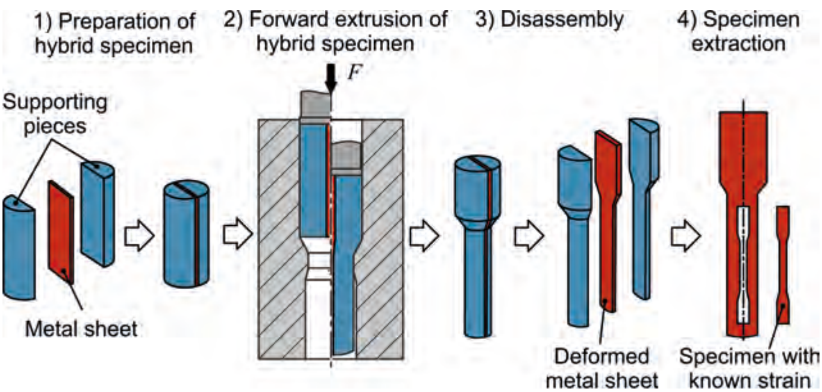
Title	Process for the production of composite parts by combination of sheet expansion, deep drawing, and forward rod extrusion
File number	DE102019002851.1 A1
Patent holder	TU Dortmund University
Status	Filed October 22, 2020
Inventors	O. Napierala • M. Izydorczyk • O. Hering C. Dahnke • A. E. Tekkaya

2.5.3 Filed Patents

Method and Device to Produce Metallic Specimens with Known Plastic Strain for Material Characterization

Application number	DE102020005670
Patent applicant	TU Dortmund University
Status	Filed
Inventors	O. Hering • F. Kolpak • A. E. Tekkaya

The invention concerns a novel process for the production of specimens made of metallic materials with known plastic pre-strains for the characterization of sheet materials. By using multiple test specimens with various known plastic pre-strains, flow curves with strains of up to 1.7 and higher can be generated. A pre-strained sheet metal test specimen is produced by placing a sheet between two solid semi-cylinders and then jointly extruding it by forward rod extrusion at room temperature. Due to the high hydrostatic pressure, the sheet specimens can reach the required large plastic pre-strains. The pre-strained sheet specimens are then removed from the half cylinders and tensile test specimens are cut from the formed sheets (e.g. by laser cutting). Conventional tensile tests on the pre-strained test specimens then allow for the determination of the flow stress up to true strains of 1.7.

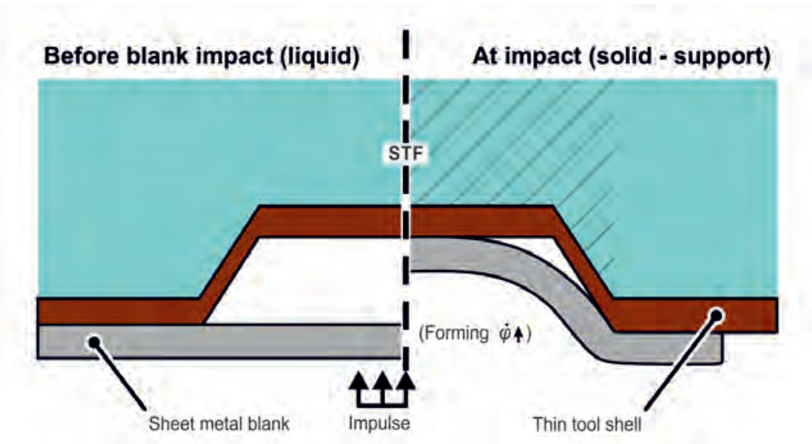


Process principle of sheet extrusion to produce sheet specimens with large known pre-strains

Process and Device for High Speed Forming of Sheet Metals

Application number	DE102020006753.0
Patent applicant	TU Dortmund University
Status	Filed
Inventors	M. Hahn • S. Rosenthal • A. E. Tekkaya

The invention relates to a novel concept for the die design in high speed forming applications. The aim is to safe or directly reuse as much tool material as possible. In conventional forming processes, massive solid tools (e.g. made of steel) are needed, whose geometry depends on the specific part. This is neither flexible nor efficient for individual parts, as e.g. in medical engineering. In the present case, the part shape is only governed by a thin shell preferably made of plastic and manufactured additively. This shell is backed by a so-called shear thickening fluid (STF, see figure on the left), which can be easily transferred before and after the forming operation. In high speed forming, the blank hits the tool shell very dynamically. This, in turn, almost instantly causes the STF to briefly act like a solid - depending on the strain rate - through a significantly increasing viscosity. Consequently, the forming forces are supported by the 'activated' STF (see figure on the right). This way, the shape-defining tool shell basically just acts as a cheap pressure transfer layer.



Schematic sketch of the impact-activated fluid-solid tool concept

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AiF

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DFG Deutsche Forschungsgemeinschaft
German Research Foundation

faurecia

KARL KOLLE STIFTUNG

Further Activities

03

3 Further Activities

3.1 Awards

"Best Short Paper Award" REV2020

At the 17th International Conference on Remote Engineering and Virtual Instrumentation, held from February 26 to 28 at the University of Georgia in Athens, USA, the ELLI2 team was awarded the Best Short Paper Award for its paper "Remote Lab to Illustrate the Influence of Process Parameters on Product Properties in Additive Manufacturing". The submission, mainly written by Mr. S. Upadhya and presented by Mr. J. Grodotzki, deals with the conceptual design, development, and implementation of a remote lab focusing on process parameters in additive manufacturing. Both IUL staff members are part of the ELLI team. The developed laboratory will be made accessible to students of TU Dortmund University in the future, so that they can familiarize themselves with the influence of different process parameters on the component properties during the additive manufacturing process of selective laser melting.

Joshua Grodotzki (left) and Alessandro Selvaggio, members of the ELLI team, receiving their award certificate

TU Dortmund University honors IUL employee Rickmer Meya with dissertation prize

The Rectorate of TU Dortmund University honors authors of excellent dissertations written at TU Dortmund University with its dissertation prize. Only 17 winners are awarded each year. Rickmer Meya, head of the department of profile and sheet metal forming at the IUL, received his award at TU Dortmund University's annual academic celebration on December 16. Unfortunately, due to the protective measures against the coronavirus, the festivities could not be celebrated on a large scale as usual. Alternatively, the speakers presented video messages on the TU Dortmund University website. Mr. Meya also recorded a short acceptance speech.

Rickmer Meya obtained his doctorate as a member of the Collaborative Research Center TRR 188 "Damage-Controlled Forming Processes" on the subject of "Damage-controlled sheet metal bending by means of compressive stress superposition". In his thesis, he shows that forming-induced damage has a decisive influence on the crash behavior, the cyclic properties, and the stiffness of bent components. In addition, with the so-called "bending with radial stress superimposition", he develops a process that applies adjustable stress superposition during the bending process and thus leads to reduced void area fractions.

Screenshot of the acceptance speech by Mr. Meya at the digital annual celebration

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

Honors

- Honorary Professor of Xi'an Jiaotong University

Memberships of Research Boards

- acatech – Member of the "German Academy of Science and Engineering" ("Deutsche Akademie der Technikwissenschaften")
- AGU – Chairman of the "German Metal Forming Association" ("Wissenschaftliche Arbeitsgemeinschaft Umformtechnik")
- CIRP – Fellow of "The International Academy for Production Engineering"
- Council member of the "European Society of Experimental Mechanics"
- Curatorship member of "KARL-KOLLE Stiftung", Dortmund, Germany
- DGM – Member of "Deutsche Gesellschaft für Materialkunde"
- FOSTA – Member of the Advisory Board of the "German Steel Federation" ("Forschungsvereinigung Stahlanwendungen e. V.")
- GCFG – Member of the "German Cold Forging Group"
- I^2FG – Member of the "International Impulse Forging Group"
- ICFG – Member of the "International Cold Forging Group"
- ICTP – Advisory Member of the Standing Advisory Board of the "International Conference on Technology of Plasticity"
- JSTP – Member of the "Japan Society for Technology of Plasticity"
- Member of "DGM-Regionalforum Rhein-Ruhr"
- MPIE – Member of the Scientific Advisory Board of the "Max-Planck-Institut für Eisenforschung" (until September 2020)
- Vice president of the German consortium of "Türkisch-Deutsche Universität" (Turkish-German University)
- WGP – Member of the "German Academic Society for Production Engineering" ("Wissenschaftliche Gesellschaft für Produktionstechnik")

Journals/Editorship

- Editor-in-Chief, "Advances in Industrial and Manufacturing Engineering (AIME)" (Elsevier)
- Deputy Editor, "Elsevier Series in Plasticity of Materials"

- Chairman of the Editorial Committee, "CIRP Annals"
- 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 Editorial Board, "Materials"
- 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"
- Member of the Scientific Editorial Board, "Romanian Journal of Technical Sciences – Applied Mechanics"

Further Memberships

- Chairman of the Scientific Committee, "The International Conference on High Speed Forming 2021" (ICHSF21)
- Member of the Advisory Committee, "The 13th International Conference on the Technology of Plasticity" (ICTP 2021), Columbus, USA
- Member of the CIRP Communication Committee
- Member of the Scientific Committee, "International Deep Drawing Research Group 2020" (IDDRG), Busan, South Korea
- Member of the Scientific Committee, "International Deep Drawing Research Group 2021" (IDDRG), Lorient, France
- Member of the Scientific Committee, "The 12th International Conference and Workshop on Numerical Simulation of 3D Sheet Metal Forming Processes" (NUMISHEET 2021), Toronto, Canada
- Member of the Scientific Committee, "The 31th CIRP Design Conference 2021", Enschede, The Netherlands
- Member of the Standing Advisory Board, "The 13th International Conference on the Technology of Plasticity" (ICTP 2021), Columbus, USA

Activities as Reviewer
In Scientific Committees

- AiF – Arbeitsgemeinschaft industrieller Forschungsvereinigung “Otto von Guericke” e. V.
- Bayerische Forschungsstiftung, Munich, Germany
- CIRP – International Academy for Production Engineering
- DFG – German Research Foundation, Member of Fachkolleqium 401 (Review Board on Production Engineering)
- ESF College of Expert Reviewers
- The Ohio State University, USA
- University of Cyprus
- University of Lisbon, Portugal
- WGP – German Academic Society for Production Engineering
- Xi’an Jiaotong University, China

For Journals

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

- International Journal of Materials and Product Technology
- International Journal of Mechanical Engineering Education
- International Journal of Mechanical Sciences
- International Journal of Mechanics and Materials
- International Journal of Precision Engineering and Manufacturing
- International Journal of 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

3.3 Participation in National and International Organizations: Prof. Dr.-Ing. Dr. h.c. Matthias Kleiner

Scientific Academies

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

Advisory Boards

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

University Advisory Boards

- Chairman of the University Council, Johann Wolfgang Goethe-University, Frankfurt
- Board of Trustees, TU Berlin
- Board of Trustees, Julius Maximilian-University Würzburg

- International Advisory Board Faculty of Engineering, Twente University
- Board of Govenors Jacobs University Bremen gGmbH

Foundation Advisory Boards

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

Professional Chairs

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

Consultant and Advisory Board

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

Cooperation Advisory Boards

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

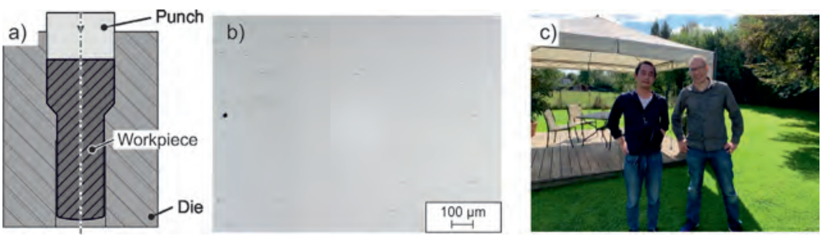
International Exchange

04

4 International Exchange

Research Stay of Yasuhisa Taki

The Japanese visiting researcher Yasuhisa ("Yasu") Taki investigated the behavior of steel and aluminum during cold forward rod extrusion from September 2019 until September 2020. His research ideas originate from his Kobe Steel colleagues' visit at IUL in April 2019. He was inspired by research results on damage in cold forward rod extrusion from CRC 188 and developed experimental set-ups, which allowed drawing conclusions on the deformation behavior based on metallographic analyses. His stay took place in the context of a larger cooperation with Kobe Steel. Finite-element simulations delivered information on the stress states, which could be critical during cold forward rod extrusion. Mr. Taki collaborated closely with the IUL colleagues Sven Lukies (metallography), Robin Gitschel, and Dr. Oliver Hering (both bulk forming) as well as Dr. Till Clausmeyer (Chief Engineer for Research). The collaboration offered the opportunity for the Department of Bulk Metal Forming to compare results for cold extrusion from CRC 188 with examples from industrial practice. Parts of the experiments were performed together with colleagues from the Institute of Metal Forming at RWTH Aachen University. Mr. Taki and his wife had decided to complete their stay in Dortmund as planned even though there were many restrictions due to the coronavirus pandemic, in particular in March and April. The Porsche cars enthusiast and passionate jazz trumpeter participated in joint non-academic activities such as intercultural seminars and visits to football games in the Westfalenstadion.



a) Principal sketch of full forward extrusion and b) icrograph of a steel specimen, c) Yasuhisa Taki and Till Clausmeyer after a joint lunch

G-CADET: International Exchange Program with Gifu University

The G-CADET exchange program with Gifu University aims to expand international cooperation in engineering sciences. In 2020, the IUL sent Mr. Fabian Stiebert to Japan for a research visit. There he performed research under the supervision of Prof. Y. Yoshida, head and coordinator of the exchange program at Gifu University, between November 2019 and February 2020 as a team member of the „Wanglab". Together with the doctoral candidate A. Kutsukake and the student T. Ishiguro, Mr. Stiebert investigated the influence of different process parameters on the additive manufacturing of components made of TI6Al4V titanium alloy. In addition, Mr. Stiebert participated in a course at the „Center for Advanced Die Engineering and Technology", in which a multi-stage die was developed for a component used in mobile communications. After the process simulation and the resulting design, the components were manufactured, assembled and tested.

G-CADET exchange student Fabian Stiebert assembling the conveyor of a multi-stage die set.

Visiting Student of the Colorado School of Mines

The American master's student Stuart Shirley from the Colorado School of Mines was a guest at the IUL for a period of two weeks in February. Mr. Shirley is very interested in forming technology and, in addition to his studies at the Colorado School of Mines, runs his own forge (classic with hammer and anvil). He visited the IUL on his own initiative as part of a Europe trip, during which he stayed at various stations with a background in metal forming. Contact to the IUL was made by Prof. Kester Clarke. During his time at the IUL, Mr. Shirley dealt with the process combination of extrusion and deep drawing, as well as incremental sheet metal forming.

Technical Equipment

05

5 Technical Equipment

Presses

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

Further Forming Machines

- CNC rotary draw bending machine, DB 2060-CNC-SE-F, transfluid Maschinenbau GmbH
- DMU 50 – 5-axis milling maschine, DMG Mori
- Hydraulic punching machine TruPunch 5000, 220 kN, TRUMPF Werkzeugmaschinen GmbH & Co. KG
- Machine for electromagnetic forming, 1.5 kJ, PPT SMU 1500 (recuperationable), self-built at IUL
- Machine for electromagnetic forming, 32 kJ, Maxwell Magneform 7000
- Machine for electromagnetic forming, 6 kJ, Poynting SMU 0612 FS
- Machine for incremental profile forming, self-built at IUL
- Machine for incremental tube forming, IRU2590, transfluid Maschinenbau GmbH
- Multi-axes forming press, five axes of motion up to 100 kN, prototype, Schnupp
- Press brake, 1300 kN, TrumaBend V 1300X
- Profile bending machine TSS-3D, self-built at IUL
- Roll forming machine RAS 24.10, Reinhardt Maschinenbau GmbH

- Spinning machine, Leifeld APED 350NC, CNC Siemens 840 D
- Swivel bending machine, FASTI 2095

Additive Manufacturing Machines

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

Material Testing Machines

- Plastometer, 1 MN, self-built at IUL
- Roughness Tester Marsurf XR1, Roughness measuring station with drive unit GD26, Mahr
- Servo-hydraulic testing machine with HT-resistance heating system up to 1200 °C and protective gas vacuum chamber, Walter + Bai LFV-100-HH
- Sheet metal testing machine, 1000 kN, Zwick BUP1000
- Sheet metal testing machine, 200 kN, Erichsen 142/20
- Test rig for the in-plane torsion test, self-built at IUL
- Universal testing machines (1x 10 kN Erichsen, 1x 100 kN Zwick, 4x 250 kN Zwick)

Measurement Technique and Electronics

- 3D-coordinate measurement machine, Zeiss PRISMO VAST 5 HTG (in cooperation with the Institute of Machining Technology, TU Dortmund University)
- 3D-video measuring system, Optomess A250
- 3MA-II measurement system, Fraunhofer IZFP
- Density measurement system, IMETER V6 by MSB Breitwieser MessSysteme
- Digital oscilloscope, 4 channels, LeCroy HDO6104A
- Digital oscilloscope, 4 channels, LeCroy Waverunner 104 MX
- Digital oscilloscope, 4 channels, Tektronix TDS 420A

- Hardness tester, Wolpert Diatestor 2 RC/S
- Infrared Camera, Resolution 1280 x 960 Pixel, Infratec VarioCam HD head 680 S
- Infrared measuring device, PYROSKOP 273 C
- Keyence Laser: non-contact distance measurement
- 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, Zwick laserXtens 2-120 HP/TZ
- Laser Surface Velocimeter (LSV): non-contact velocity measurement
- Laser-based Photon-Doppler Velocimeter for the measurement of high workpiece velocities
- Light optical microscope, adapted for polarization, Zeiss Axio Imager.M1m
- Multi-wavelength pyrometer, Williamson pro 100 series
- Near infrared pyrometer, Sensortherm Metis M316
- Near infrared pyrometer, Sensortherm Metis M318
- Optical 3D deformation analysis: 4x GOM ARAMIS (2x 5M + 1x 4M + 1x 2M), GOM ARGUS
- Optical 3D digitizer: 2x GOM ATOS Triple Scan, GOM TRITOP
- Optical 3D motion analysis: GOM PONTOS 4M
- Optical frequency domain reflectometer ODiSI-B10 by Polytec: System for the space- and time-resolved measurement of temperature and strain
- Residual stress measurement by means of hole drilling technique and Electronic Speckle Pattern Interferometry (ESPI), Stresstech Prism
- Residual stress measurement by means of hole drilling technique and strain gauge measurement, Milling Guide RS-200
- Tabletop SEM-EDX: Coxem EM-30 PLUS, RJL Micro & Analytic
- Thickness measuring device, Krautkrämer CL 304
- X-ray diffractometer for measuring residual stresses, Stresstech Xstress 3000

Miscellaneous

- 6-axes robot, industrial robot KUKA KR 5 sixx R650
- 6-axes robot, industrial robot KUKA KR 90 R3700 prime K
- Belt grinding machine, Baier PB-1200-100S
- CNC universal turning machine, DMG MORI NEF 400 V3
- DC power supply LAB4020
- Electrolytic polishing and etching machine, Stresstech Kristall 650
- Encapsulated postprocessing cabin for additive manufactured parts, joke Technology ENESKApostpro
- Etching and polishing station, LectoPol-5, Struers
- High-frequency generator, 10 kW, Hüttinger Axio 10/450
- High-performance metal circular saw, Häberle AL 380
- Hydraulic power units and pressure intensifiers up to 4000 bar (3x)
- Hydrostatic roller burnishing tool, Ecoroll, HG13 and HG6
- Industrial robot KUKA KR 30-3
- Laser processing center, Trumpf LASERCELL TLC 1005
- Measuring rack, Boxdorf HP-4-2082
- Medium-frequency generator, 40 kW, Trumpf TruHeat 3040 and 7040, with coax transformer
- Mitring band sawing machines, Klaeger HBS 265 DG
- Roll seam welding machine, Elektro-Schweißtechnik Dresden UN 63 pn
- several machines for machining purposes
- Tabletop cut-off machine Discotom-100, Struers (in cooperation with the Institute of Machining Technology, TU Dortmund University)
- Tensile testing grinder, Schütz + Licht PSM 2000
- Tensile testing punch press, 1200 kN, Schütz + Licht ZS1200CN
- Turning machine, Weiler Condor VS2

Kooperationen | Cooperations

06

Kooperationen | Cooperations

Auf diesem Wege möchten wir uns für die vielfältige Zusammenarbeit im Jahr 2020 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 2020 which have added to our joint success.

Industriebeirat des IUL | IUL Industrial Advisory Board

Das Gremium des Industriebeirates vermittelte auch im Jahr 2020 wichtige Impulse hinsichtlich des industriellen Forschungsbedarfes. An dieser Stelle möchten wir uns für diese wertvolle Zusammenarbeit bedanken.

In 2020, the Industrial Advisory Council provided yet again significant input regarding the need for research from an industrial point of view. We would like to take this opportunity to express our gratitude for this valuable cooperation.

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

Universitäre Kooperationen auf nationaler Ebene | University cooperations at national level

- Chair of Micromechanical and Macroscopic Modelling, ICAMS, Ruhr-Universität Bochum
- Cybernetics Lab IMA & IfU, Rheinisch-Westfälische Technische Hochschule Aachen
- Fachgebiet Maschinenelemente, Technische Universität Dortmund
- Fachgebiet Metallische Werkstoffe, Institut für Werkstoffwissenschaften und -technologien, Technische Universität Berlin
- Fachgebiet Werkstoffprüftechnik, Technische Universität Dortmund
- Fachhochschule Südwestfalen
- Fraunhofer-Institut für Werkstoff- und Strahltechnik IWS, Dresden
- Fraunhofer-Institut für Werkzeugmaschinen und Umformtechnik IWU, Technische Universität Chemnitz
- Fraunhofer-Institut für Zerstörungsfreie Prüfverfahren IZFP, Saarbrücken
- Fraunhofer-Projektgruppe am Dortmunder Oberflächen-Centrum DOC, Dortmund
- Gemeinschaftslabor für Elektronenmikroskopie, Rheinisch-Westfälische Technische Hochschule Aachen
- IngenieurDidaktik, Technische Universität Dortmund
- Institut für Angewandte Materialien – Werkstoffkunde, Karlsruher Institut für Technologie (KIT)
- Institut für Bildsame Formgebung, Rheinisch-Westfälische Technische Hochschule Aachen
- Institut für Eisenhüttenkunde, Lehr- und Forschungsgebiet für Werkstoff- und Bauteilintegrität, Rheinisch-Westfälische Technische Hochschule Aachen
- Institut für Fertigungstechnik und Werkzeugmaschinen, Leibniz Universität Hannover
- 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 Metallformung, Technische Universität Bergakademie Freiberg
- Institut für Metallurgie, Abteilung Werkstoffumformung, Technische Universität Clausthal-Zellerfeld
- Institut für Produktionstechnik und Umformmaschinen, Technische Universität Darmstadt
- Institut für Spanende Fertigung, Technische Universität Dortmund
- Institut für Umformtechnik und Umformmaschinen, Leibniz Universität Hannover
- Institut für Umformtechnik, Universität Stuttgart

- Institut für Werkstoffkunde, Leibniz Universität Hannover
- Institut für Werkzeugmaschinen und Betriebswissenschaften, Technische Universität München
- Institut für Werkzeugmaschinen und Fabrikbetrieb, Technische Universität Berlin
- Laboratorium für Werkstoff- und Fügetechnik, Universität Paderborn
- Lehrstuhl Baumechanik, Technische Universität Dortmund
- Lehrstuhl Fertigungstechnik, Universität Duisburg-Essen
- Lehrstuhl für Fertigungstechnologie, Friedrich-Alexander-Universität Erlangen-Nürnberg
- Lehrstuhl für Feststoffverfahrenstechnik, Ruhr-Universität Bochum
- 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
- Lehrstuhl Werkstoffwissenschaft, Ruhr-Universität Bochum
- Max-Planck-Institut für Eisenforschung GmbH, Düsseldorf
- Professur für Baumechanik, Universität der Bundeswehr München
- Professur für Theoretische Elektrotechnik und Numerische Feldberechnung, Helmut-Schmidt-Universität, Universität der Bundeswehr Hamburg
- Professur Virtuelle Fertigungstechnik, Technische Universität Chemnitz
- Professur Werkstoffwissenschaft, Technische Universität Chemnitz
- wbk Institut für Produktionstechnik, Karlsruher Institut für Technologie
- Werkzeugmaschinenlabor, Rheinisch-Westfälische Technische Hochschule Aachen
- Zentrum für HochschulBildung (zhb), Technische Universität Dortmund

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 Carnot ARTS, Université de Valenciennes et du Hainaut-Cambrésis, Valenciennes, France
- Institute for Manufacturing, Department of Engineering, University of Cambridge, UK
- KAIST – Korea Advanced Institute of Science and Technology, Daejeon, Republic of Korea
- KIMS – Korea Institute of Materials Science, Gyeongnam, 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
- AUDI AG
- AutoForm Engineering Deutschland GmbH
- Baoshan Iron & Steel Co. Ltd.
- Benteler International AG
- Bilstein GmbH & Co. KG
- BMW AG
- BÖHLER-UDDEHOLM Deutschland GmbH
- borit Leichtbau-Technik GmbH
- CARL BECHEM GMBH
- 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
- F. W. Brökelmann Aluminiumwerk GmbH & Co. KG
- Faurecia Group
- FLORA Wilh. Förster GmbH & Co. KG
- Franz Pauli GmbH & Co. KG
- Freudenberg Sealing Technologies GmbH & Co. KG
- FRIMO Group GmbH Composites & Tooling Technologies
- Gebr. Wielpütz GmbH & Co. KG
- Gerhardi AluTechnik GmbH
- Goekeler Messtechnik GmbH
- Grundfos GmbH
- GSU Schulungsgesellschaft für Stanz- und Umformtechnik mbH
- Heggemann AG
- HELLA GmbH & Co. KGaA
- Hirschvogel Umformtechnik GmbH
- HMT Höfer Metall Technik GmbH & Co. KG
- HoDforming GmbH
- HUECK Extrusion GmbH & Co. KG
- Hydro Aluminium Deutschland GmbH
- inpro Innovationsgesellschaft für fortgeschrittene Produktionssysteme in der Fahrzeugindustrie mbH
- JFE Steel Corporation
- Johnson Controls Hilchenbach GmbH
- Kirchhoff Automotive GmbH
- Kistler Instrumente AG
- KOBE STEEL, LTD.

- KODA Stanz- und Biegetechnik GmbH
- Kunststoff-Institut Lüdenscheid (KIMW GmbH)
- MATFEM Partnerschaft Dr. Gese & Oberhofer
- MK Metallfolien GmbH
- Mubea Unternehmensgruppe
- 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 Rasselstein GmbH
- thyssenkrupp Steel Europe AG
- TM Lasertechnik GmbH
- transfluid Maschinenbau GmbH
- TRUMPF Hüttinger GmbH + Co. KG
- TRUMPF Werkzeugmaschinen GmbH + Co. KG
- Viessmann Werke GmbH & Co. KG
- voestalpine AG
- VOLKSWAGEN AG
- Vossloh AG
- wefa Westdeutsche Farben GmbH
- Welser Profile Deutschland GmbH
- Wilke Werkzeugbau GmbH & Co. KG
- WILO SE
- Zentrum für BrennstoffzellenTechnik 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-Leichtbaunetzwerk
- ASM International
- CAE – Chinese Academy of Engineering
- 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.
- GCFG – German Cold Forging Group e. V.
- GDA – Gesamtverband der Aluminiumindustrie e. V.
- I^2FG – International Impulse Forming Group e. V.
- IBU – Industrieverband Blechumformung e. V.
- ICFG – International Cold Forging Group
- IDDRG – International Deep Drawing Research Group
- IMU – Industrieverband Massivumformung e. V.
- ITA – International Tube Association

Stiftungen | Foundations

- KARL-KOLLE-Stiftung
- Stifterverband Metalle e. V.
- VolkswagenStiftung
- Werner Richard – Dr. Carl Dörken Stiftung
- Wilo-Foundation

Abgeschlossene Arbeiten | Completed Theses

07

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

Allwörden, Marius A. von
Tekkaya, A. E.; Rosenthal, S.
Machbarkeitsstudie zum Tiefziehen von additiv gefertigten Sandwichblechen mit strukturiertem Kern
Deep drawing of additively manufactured sandwich sheets with structural core

Aydin, Oguzhan
Tekkaya, A. E.; Kolpak, F.
Ermittlung von Eigenspannungen kaltfließgepresster Teile mittels Konturmethode
Determination of residual stresses in cold extruded parts by contour method

Bazargan, Pedram
Tekkaya, A. E.; Clausmeyer, T.
Bewertung und Klassifizierung ultrahochfester Stähle mit Festigkeiten größer 0,8 GPa für Anwendungen in der Karosserie
Evaluation and classification of ultra-high-strength steels with strength larger than 0.8 GPa for applications in body-in-white

Christiansen-Lenger, Sean P.
Tekkaya, A. E.; Martschin, J.
Untersuchung der Produkteigenschaften beim drucküberlagerten kinematischen Biegen von offenen Profilen
Investigation of the product properties during kinematic bending with stress superposition of open cross sections

Ehsany, Ayda
Tekkaya, A. E.; Kolpak, F.
Prozessauslegung des Tiefziehens mit nachgelagertem Napf-Fließpressen zur Herstellung von Verbundbauteilen
Process design of deep drawing with subsequent backward can extrusion for the production of composite components

Esken, Lukas
Tekkaya, A. E.; Rosenthal, S.
Verbesserung der Umformbarkeit von Sandwichblechen mittels Strukturoptimierung
Improving the formability of sandwich sheets using structural optimization

Franke, Jan N.
Chen, J.-J. (Fak. Informatik); Tekkaya, A. E.
Ferngesteuerte Regelung eines Rotationszugbiegeprozesses basierend auf Inline-Konturmessungen
Remote closed loop control of a rotary draw bending process based on inline contour measurements

Güneș, Bedir T.
Tekkaya, A. E.; Kamaliev, M.
Materialeigenschaften, Schädigungs- und Crashverhalten eines HSLA-Stahls für das Bake-Hardening bei verschiedenen Vordehnungsstufen
Material characteristics, damage, and impact behavior of HSLA steel for bake hardening and various pre-strain levels

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

Haase, Max
Tekkaya, A. E.; Schulze, A.
Ermittlung von Einflussparametern auf ausgewählte Werkstoffkennwerte beim direkten Strangpressen einer neu entwickelten Kupferlegierung
Determination of influencing parameters on selected material properties during direct extrusion of a newly developed copper alloy

Hazarika, Dikshita
Tekkaya, A. E.; Gebhard, J.
Untersuchung einer erweiterten Methode zur Dornkühlung beim Stahl-Strangpressen
Investigation of an enhanced concept for mandrel cooling in steel extrusion

Herweg, Dominik
Tekkaya, A. E.; Wernicke, S.
Steigerung der Geometriegenauigkeit bei der Inkrementellen Blechmassivumformung von Zahnrädern
Improvement of the geometrical accuracy in incremental sheet-bulk metal forming

Kubasinski, Steffen
Tekkaya, A. E.; Dardaei Joghan, H.
Einfluss der Wärmebehandlung auf die Umformbarkeit von stranggepressten ME20-Magnesiumblechen
Influence of heat treatment on the formability of extruded ME20 magnesium sheets

Lennemann, Philipp
Tekkaya, A. E.; Komodromos, A.
Experimentelle Charakterisierung und numerische Analyse des Umformverhaltens von Kupferdraht im Linearwickelprozess unter Berücksichtigung des Bauschinger-Effektes
Experimental characterization and numerical analysis of the forming behavior of copper wire in the linear winding process taking the Bauschinger effect into account

Marin Tovar, Carlos A.
Tekkaya, A. E.; Upadhya, S.
Charakterisierung der Bruchfestigkeit von optimierten ferritischen und bainitischen Stählen unter Berücksichtigung der Scherbelastung
Characterization of fracture resistance of optimized ferritic and bainitic steel grades with special focus on shear loading

Merghani Ahmed, Mohamed
Tekkaya, A. E.; Grodotzki, J.
Analyse eines Sicherungsrings: Umformprozess und Performanceevaluation mittels Entwicklung eines effizienten Workflows in Abaqus/Explicit
Analysis of retainer ring: forming operation and performance evaluation by development of an efficient workflow in Abaqus/Explicit

Patrick, Johnsan
Tekkaya, A. E.; Komodromos, A.
Numerische und experimentelle Analyse der Einflussfaktoren auf den Richtvorgang von Kupfer-Flachdraht
Numerical and experimental analysis of the influencing factors on the straightening process of copper flat wire

Pylaeva, Aleksandra
Tekkaya, A. E.; Selvaggio, A.
Automatisierter Remote-Lochaufweitversuch mit photogrammetrischer Messung und robotergestützter Probenbehandlung
Remote and automated hole expansion testing with the help of photogrammetry and robotic specimen handling

Rakshit, Tanmoy
Tekkaya, A. E.; Kolpak, F.
Numerische Untersuchung des Radialumformens zur Herstellung von Monoblock-Hohlwellen
Numerical investigation of rotary swaging to produce monoblock tubular shafts

Stennei, Markus
Tekkaya, A. E.; Dardaei Joghan, H.
Entwicklung eines multivariablen Werkzeugsystems für die inkrementelle Blechumformung
Development of a multi-variable tool for incremental sheet metal forming

Stiebert, Fabian
Tekkaya, A. E.; Traphöner, H.
Charakterisierung von Feinstblechen aus Stahl im ebenen Torsionsversuch
Characterization of very thin steel sheets with the in-plane torsion test

Thier, Ulrich
Tekkaya, A. E.; Wernicke, S.
Lokale Beeinflussung des Fließbeginns durch thermisches Gradieren beim inkrementellen Blechmassivumformen
Manipulation of the yield locus by thermal grading in incremental sheet-bulk metal forming

Vügten, Simon
Tekkaya, A. E.; Rosenthal, S.
Einfluss der Schubsteifigkeit und relativen Dichte auf das Umformverhalten von additiv gefertigten Sandwichelementen
Influence of shear stiffness and relative density on the bending behavior of additively manufactured sandwich sheets

Werner, Philipp
Tekkaya, A. E.; Kamaliev, M.
Experimentelle und numerische Charakterisierung der Spannungsübertragung von granularen Medien
Experimental and numerical characterization of the stress distribution of granular media

Abgeschlossene Bachelorarbeiten | Completed Bachelor of Science Theses

Borek, Martin
Tekkaya, A. E.; Maaß, F.
Prozesserweiterung zur zugspannungsüberlagerten inkrementellen Blechumformung
Process enhancement for tensile stress-superposed incremental sheet metal forming

Flesch, Jan
Tekkaya, A. E.; Upadhya, S.
Untersuchung des Einflusses von Geometrie- und Werkstoffeigenschaften auf den Rotationszugbiegeprozess
Study on the influence of geometrical and material parameters on the rotary draw bending process

Greiten, Pia
Tekkaya, A. E.; Rosenthal, S.
Umformung additiv gefertigter Sandwichbleche – Eine Effizienzanalyse der kombinierten Prozesskette
Forming of additively manufactured sandwich sheets – Efficiency analysis of the combined process

Heimsoth, Alexander
Tekkaya, A. E.; Lueg-Althoff, J.
Analyse und Verbesserung umformtechnisch erzeugter Blech-Blech-Verbindungen
Analysis and improvement of sheet connections made by forming processes

Noske, Jonas D.
Tekkaya, A. E.; Siddharth, U.
Entwicklung einer roboterbasierten Probenhandhabung für eine automatisierte Remote-Biegezelle
Development of a robot-based specimen handling system for a remote bending cell

Polat, Halil C.
Tekkaya, A. E.; Maaß, F.
Prozesserweiterung zur druckspannungsüberlagerten inkrementellen Blechumformung
Process enhancement for compression stress-superposed incremental sheet metal forming

Powilleit, Rojan B.
Tekkaya, A. E.; Weber, F.
Zerstörungsfreie Werkstoffprüfung von hybriden Werkstoffverbindungen
Non-destructive materials testing of hybrid joints

Willerscheid, Jannis
Tekkaya, A. E.; Rosenthal, S.
Numerische und analytische Betrachtung des Versagens von additiv gefertigten Sandwichblechen unter Biegebelastung
Numerical and analytical failure behavior of additively manufactured sandwich sheets under bending loads

Würtz, Felix
Tekkaya, A. E.; Kamaliev, M.
Modellierung der thermischen Randbedingungen basierend auf der induktiven Erwärmung beim TIP-Prozess
Modeling of the thermal boundary conditions based on inductive heating in the TIP process

Abgeschlossene Projektarbeiten | Completed Project Theses

Ali, Ammar
Tekkaya, A. E.; Upadhya, S.
Automatisierung der mikroskopischen Bruchflächenbestimmung in Zugproben
Automation of microscopic fracture area determination in tensile specimens

Chen, Changqing
Tekkaya, A. E.; Gebhard, J.
Analytische Untersuchung des U-Profilbiegens bei kleinen Biegeradien
Analytical investigation of u-profile bending with small radii

Chinna Kannu, Lakshmi K.
Tekkaya, A. E.; Goyal, S.
Simulation eines Tiefziehprozesses mit Hybridstempel zur elektromagnetischen Umformung
Simulation of a deep drawing process with hybrid punch used for electromagnetic forming

Chowdari Ghattamaneni, Manish
Tekkaya, A. E.; Grodotzki, J.
Versagensanalyse in der Umformtechnik mithilfe von XFEM
Fracture analysis in sheet metal forming using XFEM

Dobrowolski, Fabian
Tekkaya, A. E.; Komodromos, A.
Numerische Analyse des direkten Presshärtens mit integrierter Werkzeugkühlung unter Berücksichtigung lokaler Reibverhältnisse
Numerical analysis of direct hot stamping with integrated tool cooling considering local friction conditions

Erdem, Nagihan; Martinez Cubides, Andres A.
Tekkaya, A. E.; Upadhya, S.
Validierung der Ausdünnungsgrenze als Versagensvorhersagekriterium und Bewertung der Durchführbarkeit von KOBE-Tests zur Charakterisierung der Kantenrissempfindlichkeit
Validation of the edge thinning limit as a failure prediction criteria and evaluating the feasibility of KOBE tests to characterise edge crack sensitivity

Knop, Roman
Tekkaya, A. E.; Traphöner, H.
Automatisierung des ebenen Torsionsversuchs
Automation of the in-plane torsion test

Matuschek, Tomasz; Sheng, Nico
Tekkaya, A. E.; Tebaay, L.
Entwicklung eines Prozessfensters für das Laserpulverauftragsschweißen bei Dünnblechen
Development of a process window for laser powder metal deposition onto thin sheets

Meier, Philipp; Rubrecht, Arvid
Tekkaya, A. E.; Dardaei Joghan, H.
Parameterstudie für das Pulverauftragsschweißen von Einzelkehlnähten mit unterschiedlichen Blechdicken
Parameter study for powder cladding of single fillet welds with different sheet thicknesses

Meyering, Kevin
Tekkaya, A. E.; Dardaei Joghan, H.
Untersuchung der Aufbaueigenschaften von Quadern auf geneigten Dünnblechen beim Laserpulverauftragsschweißen
Investigation of the structure properties of cuboids on inclined thin sheets during laser powder cladding

Mohanasundararaju, Veerendra K.
Tekkaya, A. E.; Hahn, M.
Numerische Untersuchung der Druckverteilungsgestaltung in der Umformung mittels vaporisierender Aktuatoren
Numerical study on the pressure distribution design in vaporizing foil actuator forming

Pehlivan, Berna
Tekkaya, A. E.; Rosenthal, S.
Umformtechnische Charakterisierung des Werkstoffes GP1 zur additiven Fertigung
Material characterization of additively manufactured GP1 for the use in forming technology

Powilleit, Rojan B.
Tekkaya, A. E.; Weber, F.
Numerische Untersuchung des formschlüssigen Außenhochdruckfügens
Numerical investigation of form-fit joining by outer pressurization

Rakshit, Tanmoy
Tekkaya, A. E.; Schmitz, F.
Entwicklung eines temperaturabhängigen Versagenskriteriums zur Modellierung des adiabaten Scherschneidens
Development of a temperature-dependent fracture criterion for modelling adiabatic blanking

Sandoval Macias, Efrain D.
Tekkaya, A. E.; Weber, F.
Untersuchung des Einsatzes geteilter Dichtringe beim Außenhochdruckfügen
Analysis of the applicability of separated sealing rings for joining by forming with outer pressurization

Sarker, Manabendra
Tekkaya, A. E.; Rosenthal, S.
Untersuchung des Einflusses der geometrischen Parameter von Sandwichstrukturen mittels Finite-Elemente-Methoden
Study of the influence of the geometrical parameters on sandwich structures using Finite Element Methods

Selpol, Vinod K.
Tekkaya, A. E.; Goyal, S.
Design und Analyse der Hybridspule für den Einsatz im elektromagnetischen Umformprozess
Design and analysis of the hybrid coil for the application in electromagnetic forming process

Stiebert, Fabian
Tekkaya, A. E.; Grodotzki, J.
Additive Fertigung zur Fertigung komplexer Werkzeuge und Implantate
Additive manufacturing for advanced die and implants

Ausgewählte Veröffentlichungen und Vorträge | Selected Publications and Lectures

08

Zeitschriftenbeiträge | For SCI-Journals

Bellmann, J., Lueg-Althoff, J., Niessen, B., Böhme, M., Schumacher, E., Beyer, E., Leyens, C., Tekkaya, A. E., Groche, P., Wagner, M. F.-X., Böhm, S., 2020. Particle Ejection by Jetting and Related Effects in Impact Welding Processes. Metals 10, 1108.

Demir, K., Goyal, S., Hahn, M., Tekkaya, A. E., 2020. Novel approach and interpretation for the determination of electromagnetic forming limits. Materials 13 (18), DOI: 10.3390/ma13184175.

Gitschel, R., Kolpak, F., Hering, O., Tekkaya, A. E., 2020. Increasing the Lightweight Potential of Composite Cold Forging by Utilizing Magnesium and Granular Cores. Metals 11 (1), 32, DOI: 10.3390/met11010032.

Hahn, M., Tekkaya, A. E., 2020. A quick model for demonstrating high speed forming capabilities. Mechanics Research Communications 108, DOI: 10.1016/j.mechrescom.2020.103579.

Hahn, M., Tekkaya, A. E., 2020. Experimental and Numerical Analysis of the Influence of Burst Pressure Distribution on Rapid Free Sheet Forming by Vaporizing Foil Actuators. Metals 10, 845.

Hering, O., Tekkaya, A. E., 2020. Damage-induced performance variations of cold forged parts. Journal of Materials Processing Technology 279, 116556.

Lueg-Althoff, J., Bellmann, B., Hahn, M., Schulze, S., Gies, S., Tekkaya, A. E., Beyer, E., 2020. Joining dissimilar thin-walled tubes by Magnetic Pulse Welding. Journal of Materials Processing Technology 279, DOI: 10.1016/j.jmatprotec.2019.116562.

Maaß, F., Hahn, M., Tekkaya, A. E., 2020. Interaction of Process Parameters, Forming Mechanisms, and Residual Stresses in Single Point Incremental Forming. Metals 10, 656.

Niessen, B., Schumacher, E., Lueg-Althoff, J., Bellmann, J., Böhme, M., Böhm, S., Tekkaya, A. E., Beyer, E., Leyens, C., Wagner, M. F.-X., Groche, P., 2020. Interface Formation during Collision Welding of Aluminum. Metals 10, 1202.

Pragana, J. P. M., Rosenthal, S., Alexandrino, P., Araujo, A., Braganca, I. M. F., Silva, C., Leitao, P., Tekkaya, A. E., Martins, P. A. F., 2020. Coin minting by additive manufacturing and forming, Journal of Engineering Manufacture, DOI: 10.1177/0954405420971128.

Schmitz, F., Winter, S., Clausmeyer, T., Wagner, M. F.-X., Tekkaya, A. E., 2020. Adiabatic blanking of advanced high strength steels. CIRP Annals Manufacturing Technology 69 (1), pp. 269–272.

Stankevic, V., Lueg-Althoff, J., Hahn, M., Tekkaya, A. E., Zurauskiene, N., Dilys, J., Klimantavicius, J., Kersulis, S., Simkevicius, C., Balevicius, S., 2020. Magnetic field measurements during magnetic pulse welding using CMR-B-scalar sensors. Sensors 20, 5925.

Tebaay, L. M., Hahn, M., Tekkaya, A. E., 2020. Distortion and Dilution Behavior for Laser Metal Deposition onto Thin Sheet Metals. International Journal of Precision Engineering and Manufacturing-Green Technology 7, pp. 625-634.

Tekkaya A. E., Bouchard, P. O., Bruschi, S., Tasan, C. C., 2020. Damage in metal forming. CIRP Annals – Manufacturing Technology 69 (2), pp. 600-623.

Wernicke, S., Hahn, M., Gerstein, G., Nürnberger, F., Tekkaya, A. E., 2020. Strain path dependency in incremental sheet-bulk metal forming. International Journal of Material Forming, DOI: 10.1007/s12289-020-01537-0.

Zhang, S., Lueg-Althoff, J., Hahn, M., Tekkaya, A. E., Kinsey, B., 2020. Effect of process parameters on wavy interfacial morphology during magnetic pulse welding. Journal of Manufacturing Science and Engineering, DOI: 10.1115/1.4048516.

Beiträge in Konferenzbänden & weiteren Zeitschriften | Publications in Proceedings and further Journals

Clausmeyer, T., Gutknecht, F., Gerstein, G., Nürnberger, F., 2020. Testing of formed gear wheels at quasi-static and elevated strain rates. Procedia Manufacturing 47, pp. 623-628.

Clausmeyer, T., Schowtjak, A., Gitschel, R., Wang, S., Hering, O., Pavliuchenko, P., Lohmar, J., Ostwald, R., Hirt, G., Tekkaya, A. E., 2020. Prediction of Ductile Damage in the Process Chain of Caliber Rolling and Forward Rod Extrusion. Procedia Manufacturing 47, pp. 649-655.

Gallus, S., Wernicke, S., Hahn, M., Tekkaya, A. E., 2020. Erweiterung der Prozessgrenzen beim Inkrementellen Blechmassivumformen durch Thermisches Gradieren der Halbzeuge. Extended Abstract. In: Tagungsband des 23. Umformtechnischen Kolloquiums Hannover – Innovationspotenziale in der Umformtechnik, pp. 166-167.

Hirt, G., Tekkaya, A. E., Clausmeyer, T., Lohmar, J., 2020. Potential and status of damage controlled forming processes. Production Engineering 14, DOI: 10.1007/s11740-019-00948-6.

Holstein, V., Hermes, M., Tekkaya, A. E., 2020. Analysis of incremental die bending of wires and tubes. Production Engineering 14, pp. 265-274.

Jäckel, M., Coppieters, S., Vandermeiren, N., Kraus, C., Drossel, W.-G., Miyake, N., Kuwabara, T., Unruh, K., Traphöner, H., Tekkaya, A. E., Balan, T., 2020. Process-oriented Flow Curve Determination at Mechanical Joining. Procedia Manufacturing 47, pp. 368-374.

Kleinschnittger, O., Strenger, N., Petermann, M., Frerich, S., Grodotzki, J., Selvaggio, A., Tekkaya, A. E., 2020. Remote Laboratories in Engineering Education – Deriving Guidelines for their Implementation and Operation. In: Proceedings of the 48th Annual Conference of European Society for Engineering Education (SEFI) online, pp. 251-259.

Kotzyba, P., Grötzinger, K. C., Hering, O., Liewald, M., Tekkaya, A. E., 2020. Introduction of Composite Hot Extrusion with Tubular Reinforcements for Subsequent Cold Forging. In: Proceedings of the 10th Congress of the German Academic Association for Production Technology (WGP), Dresden, Germany, DOI: 10.1007/978-3-662-62138-7_20.

Langenfeld, K., Schowtjak, A., Schulte, R., Hering, O., Möhring, K., Clausmeyer, T., Ostwald, R., Walther, F., Tekkaya, A. E., Mosler, J., 2020. Influence of anisotropic damage evolution on cold forging. Production Engineering 14 (1), pp. 115–121.

Mogylenko, O., Selvaggio, A., Upadhya, S., Grodotzki, J., Tekkaya, A. E., 2020. Augmented Reality Application for the Mobile Measurement of Strain Distributions. In: Proceedings of the 17^{th} International Conference on Remote Engineering and Virtual Instrumentation, DOI: 10.1007/978-3-030-52575-0_19.

Pragana, J. P. M., Rosenthal, S., Bragança, I. M. F., Silva, C. M. A., Tekkaya, A. E., Martins, P. A. F., 2020. Hybrid Additive Manufacturing of Collector Coins. Journal of Manufacturing and Materials Processing 4 (4), 115, DOI: 10.3390/jmmp4040115.

Rosenthal, S., Maaß, F., Kamaliev, M., Hahn, M., Gies, S., Tekkaya, A. E., 2020. Lightweight in Automotive Components by Forming Technology. Automotive Innovation 3, DOI: 10.1007/s42154-020-00103-3.

Samfaß, L., Baak, N., Meya, R., Hering, O., Tekkaya, A. E., Walther, F., 2020. Micro-magnetic damage characterization of bent and cold forged parts. Production Engineering 14 (1), pp. 77-85.

Schowtjak, A., Wang, S., Hering, O., Clausmeyer, T., Lohmar, J., Schulte, R., Ostwald, R., Hirt, G., Tekkaya, A. E., 2020. Prediction and analysis of damage evolution during caliber rolling and subsequent cold forward extrusion. Production Engineering 14 (1), pp. 33-41.

Sprave, L., Schowtjak, A., Meya, R., Clausmeyer, T., Tekkaya, A. E., Menzel, A., 2020. On mesh dependencies in finite-element based damage prediction: application to sheet metal bending. Production Engineering 14 (1), pp. 123-134.

Tekkaya, A. E., Gitschel, R., Meya, R., Hering, O., 2020. Schädigungsgesteuerte Umformprozesse. In: Tagungsband des 34. Aachener Stahlkolloquiums, pp. 19-28.

Tekkaya, A. E., Min, J., 2020. Special Issue on Automotive Lightweight. Automotive Innovation 3, pp. 193-194.

Upadhya, S., Grodotzki, J., Selvaggio, A., Mogylenko, O., Tekkaya, A. E, 2020. Remote Lab to Illustrate the Influence of Process Parameters on Product Properties in Additive Manufacturing. In: Proceedings of the 17^{th} International Conference on Remote Engineering and Virtual Instrumentation, DOI: 10.1007/978-3-030-52575-0_37.

Weber, F., Hahn, M., Tekkaya, A. E., 2020. Joining by die-less hydroforming with outer pressurization. Journal of Advanced Joining Processes 1, DOI: 10.1016/j.jajp.2020.100014.

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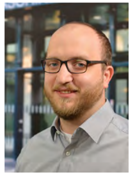

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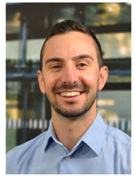

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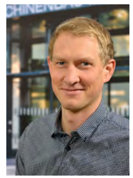
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