

# Activity Report

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## Imprint

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## Preface

Dear readers,

The past year, 2023, has been another eventful one for the Institute of Forming Technology and Lightweight Components. In the field of education, we successfully reaccredited our international Master's program "Master of Science in Manufacturing Technology (MMT)" for the third time. We are proud of our successful graduates, who are continuing their academic careers as doctoral candidates at various universities worldwide or making valuable technological contributions in the German industry or companies in their home countries. Our industrial lecture series, a platform for exchanging experiences between industry and university, featured nine exciting presentations from Germany and abroad in 2023. The hybrid format of the event significantly increased participation, especially internationally. This year, we were also able to continue our fruitful collaboration with Gifu University from Japan as part of the G-CADET program, which was made possible primarily through the generous support of the Karl-Kolle Foundation. We also maintained our student exchange program with our American partner, the Ohio State University.

In the area of research, I had to resume the spokesperson role for the SFB/TRR188 in September 2023. This role was marked by the preparation of the renewal proposal for the third funding period. We were very pleased to welcome, in addition to Dr. Shiori Gondo, two more Alexander von Humboldt Fellows: Prof. Jinjin Ha from the University of New Hampshire (USA) and Dr. Yong Hou from Tongji University (China). This enabled the IUL to showcase its international appeal with three talented young international researchers. Without the support of the Alexander von Humboldt Foundation (AvH), these research stays would not have been possible. For the third time, the IUL was able to write a keynote for the International Academy for Production Engineering (CIRP) as the "leading author." The three keynotes present the three main research foci of the IUL to the international scientific community: "Metal forming beyond shaping: Prediction and setting product properties" (2015), "Damage in metal forming" (2020), and finally "Stress superposition in metal forming" (2023). Starting with the vision that forming processes not only shape, but also influence the properties of products, the second keynote introduces a previously neglected property: ductile damage. The latest keynote describes

how new forming processes can be systematically invented and how properties can be influenced after forming.

Finally, four dissertations were successfully completed at the IUL in 2023.

Industry-related research is a special concern of the institute. Our Industry Advisory Board, established in 2010, held its 25th anniversary meeting this year. All 50 meetings have been characterized by openness and constructive discussions. We have received many valuable impulses for our application-oriented as well as basic research during these meetings and we are very grateful to all members for this. A milestone for collaboration with local and regional industry was the establishment of the Competence Center for Digital Production Technologies at TU Dortmund on March 29, 2023. This competence center, as part of TU Concept GmbH at TU Dortmund University, consists of various chairs from our university, industrial companies, and industry associations, and aims to provide extensive, fast, and uncomplicated support to the industry in deglobalization and digitalization through innovations. The Research Center for Industrial Metal Processing (ReCIMP), which was established together with the company Faurecia (now part of the FORVIA Group) in 2013, is another important activity of the IUL to implement application-oriented research. After 11 successful years, 10 more projects were initiated or completed this year with the divisions “Faurecia Automotive Seating” and “Faurecia Clean Mobility.”

In November 2023, Prof. Yannis Korkolis accepted the call from TU Dortmund University and began his duties as a professor at the IUL. Prof. Yannis Korkolis was previously an Associate Professor at Ohio State University. The internationally renowned scientist will co-lead the institute with me for approximately one year. We are very pleased to have attracted a very successful, visionary scientist to the IUL. I wish Prof. Korkolis much success and all the best at our institute.

The important results useful for science and industry could only be achieved together with all staff members. I would like to express my heartfelt thanks for the outstanding performance of the IUL team. I would also like to sincerely thank our national and international partners from academia, industry, associations, and research funding for their support and collaboration.

Finally, I would like to announce my farewell. On December 31, 2024, I will retire. Since 2007, I have conducted research in Dortmund with great joy, enthusiasm, and dedication. I had the privilege of working with many young, talented staff members and colleagues. Together, we have succeeded in making the IUL internationally known and have contributed to 8 Collaborative Research Centers (SFBs) and Transregions of the DFG, two of which I led as spokesperson and one as deputy spokesperson. We also contributed to 4 research groups and 9 priority programs (SPP) of the DFG. I am confident that under the leadership of Prof. Korkolis, the IUL will continue these research activities.



A. Erman Tekkaya



Education

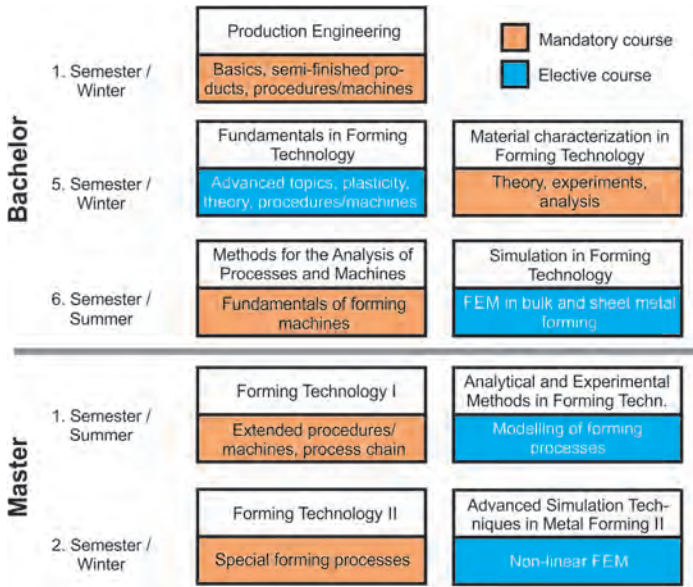
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# 1 Education

## 1.1 Offered Courses

The Institute of Forming Technology and Lightweight Components offers lectures and laboratories in the following bachelor and master degree 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.



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

In the “Bachelor Mechanical Engineering” and “Master Mechanical Engineering” degree programs students can select up to 6 specializations. These are “Mechanical Engineering”, “Production Engineering”, “Materials Engineering/ Materials Testing”, “Technical Management”, “Modeling and Simulation in Mechanics”, and “IT in Production and Logistics” (Master only). The lectures

offered at the IUL are a substantial part of the teaching scope in the specialization “Production Engineering” in the form of compulsory and elective courses. The other specializations usually offer elective courses only. The range of courses is completed by the supervision of scientific project work, bachelor and master theses. Other courses offered by the institute in 2023 were:

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



Welcome of the MMT batch 2023

On May 11, 2023, the “re-accreditation” for the international master’s program “Manufacturing Technology” (MMT) has successfully taken place. The measures discussed in the context of the re-accreditation include changes in the curriculum, such as the subject of “interdisciplinary qualification” which previously had to be taken in the 3rd semester of the students, was now set to the 1st and 2nd semester so that students can take a German course, for example, directly from the beginning of their studies. Another change concerns the students’ wish to have more choices in each individual subject. This has also been implemented: from winter semester 2023/2024 on, students now have the option of taking 35 credit points distributed over the first three semesters (previously it was 30 LP distributed over 2 semesters).

In order to bring the MMT students into a common exchange with students of other courses (outside MMT) the scope of the “Laboratory Work” has been aligned with the other courses of the Faculty of Mechanical Engineering so that MMT students can now complete it together with the students of other

courses. Another measure is that modules which were previously distributed over two semesters have now each been divided into independent modules that are completed within one semester. In future, the “Forming Technology” module offered by the IUL will be offered in the two lectures “Bulk Metal Forming” (winter semester) and “Sheet Metal Forming” (summer semester). An overview of the new lectures in the elective catalog for students and other changes in the curriculum can be found in the new module handbook.

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

- Bulk Metal Forming
- Sheet Metal Forming
- Advanced Simulation Techniques in Metal Forming II
- Additive Manufacturing
- Property control of semi-finished products
- Aluminium — Basic Metallurgy, Properties, Processing and Applications
- Laboratory Work – Material Characterization in Forming Technology

On October 9, 2023, the 13th “Welcome Event” for the new MMT students took place. After a round of introductions, Prof. Tekkaya, initiator of the program introduced in 2011, addressed a welcome to the new cohort. After coffee and snacks in a IUL seminar room, the new students visited the institute’ experimental field.



Presentation of the G-CADET program by Prof. Yoshida on September 21, 2023 at the IUL

From September 18 to 22, 2023, Prof. Yoshinori Yoshida, Gifu University, Japan, came to visit the IUL. Prof. Yoshida is the director and coordinator of the exchange program “G-CADET”. The aim of this program, which was presented

during his visit to the IUL, is to expand international cooperation in engineering sciences with Japan. This objective was successfully achieved at the turn of the year when two mechanical engineering students from TU Dortmund University traveled to Japan for a 2-months research stay and a Japanese student could also visit the IUL for two months to conduct research in the field of additive manufacturing.

Another student exchange took place with the Ohio State University, USA. Two students spent 10 weeks at the IUL for a research internship. Funded by the National Science Foundation (NSF), they conducted research on control-relevant fundamentals of incremental profile forming together with IUL staff.

**Hybride Ringvorlesung  
Sommersemester 2023**

Erfahrungsaustausch zwischen Industrie und Universität

 <p>Di., 25. April 2023 - 18:00 Uhr  (in Präsenz und online) <b>„Advanced Manufacturing for Space Applications“</b> Dr. Advenit Makaya ESA - European Space Agency</p>	 <p>Di., 30. Mai 2023 - 16:00 Uhr  (nur online) <b>„Inline-Prozessdatenerfassung und -integration in die Simulation“</b> Dr. Kerim Isik BMW Group</p>
 <p>Do., 11. Mai 2023 - 16:00 Uhr  (nur online) <b>„Hochtaktende Stanzteilfertigung für Elektronikanwendungen und die Automatisierungstechnik“</b> Dr. Chris Frederic Mertin PHOENIX FEINBAU GmbH &amp; Co. KG</p>	 <p>Do., 01. Juni 2023 - 16:00 Uhr  (in Präsenz und online) <b>„Modeling of damage-to-fracture transition for bulk metal forming applications“</b> Dr. José Alves TRANSVALOR S.A.</p>
 <p>Do., 25. Mai 2023 - 16:00 Uhr  (in Präsenz und online) <b>„Kaltmassivumformung: Herausforderungen einer Serienproduktion“</b> Jonas Wälder fischerwerke GmbH &amp; Co. KG</p>	 <p>Do., 29. Juni 2023 - 16:00 Uhr  (in Präsenz und online) <b>„Reducing CO<sub>2</sub> emissions in mining and steelmaking for automotive car components“</b> Dr. Manuel Otto SSAB Europe</p>

Flyer of the lecture series in summer semester 2023

The hybrid lecture series on forming technology is now firmly established. Whereas before the Corona period only face-to-face lectures were offered, the lecture had to be switched to a purely digital format during the pandemic. Currently, the lecture is offered in hybrid format, i.e. the lecture is

delivered in face-to-face and/or digital format and broadcasted live via Zoom. In the summer semester 2023 we were able to listen to six exciting lectures and would like to express our sincere thanks for the willingness of the industry to promote the exchange of experiences between industry and science.

At “SchnupperUni2023” high school students were able to find out more about studying at TU Dortmund University and its current research. This year, the IUL showed how basic research in the field of forming technology can help to make cycles more sustainable with its interactive lecture “The car from a can”. This offered students an insight into a lecture and the everyday life of a student. The lecture was followed by a live demonstration of chip extrusion in the experimental hall, thus presenting the everyday life of scientists.

In 2023, the following guest lecturers have contributed to the course offer at the IUL:

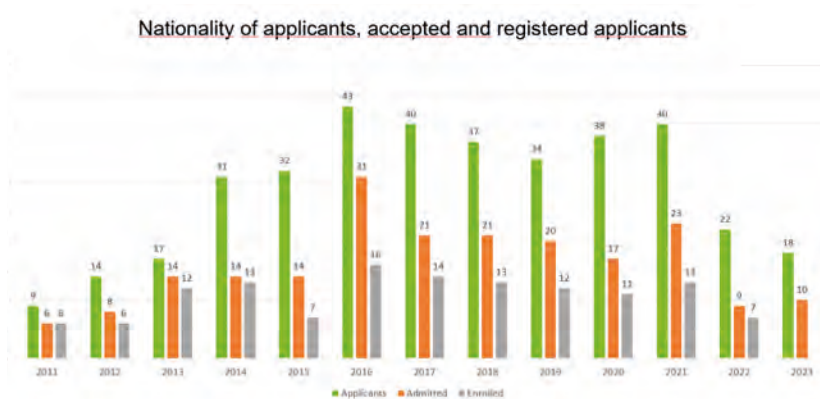
- Prof. J. Hirsch, Aluminium Consulting - Königswinter
- Prof. J. Sehr, Ruhr-Universität Bochum
- Prof. P.A. F. Martins, Instituto Superior Técnico, Universidade de Lisboa, Portugal
- Dr. G. Georgiadis, Excelix Ltd.
- Dr. K.-F. Karhausen, Speira GmbH
- Dr. J. Ostrowski, Quaker Houghton
- Dr. S. Gies, Danieli Germany GmbH
- Dr. L. Kwiatkowski, OTTO FUCHS KG
- A. Roßbach, SMS Group GmbH

For further information, please visit: [www.iul.eu/en/teaching](http://www.iul.eu/en/teaching)

## 1.2 Master of Science in Manufacturing Technology (MMT)

Coordination Prof. Dr.-Ing. A. Erman Tekkaya  
 Frigga Göckede B. B. A.  
 Kerstin Barton M. A.  
 Dr.-Ing Ramona Hölker-Jäger

For the start of studies in the winter semester 2023/24, 25 excellent students were selected from 302 applications from 18 nations for the Master of Science in Manufacturing Technology (MMT). From these, 13 have enrolled in the program (as of 01.10.2023) and started their studies in Dortmund.



Diversity of nationalities of applicants, accepted and registered applicants (as of 01.0.2023)

In order to further expand the diversity of this international program, the coordination team analyzed the countries of origin of students and prospective students and then took measures to inform prospective students from other countries about the MMT program. As part of these measures, newsletters were sent out in cooperation with the DAAD and advertisements were placed on the DAAD country pages to draw attention to the program and the application deadline. In addition, European universities of applied sciences that do not offer an English master's program in mechanical engineering or manufacturing were specifically contacted to promote MMT to students there. A newsletter was also set up, which interested students can subscribe to via the homepage in order to receive regular information on deadlines, news, and topics related to the study program.

In spring 2023, the MMT was successfully accredited. As part of this system accreditation, some changes were made to the study plan. In the future, the

module “Interdisciplinary Qualification” is no longer planned for the third semester, but for the first two semesters. The number of credit points for the laboratory work and the project work were adapted to the German-language courses. In addition, several new courses have been added to the elective catalog. In addition, as in the other courses offered by the faculty, partial credits in the curriculum will be eliminated for the most part in the future. Modules that were previously distributed over two semesters will each be divided into independent modules that are completed within one semester.

For the start of the academic year 2023/24 the new students were once again welcomed at TU Dortmund University as part of a Welcome Week. In addition to the official welcome event, a workshop on scientific writing and a workshop to prepare the students for the intercultural encounters that await them during their life and studies in Germany were offered. In addition, MMT students were able to participate in a campus rallye as well as a city tour together with the new students of the international study program “Process Systems Engineering” of the Faculty of Bio- and Chemical Engineering.

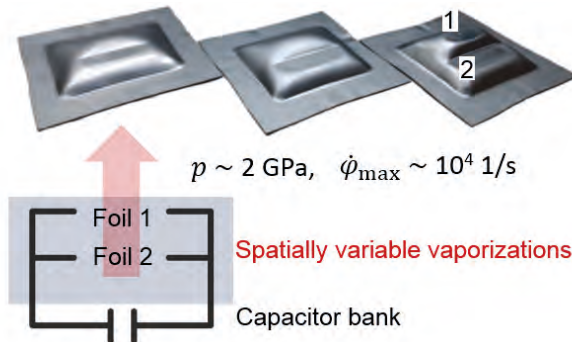
Further information: [www.mmt.mb.tu-dortmund.de](http://www.mmt.mb.tu-dortmund.de)

### 1.3 Doctoral Theses

Hahn, Marlon	Forming by Vaporizing Actuators: Experiments and Modeling
Original title	Umformung mittels vaporisierender Aktuatoren: Experimente und Modellierung
Series	Dortmunder Umformtechnik, Volume 119
Publisher	Shaker Verlag,
Oral exam	February 16, 2023
Advisor	Prof. Dr.-Ing. A. E. Tekkaya
Co-examiner	Prof. Dr.-Ing. habil. S. Reese, RWTH Aachen University

The rapid Ohmic heating of metallic foils leads to an explosion-like expansion, which is utilized to form a nearby sheet metal under high strain rates. The vaporizing foil functions as a one-way actuator in this way. Since this innovative manufacturing process is still relatively young, there are only a few fundamental works on it available so far, and there is no appropriate macroscopic modeling approach yet.

Besides basic experimental investigations, a material law is identified that allows to also analytically predict the influence of all process parameters on the electric energy deposition into the actuator until the so-called burst point. For the resulting actual sheet forming from then on, three different models are introduced: The complete model takes into account a coupling between deformable solid bodies as finite elements and particles which represent the expanding actuator. Two reduced, but more efficient models only consider the sheet blank with a well-defined impulse loading. The validated findings provide the basis to eventually adjust the process design for the implementation of spatially variable vaporizations with respect to the desired part geometry.

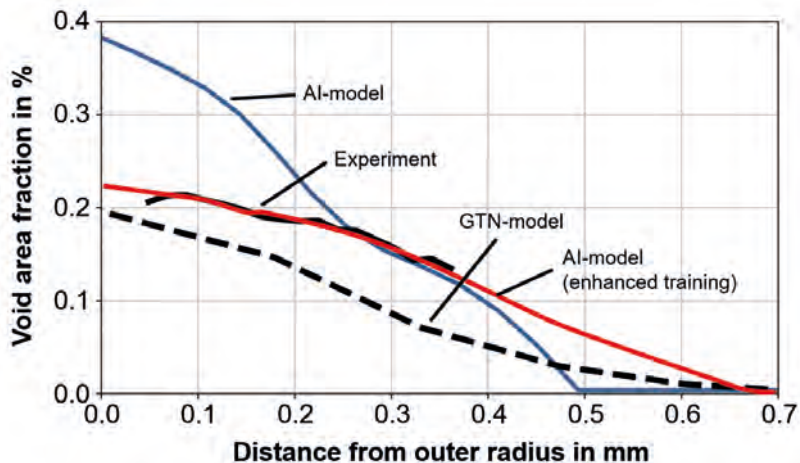


First implementation of parallel vaporizations in sheet metal forming

Schowitzjak, Alexander	Prediction of void evolution in metal forming
Original title	Vorhersage der Porenentwicklung in der Umformtechnik
Series	Dortmunder Umformtechnik, Volume 122
Publisher	Shaker Verlag,
Oral exam	Mai 26, 2023
Advisor	Prof. Dr.-Ing. A. E. Tekkaya
Co-examiner	Prof. Dr.-Ing. S. Münstermann
	RWTH Aachen University

The aim of this work is to predict void evolution in metal forming. To this end, novel methods have been developed which, in addition to macroscopic data such as force-displacement-curves and strains measured via digital image correlation, also utilize microscopic void measurements from scanning electron microscopy. When applied to commonly used damage models from the literature, such as the Lemaitre model and the Gurson-Tvergaard-Needleman model, this strategy significantly improves the prediction accuracy compared to conventional methods.

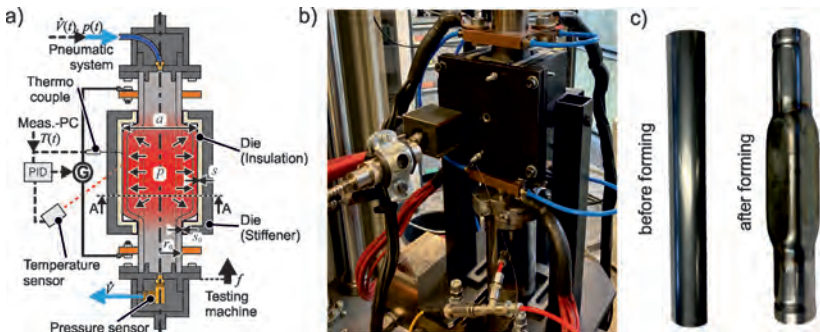
Furthermore, a model based on a neural network has been developed which is capable of predicting void evolution based on experimental void measurements. This eliminates the need for assumptions about void evolution as typically seen in constitutive models. With this model the prediction accuracy can be further enhanced (see Figure).



Evolution of the void area fraction in air bending for a constitutive model as well as the AI-model

Kamaliyev, Mike	Isothermal hydroforming of closed profiles - material characterization and process implementation
Original title	Isotherme Innenhochdruckumformung geschlossener Profile - Werkstoffcharakterisierung und Prozessumsetzung
Series	Dortmunder Umformtechnik, Volume 120
Publisher	Shaker Verlag, 2023
Oral exam	Mai 31, 2023
Advisor	Prof. Dr.-Ing. A. E. Tekkaya
Co-examiner	Prof. Dr.-Ing. W. Homberg, University of Paderborn

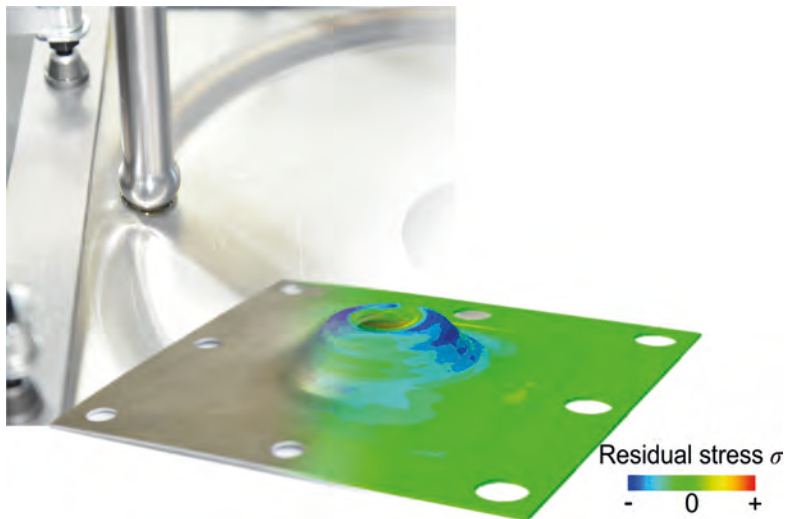
Hot forming of sheet metal materials is a conventional process for manufacturing high-strength components. By transferring the process mechanics to hydroforming, new areas of application can be accessed. The new process of isothermal high-temperature pneumoforming was developed on this premise. In this process tubes are heated by conduction and formed using internal pressure. The aim is to keep the workpiece temperature as constant as possible in order to achieve higher degrees of deformation. Process-related methods of material characterization were developed for numerical process modeling. Among other things, this makes it possible to obtain forming limit curves and flow curves for tubes under isothermal conditions. Isothermal high-temperature pneumoforming was numerically modeled and validated using geometric parameters. In addition, process windows were successfully derived.



Isothermal high-temperature pneumoforming: Schematic representation (a), experimental implementation (b), and final components (c)

Maaß, Fabian	Targeted adjustment of residual stresses in incremental sheet metal forming
Series	Dortmunder Umformtechnik, Volume 121
Publisher	Shaker Verlag,
Oral exam	October 24, 2023
Advisor	Prof. Dr.-Ing. A. E. Tekkaya
Co-examiner	Prof. Dr.-Ing. S. Härtel, BTU Cottbus-Senftenberg

Due to an inhomogeneous forming during the manufacturing process, stresses remain in the material. Depending on their characteristics, these residual stresses can significantly increase the performance of a component or lead to earlier failure under a specific load. For the targeted use of forming-induced residual stresses suitable prediction models are required in order to save resources for mechanical and thermal post-processing steps to adjust the residual stresses. A local forming zone of the incremental sheet metal forming process (ISF) below the forming tool offers the possibility to induce locally defined residual stresses into components. A fundamental understanding of the interaction between process parameters, forming mechanisms, and residual stress formation is developed through experimental and numerical process analysis. By stress-superposition, compressive residual stresses can be purposefully introduced on both sides of a component, increasing the fatigue strength of the component under cyclic load.



Residual stresses induced by incremental sheet metal forming in a truncated cone geometry



Research

02



## 2 Research

With their research, the employees (30 scientists, 12 technical and administrative staff members and more than 50 student assistants) at the Institute of Forming Technology and Lightweight Components make an important contribution to a climate-friendly design of production engineering. They develop new manufacturing processes such as joint hybrid extrusion of aluminum and high-performance plastics as well as prototype production of deep-drawing dies using an efficient 3D printing process. Furthermore, the employees develop test methods and make them ready for application. Extruded aluminum-plastic profiles enable weight reductions and the saving of CO<sub>2</sub> emissions during operation in various fields of application.

An expression of the successful research at the institute are nationally and internationally visible awards such as the JSTP International Award for Young Researchers for Mr. Eike Hoffmann and the International Karl-Kolle-Prize for Dr. Till Clausmeyer. The keynote paper on the use of stress superposition in forming technology in the CIRP Annals (first author: A. Erman Tekkaya) with internationally recognized co-authors also emphasizes the international networking. The participation in the Collaborative Research Center CRC 188 (spokesperson), approved grants in two priority programs (SPP 2013 and SPP 2183) as well as a cooperation project within the scope of the funding program “TTP Leichtbau” are proof of the institute’s research strength. In addition to the three departments

“Bulk Metal Forming”, “Profile and Sheet Metal Forming”, and “Non-Conventional Processes”, the institute structure shown in the diagram consists of the three inter-divisional units “Research Center for Industrial Metal Processing” (ReCIMP), “Research Group on Additive Technology” (ReGAT), and “Research Group Applied Mechanics”. In the following, the department-specific research objects and research projects are described in detail.



Institute structure

## 2.1 Research Groups and Centers

### 2.1.1 Collaborative Research Center Transregio 188 – Damage Controlled Forming Processes

Funding	German Research Foundation (DFG)
Project-ID	TRR 188/2023
Deputy Spokesperson and Spokesperson for Dortmund	Prof. Dr.-Ing. A. Erman Tekkaya

For six years now, scientists from manufacturing technology, materials science, materials testing technology, and mechanics have been doing research on damage during forming processes. Their goal is to first understand the mechanisms of material damage during forming from the micro to the macro scale in detail in order to then, on the one hand, quantitatively predict the damage evolution on this basis and, on the other hand, specifically adjust the damage states with regard to component performance. While other component properties that are also influenced by forming processes such as strain hardening or residual stresses can be controlled and optimized to improve the performance of metallic components, controlling forming-related damage remains a challenge. Damage-related failure can occur prematurely under unfavorable conditions, hindering the full exploitation of the material's potential. Only through comprehensive damage control along the entire process chain, as pursued by the Collaborative Research Center TRR 188, the full potential of the materials can be safely exploited.

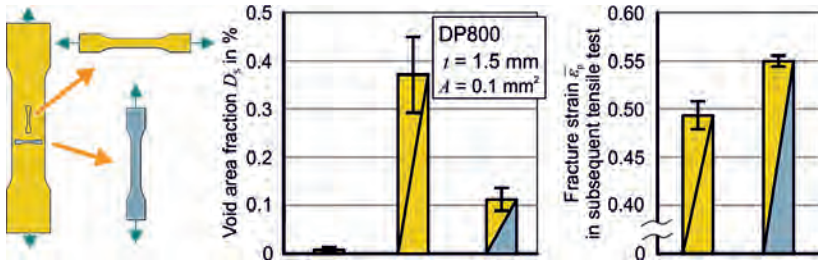


Figure 1: Change in strain path leads to less damage evolution (project A05, Lennemann)

The research work carried out so far demonstrated, using typical sheet metal and bulk forming processes, that damage can be influenced and possibly reduced by modifying the forming process. Furthermore, it was shown that a reduction of the damage through process modifications can increase

the performance of the material. For example, in cold-extruded samples made of the material 16MnCrS5, the apparent Young's modulus was increased by about 10 %, the number of load cycles until failure by about 20 % and the notched bar impact energy by up to 79 % by deliberately changing the load path, i.e. the temporal distribution of stress and strain. Also in sheet metal forming a change in the strain path leads to less damage evolution and, thus, to about 15 % higher fracture strains (Figure 1).

Another important aspect is the consideration of thermally activated mechanisms in both hot forming of components and heat treatment of cold-formed components and their influence on resulting damage. Figure 2 shows an example of the effects of stress relief, heat treatment, recrystallization annealing, normalizing, and case hardening on the impact energy of two specimens, one with high damage (red samples) and one with low damage (blue samples). Obviously, for the material 16MnCrS5 the effect of damage is preserved by stress relieving, while for the other one the effect of damage is more or less erased during heat treatment. However, the situation is completely different for the material 34MnB5, which is first cold radial forged and then fully hardened. Here, the damage increases significantly after heat treatment. These contradictory results are to be investigated further in the third funding period. These and other achievements were made possible by the close cooperation of the three project areas "A - Process Technology", "B - Characterization", and "C - Modeling". New characterization methods developed in the B area enable the evaluation of the formed components of the A area as well as the parameterization and validation of the models of the C area. These models are able to describe the damage mechanics on different scales and provide the link to the performance models.

Three industrial transfer projects have been initiated in the current second funding period (2021-2024) that enabled the early transfer of knowledge to industrial applications. TRR 188 also receives important impulses for the application relevance and the orientation of further research work through an industrial advisory board, which has constructively supported TRR 188 since the beginning of the first funding period. The composition of the industrial advisory board is guided, on the one hand, by the forming process chains considered in TRR 188 and, on the other hand, by participating areas of expertise. Therefore, material and semi-finished product manufacturers, technicians from sheet metal and bulk forming, component users as well as companies from the fields of software and measurement technology are represented. Every year the members of the industrial advisory board get together for a one-day meeting where the current research results of the TRR 188 are presented and discussed together.

For a broader exchange of knowledge with numerous interested participants

from science and industry, the 4th Industrial Colloquium of TRR 188 was held in Aachen in November 2023. This year, the focus was on the potentials of controlling damage evolution and improving component performance by process design as well as by adjusting damage-tolerant microstructures. Top-class speakers from both industry and research presented their latest findings, demonstrated the potential for industrial applications, and gave an outlook on future development trends. In addition, TRR 188 presented its current research results in an accompanying poster session which led on to many stimulating technical discussions during the breaks.

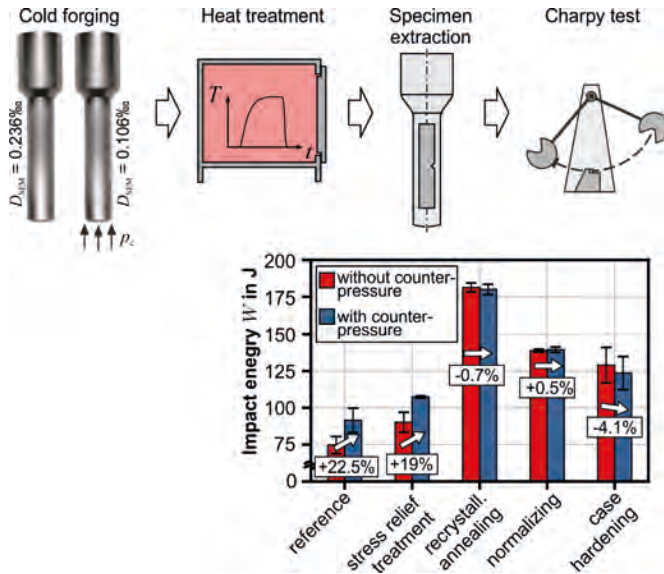


Figure 2: Effect of various heat treatment on the performance of cold forged components (project A02, Gitschel)

RWTH Aachen University as the current spokesman university and TU Dortmund University are involved in TRR 188. In Aachen the project leaders come from the Institute of Metal Forming (IBF), the Steel Institute (IEHK), and the Institute for Physical Metallurgy and Materials Physics (IMM) from the Faculty of Georesources and Materials Engineering as well as the Laboratory for Machine Tools and Production Engineering (WZL) from the Faculty of Mechanical Engineering and the Central Facility for Electron Microscopy (GFE). In Dortmund the projects are being carried out by the Institute of Forming Technology and Lightweight Components (IUL), the Institute of Mechanics (IM), and the Chair of Materials Test Engineering (WPT) of the Faculty of Mechanical Engineering and by the Chair of Structural Mechanics (BM) of the

Faculty of Architecture and Civil Engineering. The Institute for Applied Materials - Materials and Biomechanics (IAM-WBM) of the Faculty of Mechanical Engineering at KIT Karlsruhe and the non-university institute Max-Planck-Institut für Eisenforschung GmbH (MPIE) in Düsseldorf are also involved in TRR 188.

## 2.1.2 ReCIMP – Research Center for Industrial Metal Processing

**Head** Florian Weber M. Sc.

The cooperation with the international automotive supplier Forvia-Faurecia, established since 2013, was successfully continued in the year 2023. The “Research Center for Industrial Metal Processing” (ReCIMP) is an application-oriented research cooperation of the IUL with the divisions “Faurecia Automotive Seating” and “Faurecia Clean Mobility”. ReCIMP collaborates on a wide range of innovative projects in the fields of process development, materials science, and lightweight construction. The overarching objective of each project is to improve and deepen basic knowledge of the processes and process chains. In addition, there is a focus on identifying and investigating new scientific research areas in the field of manufacturing technology. The synergies resulting from cooperations with other industrial companies and research institutions are a welcome side effect. In addition, the IUL’s cooperation with Forvia-Faurecia also promotes a practical collaboration at the company’s various sites.

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

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

The project work is performed by scientists from the various IUL departments on a subject-specific basis. The Advisory Board of ReCIMP regularly discusses the progress of the individual projects as well as the overall strategy of the research center. The figure on the following page gives an overview of the projects carried out in 2023.

The researchers are supported by a large number of student assistants and students who prepare project, bachelor, or master theses in the projects. Since the establishment of the research center, far more than 70 students have been involved in ReCIMP projects. For several current scientific employees of the IUL a thesis initiated in ReCIMP was the first step towards a scientific career. The cooperation is particularly effective when the research topics

Extension of forming limits	Strain state control by tool design
Characterization of advanced steel grades	Influence of shot peening on the mechanical properties
	High temperature characterization of ferrite steels
	Deformation induced martensite
Flexible production	Machine learning to predict mechanical properties
	Green manufacturing
Processing of tube	Residual stresses in welded connections
	Forming controlled fatigue strength of tubes
Alternative production methods	Alternatives to aluminum extrusion
Lightweight structures	Numerical optimization of a silencer shape

Running projects

Completed projects

Research projects worked on in 2023

initially dealt with in the research center lead to fundamental questions and research fields for externally funded projects – as has happened several times in recent years.

One of the research projects in 2023 dealt with the generation of residual stresses in tool surfaces by means of shot peening. The hypothesis is that residual compressive stresses close to the surface will increase the tool life, as the adjusted stress state counteracts the initiation of cracks.

The tool was also the focus of investigations in a project on the influence of strain state in the production of deep-drawn square cups. By varying the punch geometry a more homogeneous strain distribution can be achieved. From these basic investigations, findings are to be derived which should prevent the occurrence of edge cracks in the future when designing tools for complex deep-drawn components.

In another project the use of environmentally friendly deep-drawing lubricants is being tested. The test results with regard to process forces and component

thinning during the production of a cross-cup geometry show comparable results between the currently used lubricants containing mineral oil and their environmentally friendly alternatives.

The service life of joints manufactured by tube buckling is negatively affected by cracks appearing at the inner bend of the buckling bead. Scanning electron microscope images indicate that shearing are the cause of these cracks. A circumstance about which there has been uncertainty in the literature up to now.

A new approach toward the determination of flow curves is pursued through the application of machine learning. A synthetic data set is generated on the basis of real data which is used to train the algorithms in order to predict the flow behavior of different steel grades.

Further information on the individual projects can be found in the respective subchapters of the departments.

### 2.1.3 ReGAT – Research Group on Additive Technology

Contact Hamed Dardaei Joghhan, M. Sc.

Additive manufacturing processes have been included in the research activities at the IUL for several years in order to support and complement metal forming technologies. For this purpose, the working group “ReGAT - Research Group on Additive Technology” was initiated at the institute. The scope of ReGAT’s research covers the forming of additively manufactured semi-finished products as well as additively manufactured tools for forming technology. Two different additive manufacturing machines for the processing of metal powders are available at the IUL for the conceptual realization.

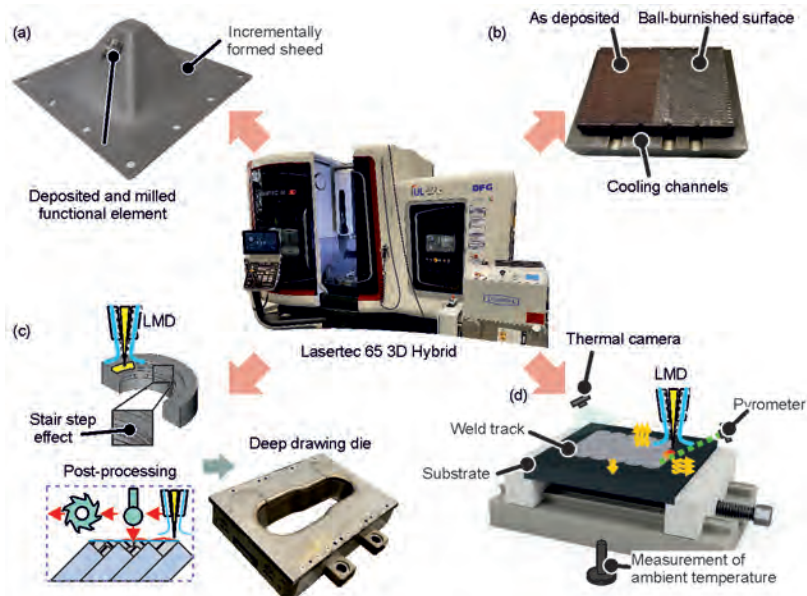


Figure 1: (a) Deposition of the functional elements on incrementally formed sheets, (b) Manufacturing of hot stamping dies and ball burnishing of the surface, (c) Process route of hybrid additive metal laminated tooling and deep drawing die, (d) Modeling the LPA process by „Particle Finite Element Method“

The 5-axis Lasertec 65 3D hybrid milling machine by DMG MORI allows the integration of laser metal deposition (LMD) with other different forming processes such as incremental forming or ball burnishing. The ability to perform incremental forming in the same setup allows for incremental forming of sheets to the target geometry and deposition of functional elements by LMD

(Figure 1a) and further modifications by milling without disassembly, which leads to an increase in productivity and cost savings (DFG 385276922).

In addition, a ball burnishing tool is integrated in the machine to improve the surface roughness of the deposited areas and also to induce residual stresses. This combination offers the possibility of producing near-surface cooling channels (Figure 1b) for hot stamping dies with elevated surface roughness (DFG 417202720).

In addition, a new concept of hybrid additively laminated deep drawing dies is realized in this machine (Figure 1c). In the new manufacturing route the stair-step effect of sheet lamination is eliminated by depositing metal powder and the surface roughness is smoothed by three different post-processing methods, namely ball burnishing, milling, and laser polishing. The results of the project show a promising application of this novel process in the manufacture of deep drawing dies. The main features of the hybrid process include low energy consumption, short manufacturing time compared to fully deposited parts by LMD, and it eliminates the additional hardening process in contrast to the conventional method (DFG 426515407).

The modeling and analysis of laser metal deposition by „Particle Finite Element Method“ is an ongoing project in cooperation with the Institute of Mechanics at TU Dortmund University (Figure 1d). The aim of this project is to simulate the manufacturing of components using LMD in order to accurately predict the final contour as well as the process-induced residual stresses and to study the influences of the selected process parameters and the deposition strategy (DFG 504955789).

The Powder Bed Selective Laser Melting (SLM) machine manufactured by DMG MORI, commercially known as Lasertec 30 SLM, enables the production of complex geometries. In order to overcome the main disadvantage of the powder bed fusion process, which is the long manufacturing time, the sandwich with complex core sheets is manufactured as flat sheets and then formed in a short time. This speeds up the process by 360 % compared to manufacturing the complex shape (Figure 2a). In collaboration with the Institute of Product Engineering (IPE) at the University of Duisburg-Essen, a core structure is produced by SLM and joined to the face sheets (rolled) by form-fit or material-fit to further speed up the process. In addition, this new innovative process route offers the production of different types of face sheets with better surface roughness. It also enables the production of large-size sheets (DFG 317137194)

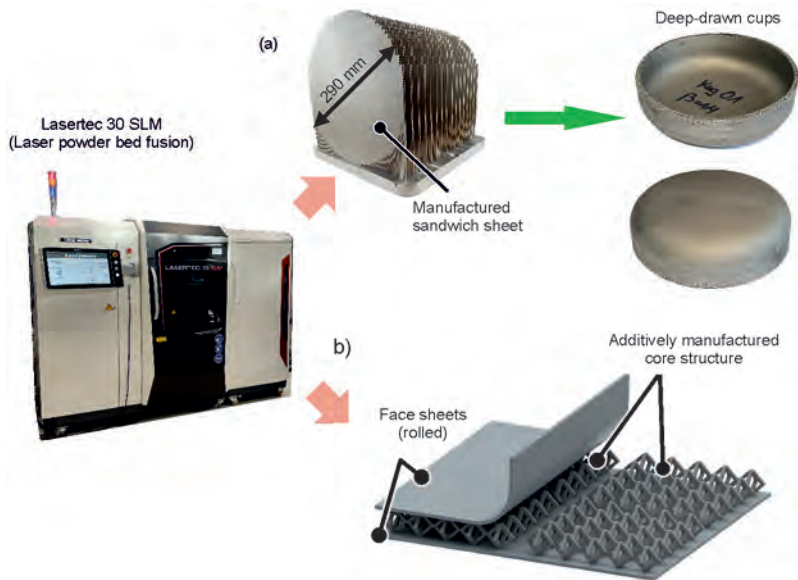


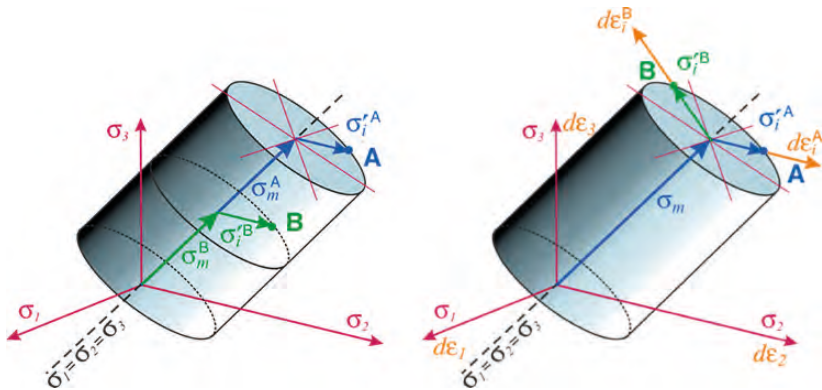
Figure 2: (a) Principle of additively manufactured semi-finished part, (b) Sandwich sheet with rolled face sheets

In order to familiarize students of the IUL at TU Dortmund University with additive technologies in the field of forming technologies, ReGAT offers a laboratory course. The project-based laboratory course allows students not only to design and manufacture their ideas with metal-based machines, but also to produce their initial ideas with the three available FDM (Fused Deposition Modeling) machines for processing polymers.

## 2.1.4 Research Group Applied Mechanics

Contact Dr.-Ing. Till Clausmeyer

The Research Group Applied Mechanics concentrates on the competences of the Institute of Forming Technology and Lightweight Components in the fields of analytical approaches, material characterization, material modeling, and simulation for forming applications. The researchers working in these fields discuss these topics and jointly develop new mechanical and microstructural characterization methods at the IUL. The development and application of the aforementioned methods is conducted for the forming technologies available at the institute: bulk, sheet, and profile forming as well as non-conventional forming methods. The researchers at the IUL also contribute their expertise to national cooperative projects, e.g. to the priority program SPP 2183: "Property-controlled forming processes". With teams from Fraunhofer Institutes IWM in Freiburg and IWU in Munich IUL researchers work in the research group FOR 5380, which focusses on the use of high-speed shear cutting, on efficient simulation methods for shear cutting processes. In these processes strain rates of 100,000 1/s and tool accelerations of  $> 10,000$  g occur.



Graphical representation of the stress superposition of processes A and B with stress states  $\sigma_A$  and  $\sigma_B$ . Left: superposition of a pure hydrostatic stress state  $\sigma_m^A$ , right: purely deviatoric stress superposition  $\sigma_i^B$

Other projects in which the methods supported by the Research Group Applied Mechanics play an important role include a DFG project on the Bauschinger effect in solid forming, AiF projects on the modeling of spring winding, and the simulation of microstructures in extrusion. The research group members

present their work to the public in journals, lectures, and at conferences. In 2023, the researchers were pleased to exchange ideas with international scientists during their research stays at the IUL. Prof. Kaan Inal visited the IUL in April as part of the successful collaboration with the Computational Mechanics Research Group at the University of Waterloo, Canada, and the long-standing collaboration with Prof. Yanshan Lou of Xi'an Jiatong University continues with his doctoral student Chong Zhang.

The result of the exchange with the Canadian scientists is a paper in the journal "Manufacturing Letters" on predicting the decrease in stiffness due to void growth using machine learning methods. In the CIRP keynote paper on stress superposition in metal forming, first author Prof. A. Erman Tekkaya presented the technological advantages of using stress superposition for applications such as profile bending, extrusion, and wire drawing jointly with his co-author Prof. Groche from Darmstadt, Prof. Kinsey from New Hampshire, and Prof. Wang from Japan. In particular, the analytical description of the stress superposition and the separation into a deviatoric part, responsible for shape changes, and a hydrostatic part represents a novelty.

## 2.1.5 Competence Center for Digital Production Technologies Dortmund

**Managing Director**

**Dipl.-Infom. Alessandro Selvaggio**

The newly founded competence center for digital production technologies offers companies the opportunity to place joint development projects and influence industry-specific projects. Members can participate in the competence center's technology network and benefit from the network's expertise. Projects are processed in close coordination with the scientists at TU Dortmund University, which guarantees a maximum level of quality.

The competence center supports its partners with holistic solutions in the form of development projects, service, training, and further education. It also offers advice on relevant technologies. Thanks to the expertise available at TU Dortmund University, the competence center addresses the following topics in particular:

- AI in production technology
- Digitalization/Industry 4.0
- Big Data
- 5G/6G
- E-mobility
- Development of material alternatives with a focus on manufacturing processes
- Technology development for production engineering

The competence center aims at playing a central role in the future in regard to the described topics. The broad technological positioning of those involved is both a unique selling point and a guarantee for the successful processing of complex tasks.

Under the umbrella of the competence center, we want to bring together companies and acknowledged scientists and support companies in the recruitment of specialists. In future, we would like to serve as a platform for (joint) research and industry-specific development projects. The transfer of knowledge from research to industry will take place through various services in the field of research and development which will also include the use of technologically advanced equipment for carrying out experiments. Furthermore, the competence center organizes events on relevant topics and encour-

ages the transfer of technology and knowledge within the network. A central goal is to strengthen cooperation between regional industry and science and, in particular, between the members of the competence center.

## 2.2 Department of Bulk Metal Forming

Head      Johannes Gebhard M. Sc.

The department of bulk metal forming predominantly works in the field of hot extrusion and cold forging. The objectives contain fundamental research of the mentioned processes as well as the new and further development of process variants.

In the area of fundamental research, solid-state welding of surfaces containing oxides and the intrinsic co-extrusion of aluminum and polymer are investigated. In cold forging, basic damage mechanisms are investigated and damage prediction models are validated. The knowledge gained is transferred to an industrial process route of radial and axial forging with subsequent heat treatment in a transfer project. The new technology of continuous extrusion is investigated with numerical and physical model experiments. In the field of conventional extrusion, the occurrence of undesirable longitudinal weld streaks as well as the production of hollow profiles with low wall thicknesses for a resource-efficient use of aluminum are analyzed.

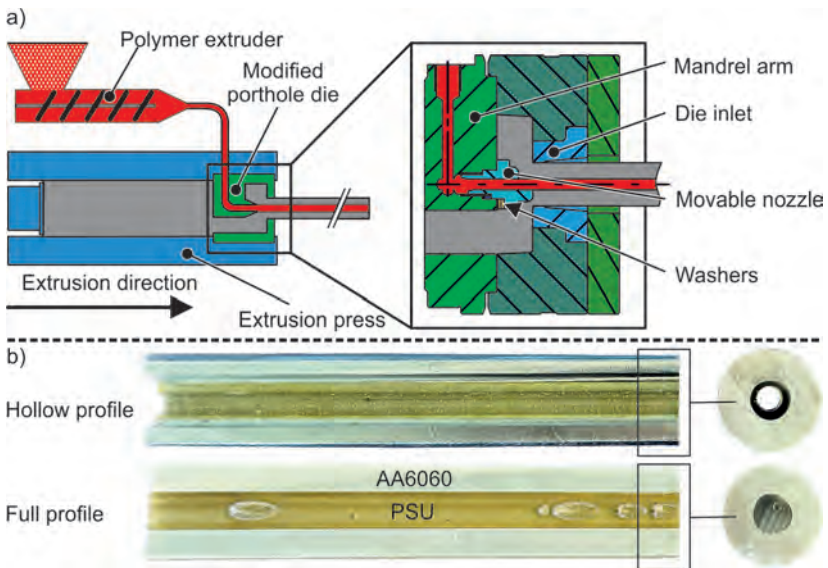


Members of the department of bulk metal forming

## 2.2.1 Development of a Continuous Process for the Intrinsic Production of Plastic-Metal Composite Structures

Funding	German Research Foundation (DFG)
Project	490989965
Contact	Patrick Kotzyba M. Sc.

The aim of the project is to develop a technology for the continuous production of hybrid profiles made of aluminum and polymer in a single process step. In collaboration with the Institute of Polymer Materials (IPW) of the Leibniz Institute for Polymer Research e.V. in Dresden, a polymer extruder is being connected to an extrusion press, making it possible to extrude a liquid polymer melt directly into the aluminum flow (Figure a). The challenge is to combine the process windows of the different methods in terms of temperature, pressure, and process speeds and to produce reproducible and stable hybrid profiles. Profiles with polymer cores have already been produced in the current project (Figure b). The decisive factor here is the pressure difference between the polymer extruder and the injection point of the polymer in the porthole die, which can be specifically adjusted via the ram speed of the extrusion press. If the difference is larger than the pressure in the polymer extruder, a hollow profile is produced. A solid profile can be produced by a sufficiently high polymer pressure.

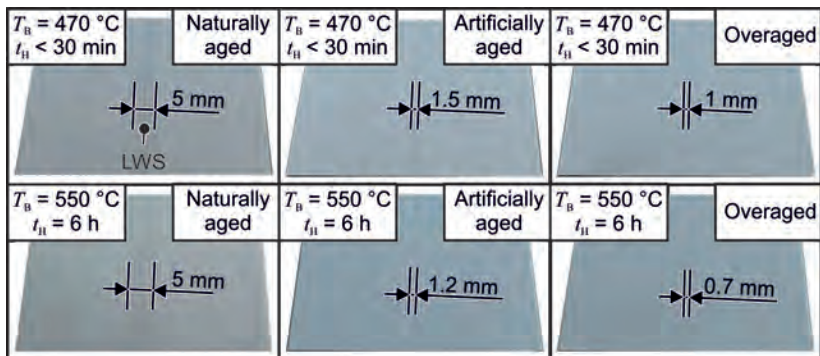


a) Schematic of the process b) Cross-section of a hollow and a full profile

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

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

Longitudinal weld streak (LWS) defects on extruded and anodized aluminum hollow profiles lead to rejection, especially in the application area as visible profiles. In the first project phase, it was already demonstrated that the extrusion parameters have a minor influence on the visibility of the streak, whereas alloying composition and block homogenization have a significant impact. In the current second phase of the project, in collaboration with the Institute for Applied Materials – Materials Science and Engineering at KIT Karlsruhe, the influence of alloy composition on the visual appearance of the seam marking is examined through extrusion, heat treatment, and surface treatment of different batches of the aluminum alloy AA6060. The appearance of the seam is influenced by the silicon, magnesium, and iron content, as these are crucial for the formation of precipitates during the thermal treatment of the material. Specific heat treatment after extrusion can affect the visual appearance of the seam (see figure), where a longer and warmer ageing process leads to streakings with a higher contrast. Furthermore, it will be investigated whether heat treatment can prevent the occurrence of weld streaks.

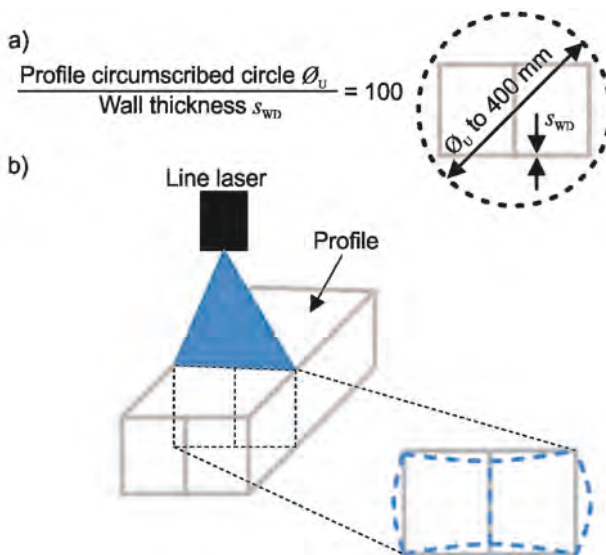


Effect of different heat treatment parameters on the appearance of longitudinal weld streaks

## 2.2.3 Light Battery Trays made from Thin-Walled Large Scale Extruded Profiles

Funding	BMWK
Project	03LB1016C
Contact	Oliver Schulz M. Sc.

The aspect of sustainability and increasingly resource-efficient production is becoming more and more important with regard to the rising demand for aluminum for e-vehicles. Extrusion, in particular, offers a great potential for lightweight construction. Together with OTTO FUCHS KG and the ISPT, possibilities for the production of thin-walled large scale profiles with a ratio of profile circumscribed circle to wall thickness of 100 are being developed (see Figure a), using the example of a battery tray. In addition to the challenges of such a profile, the focus is also on process control to avoid defects such as warping (see Figure b). An assistance system is to provide the machine operator with information on profile quality directly on site. By means of inline monitoring of process parameters and numerical data sets from AI simulations an early correction of process-related defects will be made possible. In addition to the influence of extrusion, thermal influences due to various cooling strategies will also be investigated on a test rig redeveloped for this purpose.



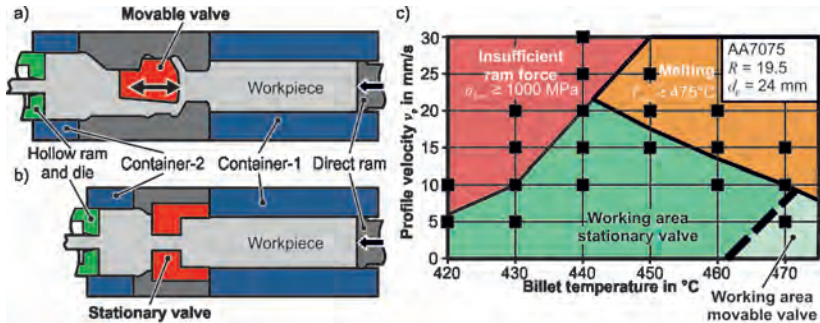
a) Concept thin-walled large scale profile b) Concept inline monitoring

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

Funding  
Project  
Contact

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

In the continuous hot extrusion process direct and indirect hot extrusion are combined by a movable (see Figure a) or stationary valve (see Figure b). This enables the extrusion of profiles while reloading billets and a constant profile exit velocity can be established during the complete extrusion cycle. By using a scaled setup of continuous extrusion and plasticine as model material it can be shown that both the movable and the stationary valve prevent backflow and, thus, enable continuous extrusion. Compared to the movable valve, the stationary valve offers the main advantages that no moving parts are necessary, the friction and, thus, the ram force is lower during the direct extrusion phase, and a lower profile exit temperature is achieved. With numerical process simulation the process windows (see Figure c) for continuous extrusion with a movable and a stationary valve were established. For the investigated parameters the profile velocity can be increased by approx. 400 % with a stationary valve compared to the movable valve.

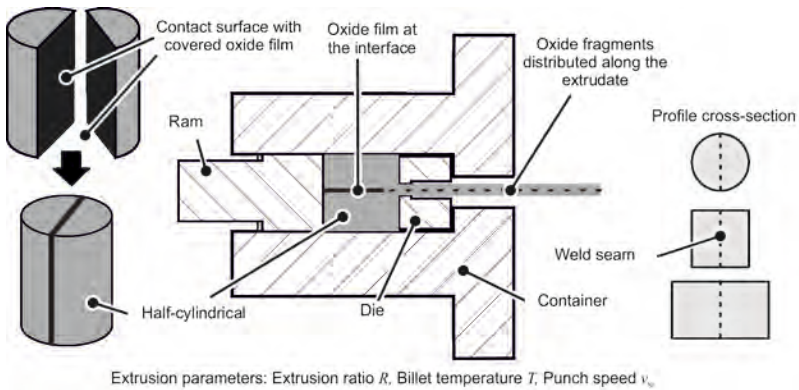


Continuous hot extrusion with a) Movable and b) Stationary valve, and c) Process window

## 2.2.5 Solid-State Welding of Oxide-Containing Aluminum Surfaces in Forming Technology

Funding	German Research Foundation (DFG)
Project	470385288
Contact	Gabriel Marín M. Sc.

The primary objective of this work is to investigate how various physical parameters influence the quality of solid state welding of oxidized surfaces. In addition, an automatable measuring method for the bond strength will be developed and the results can be used to validate a numerical method for the prediction of the weld strength. To achieve these goals, the research follows a two-fold approach. Firstly, a comprehensive qualitative analysis of seams created during extrusion under varying process parameters is conducted (see figure). Here, metallographic analysis (e.g. optical microscopy) is applied with a particular emphasis on measuring the seam thickness. Secondly, quantitative mechanical testing to precisely quantify the bond strength within these seams is performed. These results are expected to establish a significant correlation between optical measurements and weld strength. Ultimately, this research aims at enhancing the accuracy of models for the prediction of solid-state bonding.



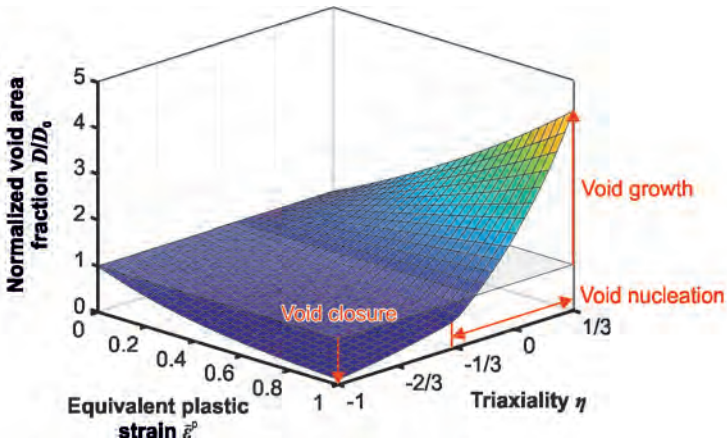
Extrusion of halved blocks for the targeted production of welded surfaces

## 2.2.6 Influencing the Evolution of Damage in Cold Extrusion

Funding  
Project  
Contact

German Research Foundation (DFG)  
TRR 188 • Subproject A02  
Robin Gitschel M. Sc.

In metal forming, ductile damage occurs in the form of nucleation, growth, and coalescence of voids at the microscopic level. Such voids affect the performance in service life of manufactured components. Accordingly, damage-controlled cold forging processes can produce components with enhanced product performance. In order to predict local distributions of damage in complex components, efficient modeling methods are required. However, most of the established damage models do not correctly represent damage evolution under large hydrostatic pressures. For example, the decrease in void area under large hydrostatic pressures in cold forging cannot be illustrated. Therefore, a new model was developed that can represent void nucleation, void growth as well as void closure (see figure). Through a parameter identification scheme based on scanning electron microscopic void area measurements on forward rod extruded parts, the new model enables a good prediction accuracy for complex cold-forged components.



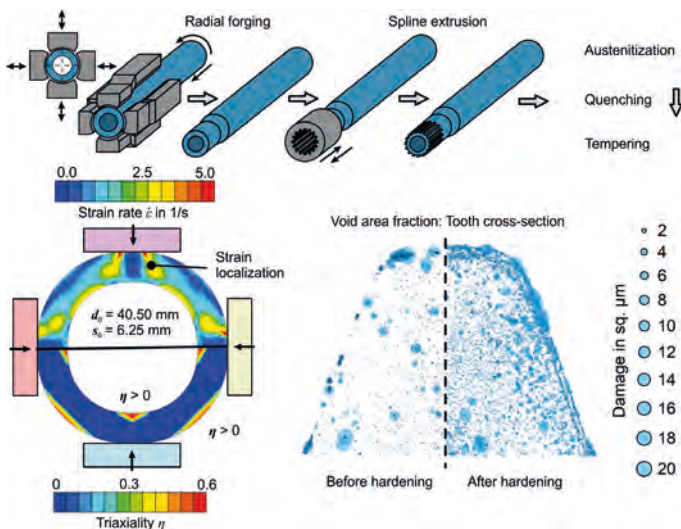
Damage prediction under constant load path, considering void nucleation, growth, and closure

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

Funding  
Project  
Contact

German Research Foundation (DFG)  
TRR 188 • Subproject T01  
Tanmoy Rakshit M. Sc.

The electrification of vehicles leads to an increase in their weight, hence increased acceleration and braking torques are observed, which have to be transmitted by hollow drive shafts. As part of the project, in cooperation with the companies GKN Driveline Deutschland GmbH and Simufact Engineering GmbH (Germany), the production of drive shafts suitable for high loads by means of radial forging, spline extrusion, and martensitic hardening is investigated. Radial forging is an incremental forming process with an oscillating load path. At each hammer stroke the inner and outer surfaces experience an alternating positive and negative triaxiality. Positive triaxialities are the cause for surface micro cracks. During spline extrusion the surface damage increases further. After spline extrusion the shafts are austenitized, quenched, and tempered to obtain a tough martensitic shaft. After hardening the void area fraction of the tooth increases (see figure). The voids localize along the external contour of the shaft. The aim is to design a process chain in terms of reduced damage of the components to achieve a longer life to failure under dynamic loading.



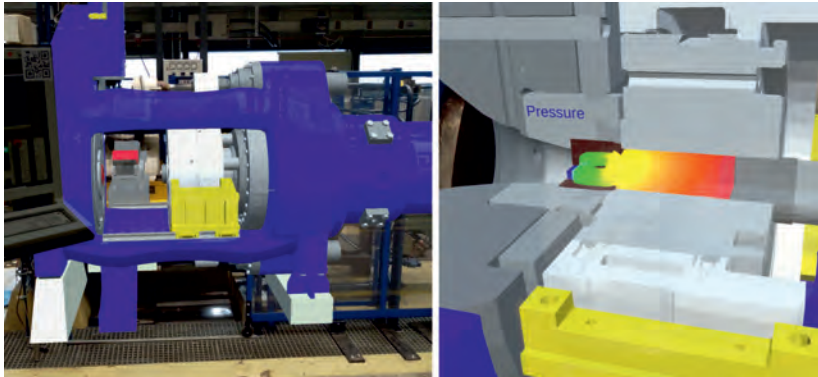
Process chain, stress state while radial forging, and void area fraction during hardening

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

Funding	BMBF/PTKA
Project	02P20Z004
Contact	Joshua Grodotzki M. Sc. Dipl. Inform. Alessandro Selvaggio

Together with the Institute for Lightweight Structures and Plastics (TU Dresden), the Institute for Machine Tools and Industrial Management (TU Munich), the Laboratory for Materials and Joining Technology (Paderborn University), and the Institute of Processing Machinery and Recycling Technology (TU Bergakademie Freiberg) sustainable material cycles for the production of lightweight and functionally adapted battery frames are investigated. The research institutes analyze how the respective processes need to be adapted so that they achieve comparable results with recycled material as with conventional (raw) material.

At the same time, the manufacturing process is considered as a socio-technical system. By Mixed-Reality approaches additional information (see figure) can be fed into the field of vision, particularly by means of Augmented Reality. Novel human-machine interfaces enable bilateral communication for controlling and monitoring industrial production machines. Corresponding technologies also improve remote maintenance and interactive-immersive training of new employees.

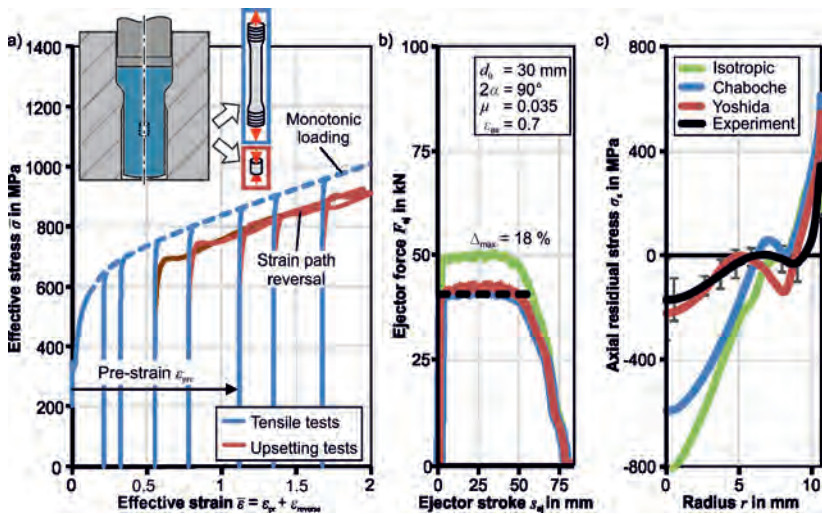


Field of vision with augmented reality for aluminum hot extrusion

## 2.2.9 Influence of the Multiaxial Bauschinger Effect in Cold Forging

Funding	German Research Foundation (DFG)
Project	418815343
Contact	Johannes Gebhard M. Sc.
Status	Completed

Load reversals often occur in the process chain of cold forging. This is why numerical process simulation with conventional isotropic models does not correctly represent the material behavior. To calibrate corresponding anisotropic strain hardening models a methodology based on tensile, torsional, and compression tests was developed on material pre-strained by full forward rod extrusion (see Figure a). Thus, the anisotropic strain hardening behavior could be characterized up to a plastic strain of  $\epsilon_p = 1.6$  and was implemented by modifying the Yoshida and Uemori model (2002). The effect on the prediction accuracy was validated by evaluating the ejector forces after forward rod extrusion. The present load reversal leads to a deviation of the determined ejector force of 18 % (see Figure b) if the anisotropic hardening is not taken into account. This also affects the calculation of residual stresses, which could be significantly improved by taking anisotropic hardening into account (see Figure c).

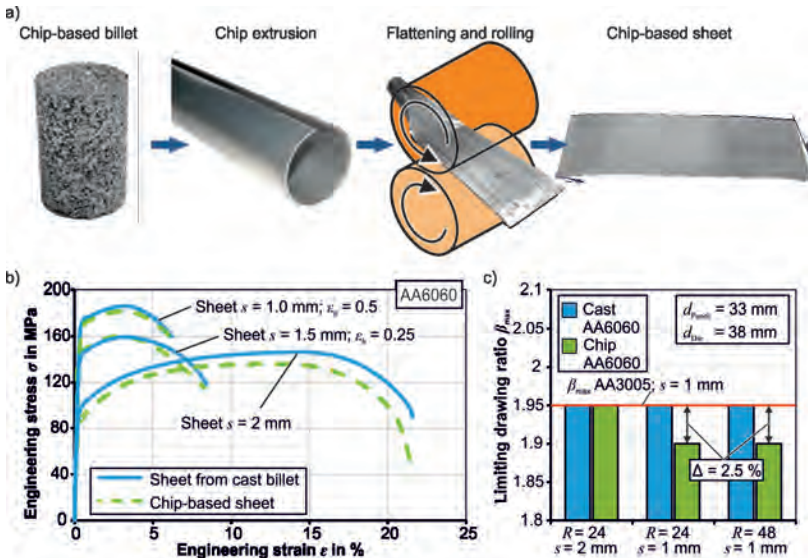


a) Characterization, numerical and experimental b) Ejector forces and c) Residual stresses

## 2.2.10 Production of Sheets by Hot Extrusion of Aluminum Chips

Funding	German Research Foundation (DFG)
Project	437426733
Contact	Johannes Gebhard M. Sc.
Status	Completed

By direct extrusion of billets compacted from chips, the energy-intensive remelting for recycling of the chips can be avoided. When extruding an open tube profile and then flattening and rolling it, chip-based sheets can be produced (see Figure a). Even after extrusion the tensile strength of the chip-based sheets (AA6060) is only 6 % lower than the tensile strength of sheets produced from cast billets. Furthermore, it could be shown that the welding of the chips and, thus, the tensile strength of the sheets can be further increased by rolling (see Figure b). Using exemplaric deep drawing experiments, it was shown that the formability is comparable with sheets produced from cast billets and comparable to conventionally rolled sheets of AA3005 (see Figure c). Based on numerical process simulation, the weld strength can be predicted. In particular, the geometrical properties of the extrusion die and the change in sheet thickness during rolling are decisive for the mechanical properties of the sheet. The calculation of the welding quality was validated by microstructure investigations.

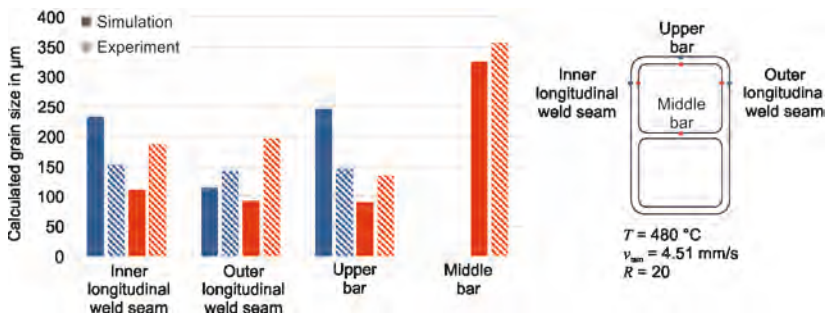


a) Process chain, b) Tensile strength of sheets, and c) Limiting drawing ratio

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

Funding	AiF/ Stifterverband Metalle e.V.
Project	21682 N
Contact	Oliver Schulz M. Sc.
Status	Completed

The microstructure is decisive for the mechanical and optical properties of extruded profiles. Recently, the microstructure could only be predicted numerically in a rudimentary and unreliable way. In cooperation with Fraunhofer Institute for Mechanics of Materials IWM in Freiburg, a mean-field model for the prediction of grain size and recrystallized fraction was calibrated with experimentally determined microstructure data. For this purpose, the development of the microstructure in hot upsetting tests and miniature extrusion tests for alloys AA6060 and AA6082 was evaluated and supplemented by the numerically determined local state variables temperature, strain, and strain rate. The validation on further extrusion test showed a correct prediction for the recrystallized regions. The grain size could be predicted in a comparable order of magnitude. A final validation using a two-chamber profile on an industrial scale (see figure) also predicted agreement of the grain size in the same order of magnitude.

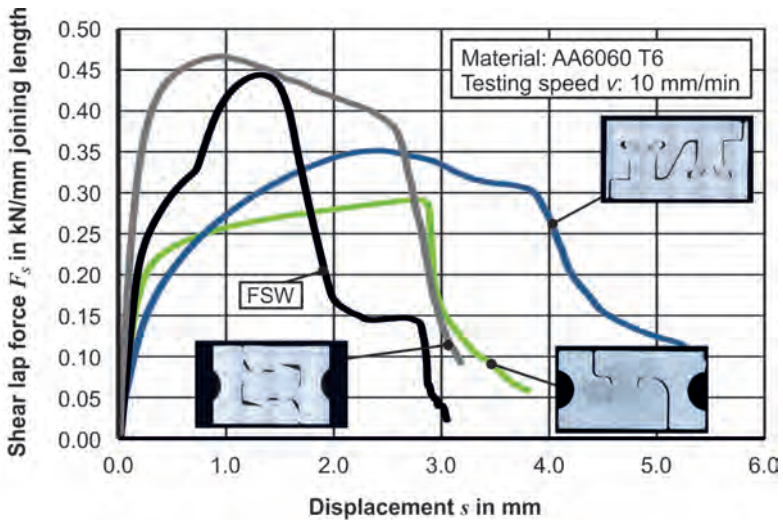


Validation of the grain size in the industrial profile

## 2.2.12 Longitudinal Mechanical Joining of Extruded Aluminum Profiles with Increased Tightness Requirements

Funding	AiF / Stifterverband Metalle e. V.
Project	21048N
Contact	Florian Kneuper M. Sc.
Status	Completed

In cooperation with the Laboratory for Material and Joining Technology (LWF) at the University of Paderborn a new type of aluminum hot extruded profile concept was developed to produce tight base assemblies for battery housings using a mechanical single stroke joining process. The longitudinal mechanical joint replaces the currently used time and cost-intensive friction stir welding. Three profile geometries, which had previously been simulated and then produced on a 10 MN extrusion press at the IUL, were successfully joined at the LWF. Micrographs have confirmed the successful forming of the joint geometries and measurements with a helium sniffer leak detector have proven high tightness of the joints. Shear tensile and bending tests have shown that mechanical joints can achieve similar load-bearing capacities as the friction stir welded joints to be replaced. Finally, the potential of the joining concept was highlighted by means of a benchmark and first demonstrators of battery housings were produced.



Longitudinal joining: comparison of shear lap forces

## 2.3 Department of Profile and Sheet Metal Forming

Head      Joshua Grodotzki M. Sc.

In the Department of Profile and Sheet Metal Forming a team of 10 members is researching new as well as application-oriented processes for the forming and characterization of sheet metal products and profiles. In addition to the experimental side, models are being further developed that can describe the material behavior analytically and numerically.

New methods help to accelerate parameter identification and to predict damage evolution more accurately. These models can then be used for forming processes, such as roll forming, or in complex process sequences to design and manufacture higher performing components. If high strains occur, for example in passive press hardening of tubes using granular media, precise flow curves are needed. These may come from new characterization techniques, such as in-plane torsion testing for curved semi-finished products. Press hardening can also be used in addition to local heating strategies to locally adjust component properties. This is currently investigated in bending of non-symmetrical profiles. Composite roll cladding enables the production of press-hardenable semi-finished products for induction heating. For the adjustment of local cross-sectional gradations with short transition zones, room-temperature roll sliding is still being researched. For spring production, a tool has been successfully developed which helps companies to accelerate their set-up process.

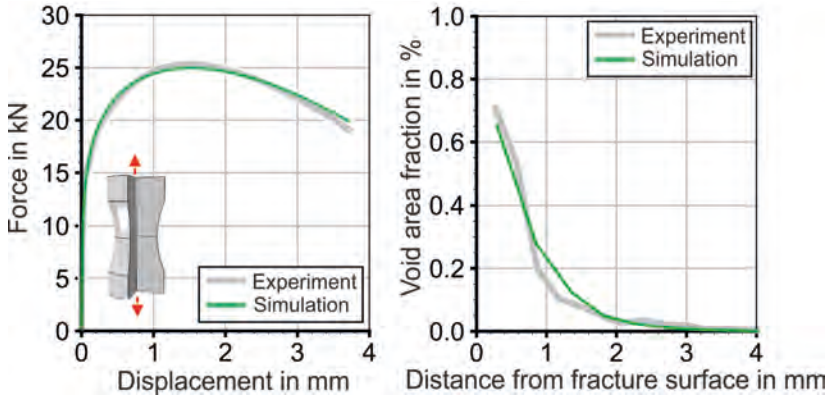


The team of the Profile and Sheet Metal Department on the top platform of the IUL experimental hall

### 2.3.1 Model Integration for Process Simulation

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

The primary objective of the TRR188 is to enhance the product properties by damage-controlled forming. The focus of subproject S01, which is being carried out in collaboration with the Institute of Mechanics at TU Dortmund, is on the accurate prediction of ductile damage in the sense of void fractions and their effects on mechanical properties, and, ultimately, the performance of the final products. In order to enable meaningful damage simulations of the forming processes, the constitutive damage models in finite element simulations require prior identification of the model parameters. Besides conventional model calibration that relies solely on load-displacement curves of notched tensile tests, contour data and high-resolution void measurements were considered in the new approach. This enables the prediction of the macroscopic behavior and damage in the sense of microscopic void area fractions (see Figure). The calibrated models were validated using cold extrusion and provide quantitatively good predictions of the void area fraction.



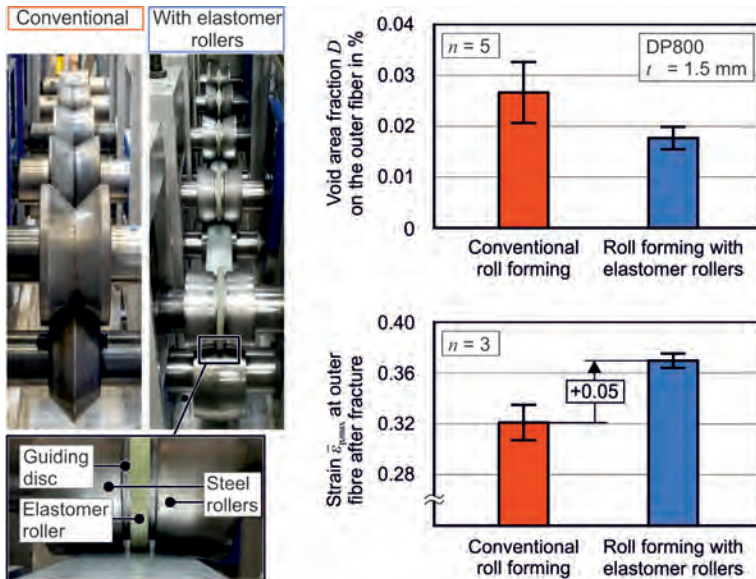
Parameter identification based on experimental data of different scales

## 2.3.2 Damage in Sheet Metal Bending of Lightweight Profiles

Funding  
Project  
Contact

German Research Foundation (DFG)  
TRR 188 • Subproject A05  
Philipp Lennemann M. Sc.

Ductile damage occurs during metal forming and refers to the nucleation, growth, and coalescence of voids. The triaxiality and, thus, the damage evolution can be lowered by the superposition of compressive stresses during forming. Therefore, elastic rollers were used in roll forming of DP800 to influence the stress state at the damage-critical outer bend. Void area measurements by SEM revealed a reduction of the void area fraction by 33 %. This resulted in increased component performance with a 9 % higher stiffness and 15 % higher formability. With regard to multistage forming processes, load and strain path changes are considered. Orthogonal strain path changes were found to be less critical regarding the promotion of damage than monotonic strain paths which led to higher fracture strains after strain path changes. This can be attributed to the orientation of martensite cracks. In the field of hot sheet metal forming, the influence of phase transformation, forming temperature, and holding time on damage evolution during press hardening is being investigated.



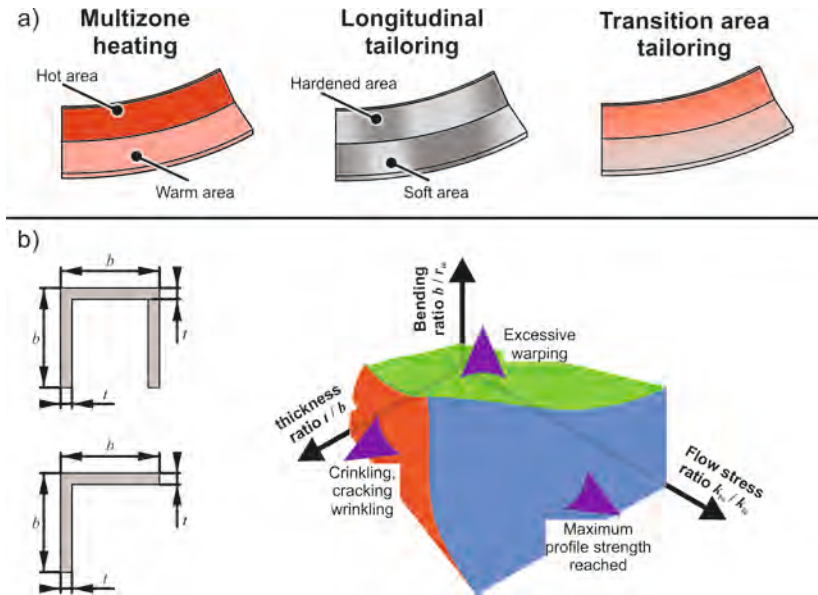
Roll forming: conventional and with elastomer rollers

### 2.3.3 Kinematic Profile Bending with Locally Heated Cross Section for Tailoring of Mechanical Properties

Funding  
Project  
Contact

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

Aim of the project is the evaluation of a combined profile bending and mechanical tailoring process with a simultaneous minimization of profile warping. Therefore, profiles of 22MnB5 and X20Cr13 are kinematically bent. The setting of material properties as well as a warping reduction of the profiles is achieved through partial inductive heating above the recrystallization temperature and subsequent quenching. To allow for the production of a broad spectrum of parts with this process, various heating strategies as well as profile geometries will be investigated during the course of the project. The expected results will provide the necessary fundamentals to design processes for the production of bent profiles with tailored properties. The manufactured profiles with the aforementioned properties can, for example, be used in vehicle design in crash-relevant areas where the components need to possess a high-energy absorption while material failure is not allowed at the same time.



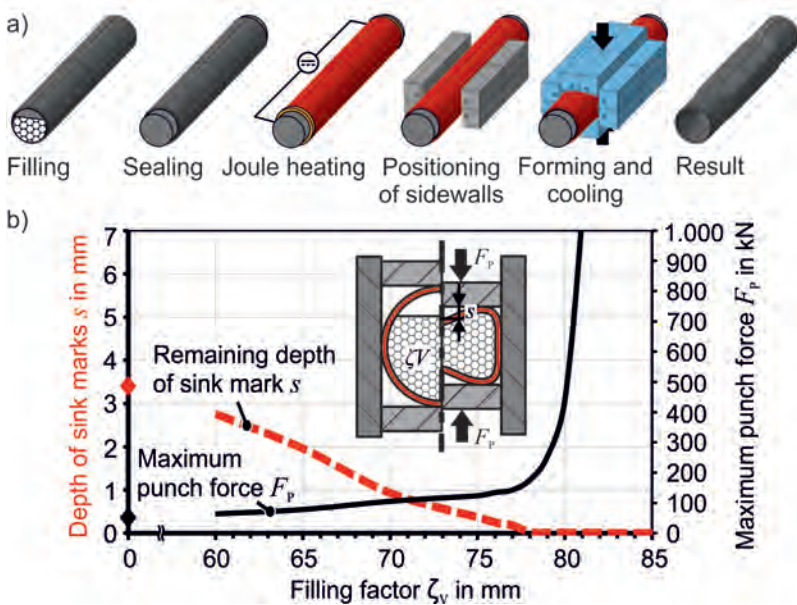
a) Possible heating areas, b) Process window example

### 2.3.4 Passive Granular Medium-Mased Tube Press Hardening

Funding  
Project  
Contact

German Research Foundation (DFG)  
427196185  
Florian Kneuper M. Sc.

For the manufacturing of tubular components with high strength and high stiffness, a new process for press hardening of tubes is being developed. Granules are used as a passive forming medium. Tubes filled with granules and heated to austenitizing temperature are formed by a punch acting on the tubes circumference and simultaneously quenched in the die. First, a forming to a rectangular profile cross-section is considered. The resulting reduction of the internal volume of the tube leads to compression of the granules inside. The generated pressure prevents the otherwise typical sink marks in the middle of the tube and improves the forming of the corner radii. From 2D and 3D simulation, it is found that even small pressures of 6 MPa are sufficient to prevent sink marks. A double-acting process reduces the friction on the die and leads to a symmetrical forming of the tube. These and other results on occurring joining forces and the temperature history were used for the design of a forming tool.

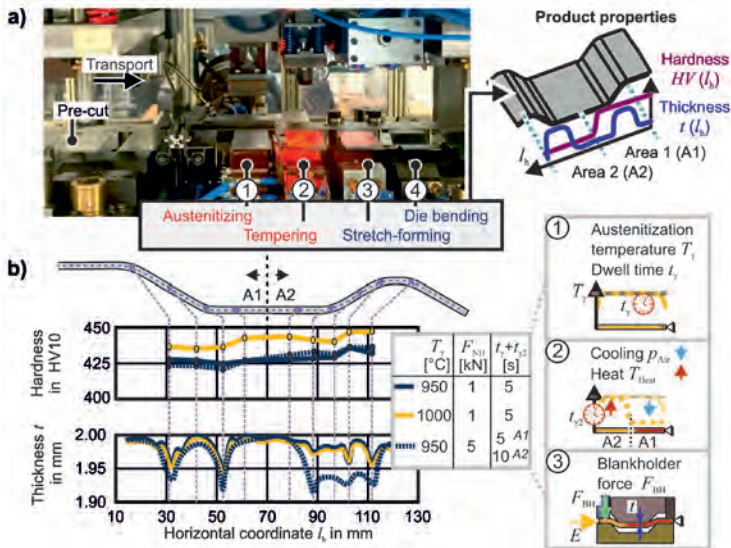


a) Process sequence and b) Depth of the sink mark and punch force as a function of the filling factor

## 2.3.5 Property-Controlled Multi-Stage Hot Sheet Metal

Funding German Research Foundation (DFG)  
 Project TE 508/81-2 (SPP2183)  
 Contact Juri Martschin M. Sc.

Multi-stage hot forming in the progressive die offers the potential to produce small to medium-sized hardened components with a complex geometry and tailored product properties. For this purpose, the thermal and mechanical process history, which determine the resulting product properties, are to be adapted step by step by means of actuators integrated into the tooling system. To adjust the hardness and sheet thinning, an inductive heating system, a tempering stage consisting of a direct-current heating system, an air-cooling system, and a blankholder with controllable force were implemented in a demonstrator die (see Figure a). In try-out tests (see Figure b) with the press hardening steel 22MnB5 it was possible to adjust the level of the hardness profile by varying the austenitizing temperature. By increasing the blankholder force and simultaneously adjusting the control variables of the tempering stage, it was possible to locally control the sheet thickness in the area 2 at a specific hardness level. The project is being carried out in collaboration with the Institute of Mechanical Process Engineering and Mechanics at KIT Karlsruhe.

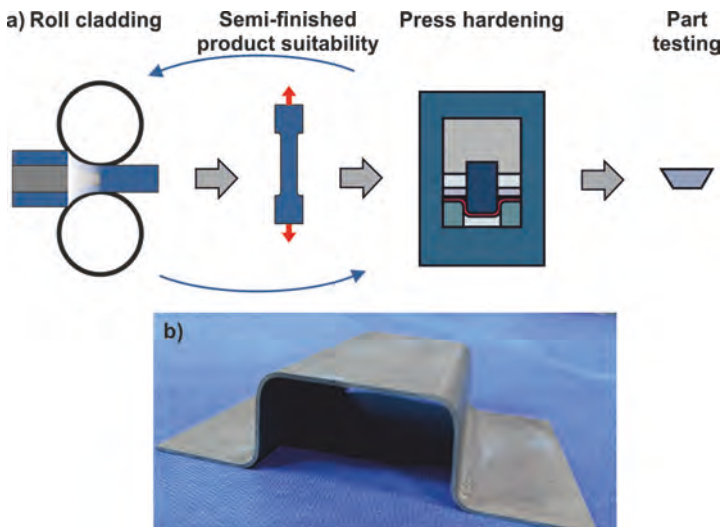


a) Progressive die with extended actuator arrangement,  
 b) Product properties set in try-out tests

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

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

Together with the Institute of Metal Forming at RWTH Aachen University, a new composite material was developed for press hardening in which the conventional AISi-coating is substituted by two stainless steel sheets (X5CrNi18-10). During the roll-cladding of the sandwich composite the two steels form a material bond with a proven resistance to delamination during forming and heat treatment. During press hardening of hat profiles cracks appeared at the outer bending radius due to the reduced formability of the semi-finished product. The following analysis revealed that diffusion-induced formation of chromium carbides and interlaminar cracking during the rolling operation were responsible for the low remaining formability. The development of a new rolling strategy with variation of the temperature control improved the properties of the semi-finished products and enabled a failure-free production of press-hardened hat profiles. For the application-oriented design of the new press-hardened composite, a model was developed which predicts the material properties based on the composite composition.

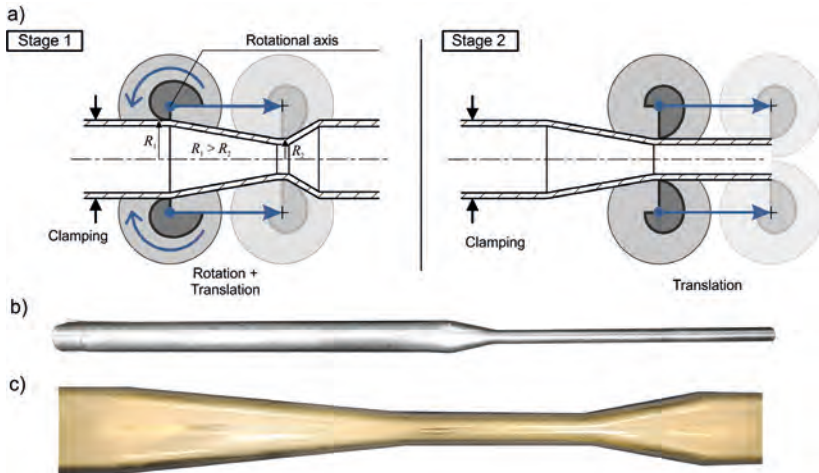


a) Project course and b) press-hardened part of the roll-clad composite

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

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

The main focus of the project, funded by the BMWK, is on a combined rolling-drawing-process in cooperation with Otto Fuchs KG and MSG Maschinenbau GmbH. Through a combination of rolling and drawing with a non-constant drawing gap, a local change or reduction of the cross-sectional geometry is achieved by this process. This reshaping results in lower material usage in production as well as reduced component weight, which can save CO<sub>2</sub> emissions. Possible areas of application for such load-optimized profiles can be found in various mobility applications. To extend the range of applications, the formability of different initial geometries is investigated and the forming result is improved by adapting the geometry of the semi-finished product and the roller. It is shown that oval profiles can be successfully graded by the roll-drawing-process.



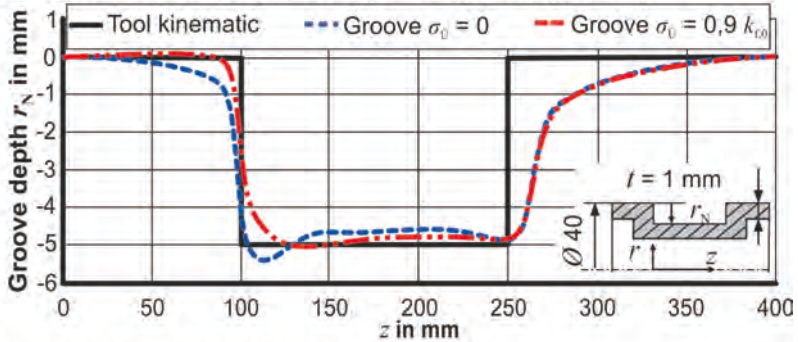
a) Combined roll gradation process, b) Formed pipe (round),  
c) Formed profile (initial geometry oval)

### 2.3.8 Profile Forming with Stress Superposition

Funding German Research Foundation (DFG)  
 Project 509859510  
 Contact Markus Stenei M. Sc.

Incremental profile forming (IPF) is a kinematic forming process to produce tubes with axially variable cross-sections. To manipulate the cross-section, the machine developed at the Institute of Forming Technology and Lightweight Components offers six rotationally mounted radially, individually adjustable tools of different shapes in addition to the axial feed axis. As common in classical kinematic processes, shape deviations occur between the movement of the tools and the final component geometry, which stem from complex springback conditions in the tube in this case. The deviation of a produced axial groove is illustrated in Figure 1a. In this project the influence of stress superpositions on the forming zone during and after manufacturing is investigated with the aim of selectively influencing the plasticized area to increase the forming accuracy. To realize the superposition, radial internal pressure, axial tensile/compressive load, and torsional load are tested as part of the research in this project (Figure 1b).

(a) Effect of stress superposition  $\sigma_0$  on the groove geometry



(b) Types of stress superposition  $\sigma_0$  studied

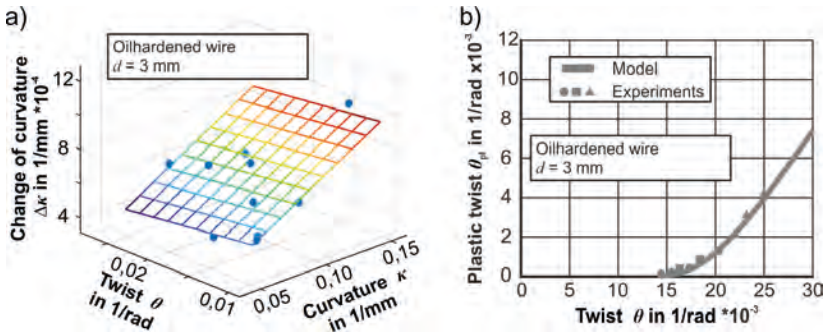


Effect and types of stress superposition in incremental profile transformation

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

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

Helical compression springs are manufactured in a multi-stage process consisting of coiling, heat treatment, and pre-setting. The geometry of the springs produced by coiling is changed during heat treatment by the release of residual stresses and during pre-setting by plastic deformation. Analytical and empirical approaches have been developed to predict this previously unknown geometry change. Due to the high effort of material characterization for analytical models, the empirical models are qualified for practical use. The models use bilinear compensation functions to determine the distortion as a function of the spring dimensions during heat treatment (see Figure a). In the case of the pre-setting model a description of the plastic twist is given as a function of the total twist applied to the wire by pre-setting (see Figure b). Both models are combined in an Excel tool, which can be used to support the operators in the previously experience-based setup of the coiling machines.

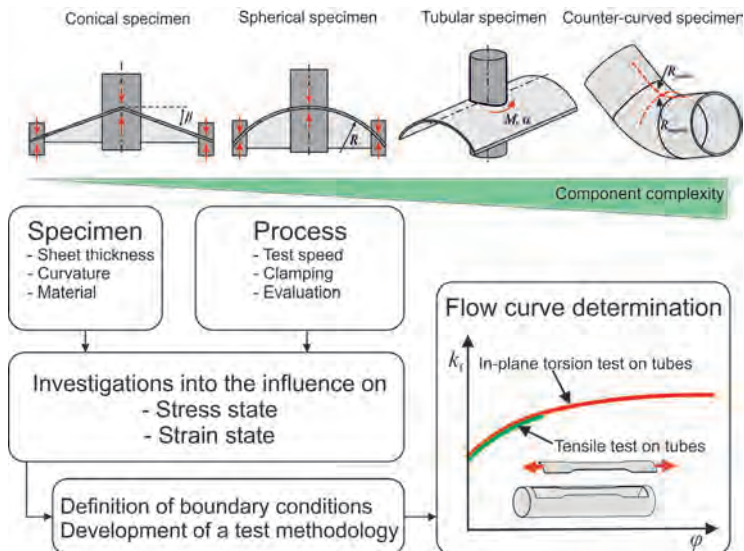


- a) Flow curves from tension and compression tests  
 b) Stress relaxation behavior of oil-hardened wire

## 2.3.10 Novel In-Plane Torsion Specimen for the Characterization of Damage and Hardening – Curved Sheets and Components

Funding	German Research Foundation (DFG)
Project	327544970
Contact	Fabian Stiebert M. Sc.

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



Overview of the most important investigations regarding the torsion test of non-planar sheets and components

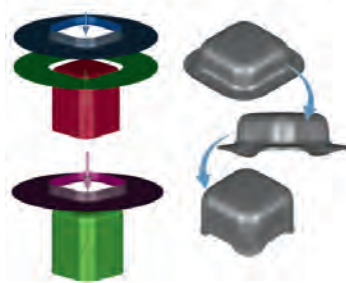
### 2.3.11 Strain State Control by Tool Design

Funding  
Contact

ReCIMP  
Gabriel Marín M. Sc.

Since December 2022, the Research Center for Industrial Metal Processing, in cooperation with the Institute for Forming Technology and Lightweight Components and Forvia-Faurecia, has undertaken a study probing the influence of tool geometry on strain distribution within drawn cups. The motivation for this inquiry stems from edge cracks observed in automotive deep-drawn components, requiring a subsequent trimming operation, which impairs the material efficiency. The research primarily focuses on square cups (refer to Figure) and involves a process alteration by introducing a round punch during drawing. This strategic adaptation aims at manipulating the strain development, successfully mitigating wrinkling in the components, and averting crack initiation. Subsequent phases of investigation will concentrate on both experimental and numerical assessments, thoroughly evaluating the performance of cups manufactured using this novel and optimized process sequence.

#### Conventional process route



#### Innovative process route



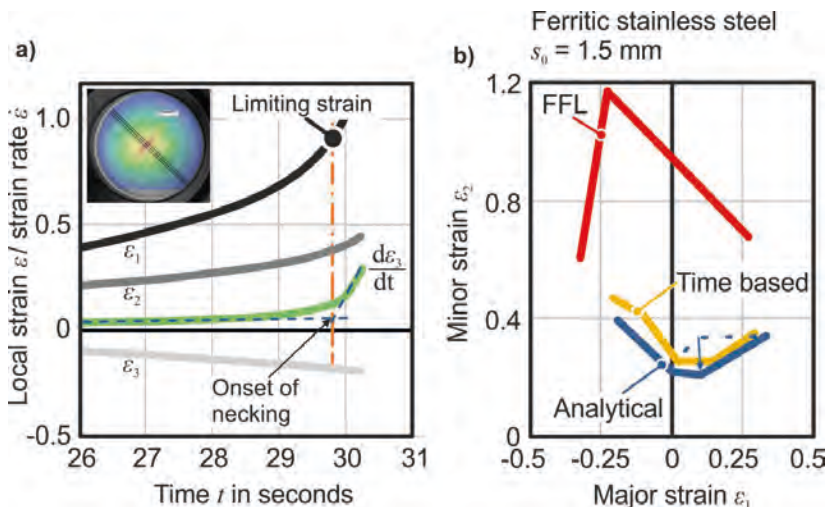
Influence of the process route on the cup geometry

### 2.3.12 Formability of Ferritic Stainless Steels and Modern Steel Grades

Funding  
Contact  
Status

ReCIMP  
Jan Bechler M. Sc.  
Completed

The focus of this project was on the identification of new methods for characterizing the formability of ferritic stainless steels and modern steel grades. The primary tools for assessing local and global formability are both the fracture forming limit (FFL) and the forming limit curve (FLC). The material can be used more efficiently by the usage of a novel time-dependent methodology. In contrast to the standard, the time-dependent method determines the onset of necking with respect to the decrease in sheet thickness, which leads to an increase of the FLC. An analytical lower boundary of the FLC is determinable for high-strength steels with tensile test data. The analytical model was enhanced for ferritic stainless steels by the statistical modification of the parameters. The analytical models allow a rapid estimation of the forming limit in the design phase. The usable forming area is increasable by the usage of the fracture forming limit which is determinable by the measurement of the fracture thickness and width for the materials.



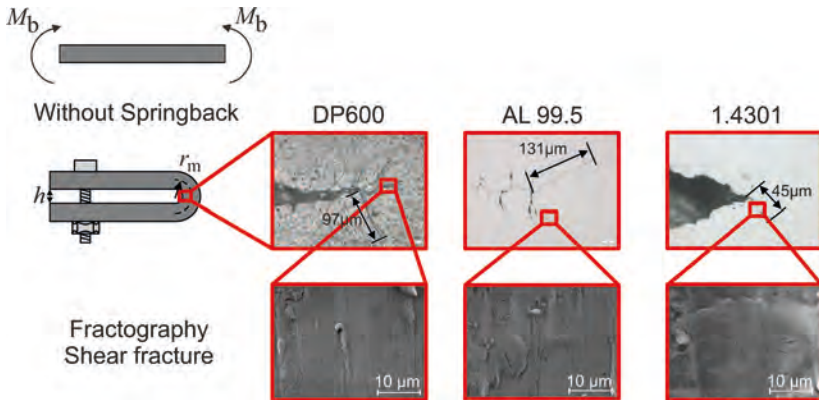
a) The basic principle of the time-based method and b) FFL and FLC for ferritic stainless steels

### 2.3.13 Forming-Controlled Fatigue Strength of Tubes

Funding  
Contact

ReCIMP  
Jan Bechler M. Sc.

The aim of this project is to predict and increase the fatigue life cycle of upset formed joints. From the literature it is known that initial cracks occur at the inner bending radius. Here, shearing and elastic springback are claimed as the reasons for the cracks and are therefore investigated in the following. SEM analyses revealed that for different strain states shear fractures occur at the inner bending radius, confirming shearing as the cause of cracks. The influence of the elastic springback on the crack initiation is investigated by bending experiments on DP600, Al99.5, and 1.4301 (see Figure). To prevent elastic springback, the specimens are secured with screws post-bending which are later removed. Microscopic analyses of the secured bent samples revealed initial cracks in the materials, which proves shearing as the root cause. Comparing the same initial crack in fastened and unfastened condition showed an increased crack length after fastener removal. Future analyses will focus on the influence of the microstructure on the fatigue life.



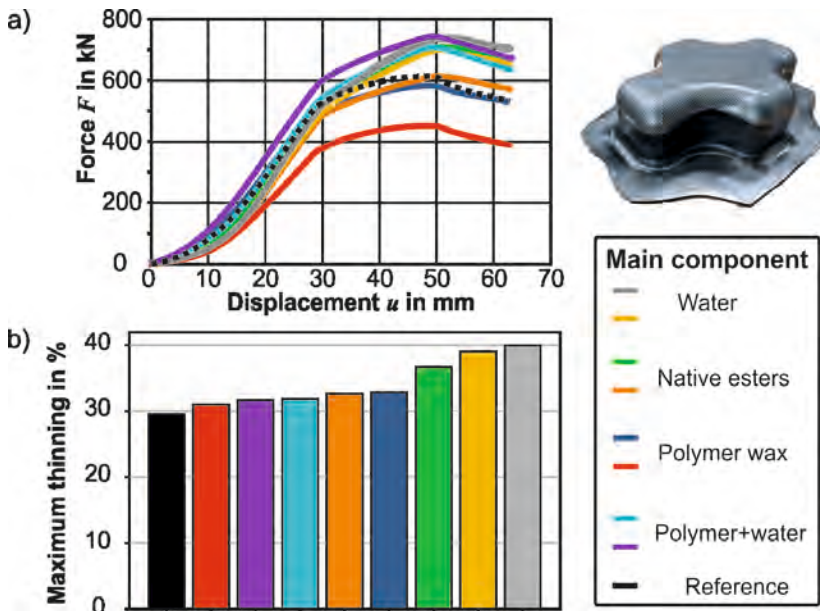
Crack initiation without springback in bending specimens & SEM confirming shear fracture causing the crack initiation

### 2.3.14 Study on the Application of Environmentally Friendly Lubricants

Funding  
Contact

ReCIMP  
Philipp Rethmann M. Sc.

In automotive engineering deep drawing of sheet metal is a key process to create complex shapes for body and structural components. For the production of challenging components deep drawing lubricants containing mineral oil are used, which pose a potential hazard to humans and the environment. „Green“ biodegradable lubricants made from renewable raw materials promise to solve this problem and could also save costs by eliminating washing processes. A comparison of maximum process forces and maximum sheet thinning (see Figure) in cross-cup deep drawing tests shows that „green“ lubricants can keep pace with conventional deep drawing lubricants in terms of performance. Water-based wax dispersions, for example, achieve the lowest process forces of all lubricants tested. In the next step, optical examinations of component contamination and thermogravimetric analyses will determine which products require component cleaning.

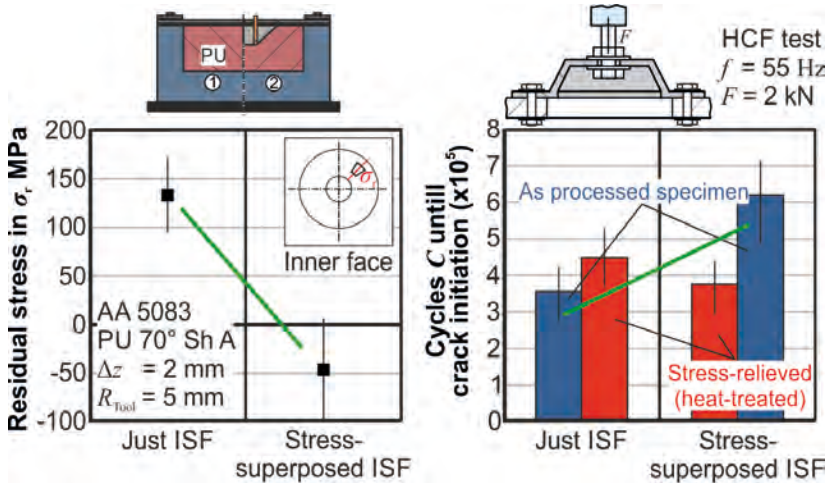


a) Force-displacement curves for deep drawing tests with different green lubricants  
b) Maximum thinning of the sheets during deep drawing tests

## 2.4 Department of Non-Conventional Processes

Head Dr.-Ing. Marlon Hahn

The department analyzes and develops forming processes that offer advantages over conventional manufacturing processes, such as shorter process times or product properties unattainable by other means. The general aim is to address experimental, numerical as well as analytical considerations in the projects. There is the following categorization: high speed forming (including cutting), incremental forming, joining by forming (including different materials), and new hybrid components, for tooling as well as semi-finished products. As in the other departments, one of the principles used is stress superposition. This can be seen exemplarily in the figure. By introducing a counter pressure during incremental sheet metal forming, otherwise undesirable tensile residual stresses are changed by the forming process to compressive residual stresses while the geometry remains the same. This eventually enables a longer service life of the thus produced component. The project topics are characterized by a high variety and interdisciplinarity. At present, the department is composed of seven scientific staff members.

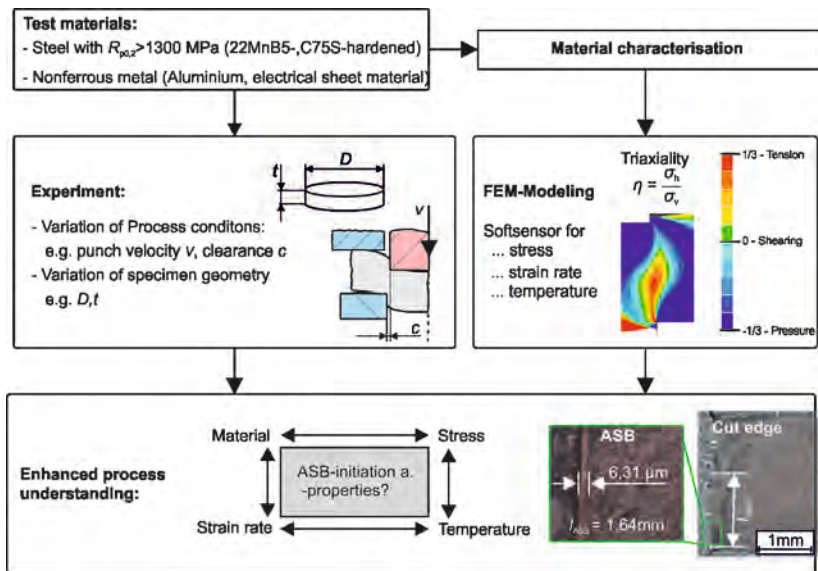


Example of incremental sheet forming (ISF): Property improvement by elastomer (PU) counter pressure

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

Funding German Research Foundation (DFG)  
 Project 460484491 (FOR 1580)  
 Contact Olaf Schrage M. Sc.

Analyzing the formation of adiabatic shear bands (ASB) and their properties at the cut edges produced by high-speed blanking is the scope of the project. In addition to the material properties, the stress state resulting from the process boundary conditions is identified as another main influencing factor, which is to be systematically investigated by varying the process parameters. Methodically, the experimental investigations are coupled with a comprehensive FEM modeling as a soft sensor for stress, strain rate, and temperature. The process understanding gained in basic experiments is subsequently transferred to complex geometries and used for property control of ASB. A comprehensive understanding of the ASB formation and the resulting ASB properties is aimed at in cooperation with TU Chemnitz, TU Munich as well as Fraunhofer IWU (Chemnitz) and Fraunhofer IWM (Freiburg) within the research group FOR FUND<sup>3</sup>AMENT.

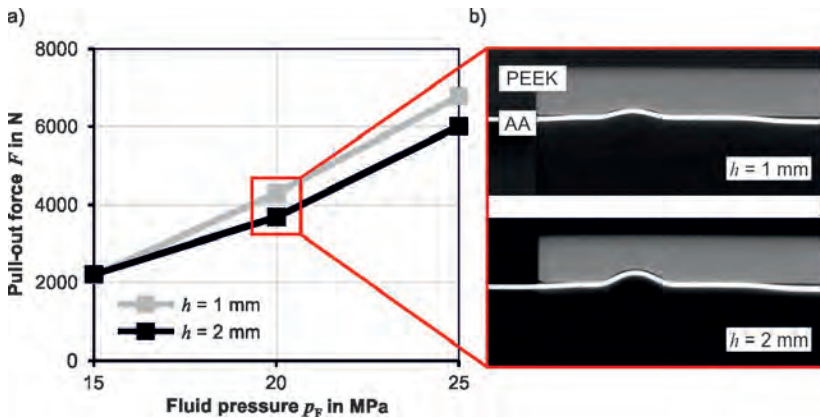


Procedure for the analysis of ASB formation and its properties

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

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

In this collaborative project the Institute of Forming Technology and Lightweight Components, together with PFW Aerospace, Steitz Präzisionstechnik, and Fraunhofer IZFP, investigate the joining by forming of metal-polymer joints for use in the aerospace sector. Within the scope of the experimental tests for joining by hydraulic expansion (IHF), the influence of form-fit elements, which are integrated into the thermoplastic joining partner made of polyetheretherketone (PEEK), on the transferable tensile forces is investigated. As a result of a higher degree of filling of the grooves by a metallic joining partner made of aluminum (EN AW-6061 T6), higher tensile forces can be transmitted by the joint. This is confirmed by computer tomographic (CT) images (Figure). Additionally, investigations on electromagnetic joining show the fundamental applicability of the process for this material combination, although the brittle material behavior of the PEEK must be emphasized as a limiting factor.



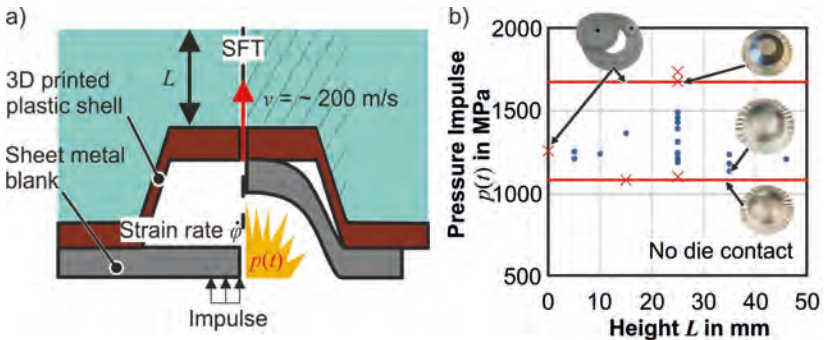
a) Pull-out forces after IHF and b) CT scans for groove filling for different groove depths  $h$

## 2.4.3 Forming by Locally Varying Vaporizing Actuators

Funding  
Project  
Contact

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

The focus of the continuation project is on increasing the flexibility of forming by vaporizing foil actuators for small part quantities. Solid, inflexible steel dies, which can only be used for certain component geometries, are replaced by thin, flexible 3D-printed plastic shells. These are supported by shear thickening fluids (STF) (Figure a). The fluid is liquid in its initial state and solidifies quasi-instantaneously due to high strain rates during workpiece impact. The filling level  $L$  and the wall thickness of the shell must be selected in a way to withstand the impact forces of the sheet metal workpiece. The variation of the energy of the capacitor shows an upper and lower process limit: If the discharge energy is too low, the part is not fully formed, whereas too high energies cause the die to break (Figure b). The filling level has no influence on the forming behavior since even low filling levels (5 mm) support the die sufficiently. Furthermore, it can be seen that trimming before or after forming has no influence on the elastic recovery.

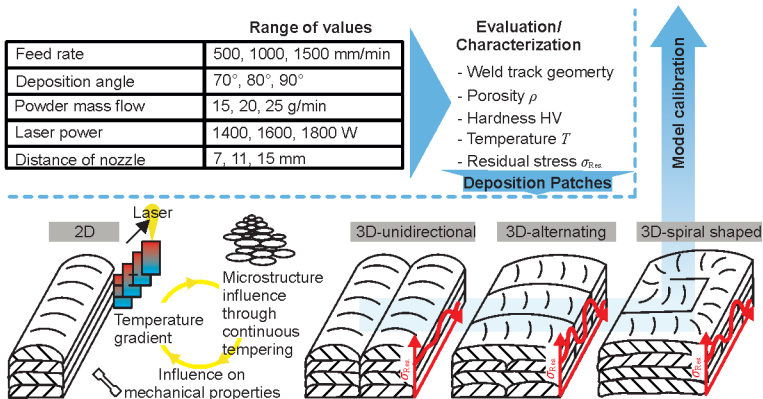


a) Schematic diagram of the flexible tool concept, b) Determined process limits for titanium sheets

## 2.4.4 Modeling and Analysis of Process-Induced Properties of Structures Additively Manufactured by Laser Metal Deposition

Funding German Research Foundation (DFG)  
 Project 504955789  
 Contact Hamed Dardaei Joghann M. Sc.

The objective, in cooperation with the Institute of Mechanics, is to simulate the manufacturing of components by laser metal deposition in order to predict the final contour of the manufactured component as well as the residual stresses and to investigate the influences of the selected process parameters. The basis of the simulations is a thermodynamically consistent material model based on micromechanics which provides physically plausible results and data. This plausibility enables, among other things, the application of the new methodology to problems in which no or only limited experimental data are available to validate the simulations. The incorporation of data-based methods also enables an optimal trade-off between accuracy and computation time that would not be achievable with classical methods. First, the relationship between the process parameters and the resulting weld track geometries, including the dilution zone, the resulting distortion, and the residual stresses will be investigated by means of XRD measurements.

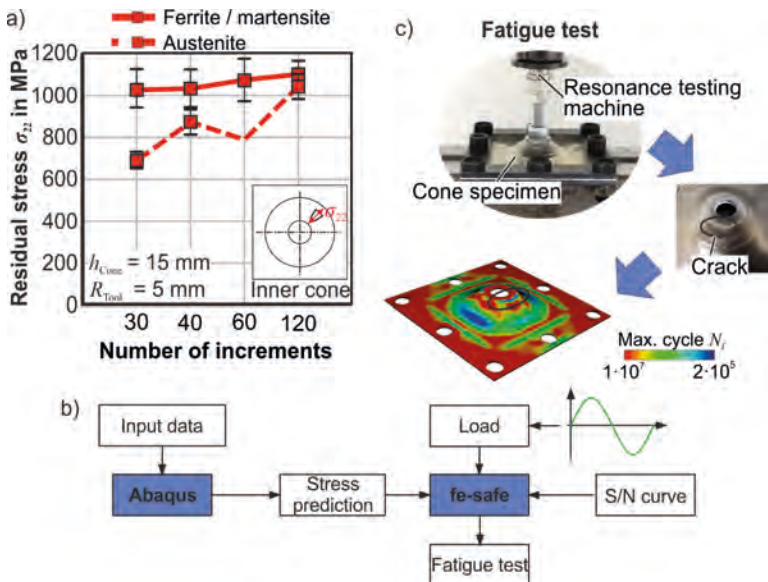


Experimental test plan

## 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.
Status	Completed

In the third funding period of the DFG priority program SPP 2013, in cooperation with the Chair of Materials and Surface Engineering of TU Chemnitz University, the amount and distribution of the residual stresses are purposefully adjusted by the process parameters of the incremental sheet metal forming (ISF) process and by using compressive stress superposition. The effect of the forming-induced residual stress were demonstrated for both aluminum alloy AA5083 and dual-phase steel 1.4462 (Figure a). Forming-induced compressive residual stresses were used to increase the fatigue strength (Figure c), even under corrosive conditions. The crack location and the maximum number of cycles until crack initiation for a given residual stress state were predicted by a numerical fatigue model (Figure b). The potential of this approach for industrial application will be examined in a DFG-funded transfer project together with the automotive supplier Faurecia Autositz GmbH.

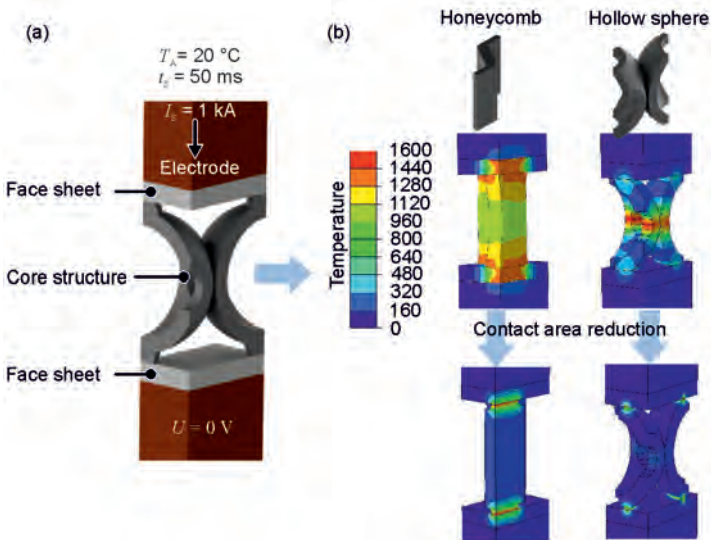


a) Residual stresses for 1.4462, b) Experimental and c) numerical fatigue test

## 2.4.6 Forming of Additively Manufactured Sandwich Sheets with Optimized Core Structures

Funding	German Research Foundation (DFG)
Project	317137194
Contact	Hamed Dardaei Joghani M. Sc.
Status	Completed

Sandwich sheet composites with core structures optimized for forming were investigated in collaboration with the Institute of Product Engineering at the University of Duisburg-Essen. To overcome the build space limitations of additive manufacturing machines, the additively manufactured core is joined with rolled face sheets to produce load-adapted semi-finished products. In addition to form fit, material fit was also researched using resistance welding where the core structures are welded to the face sheets. The effect of the welding parameters and the geometry on the quality of the joint was investigated (see Figure). Quasi-static shear tests and metallographic analysis were performed to evaluate the joint quality. Point contacts achieved the best joint strength. Increasing the welding time could increase the joint strength, however, it caused a considerable heat build-up, particularly for larger area contacts.

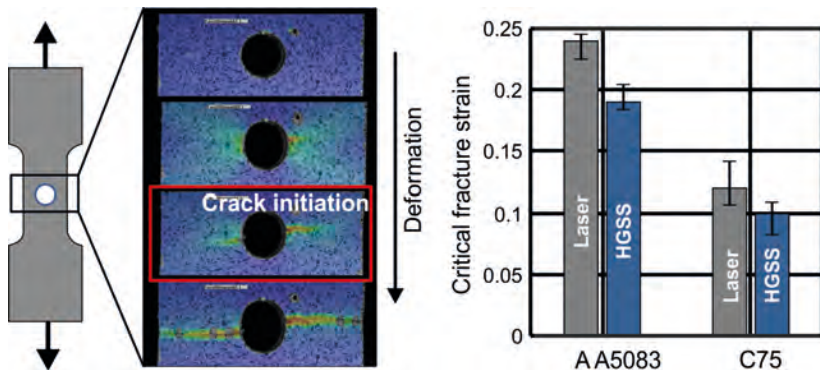


a) Model setup, b) Electrically-thermally coupled simulation

## 2.4.7 Application and Analysis of Adiabatic Blanking

Funding	German Research Foundation (DFG)
Project	428780322
Contact	Dr.-Ing. Marlon Hahn
Status	Completed

In high-speed shearing (HGSS) the resulting process heat does not really dissipate and leads to severe thermal softening. The local interaction between a high strain rate and temperature can lead to adiabatic shear bands (ASB) which provide different properties compared to conventional shear cutting. Hence, among other things, novel characterization methods for different steel and aluminum materials were investigated together with the Chair of Materials Science (LWW) at Chemnitz University of Technology. A temperature-dependent failure model was introduced and verified in order to be able to model an increase in ductility. Several relevant energy variables (machine, kinetic, shear energy) were determined experimentally for the first time to estimate the actual efficiency. In addition, it was found for post-forming, in terms of the edge crack sensitivity, that there is not necessarily an advantage over other cutting processes (see Figure). The project provides a basis for further investigations within the framework of FOR1580.



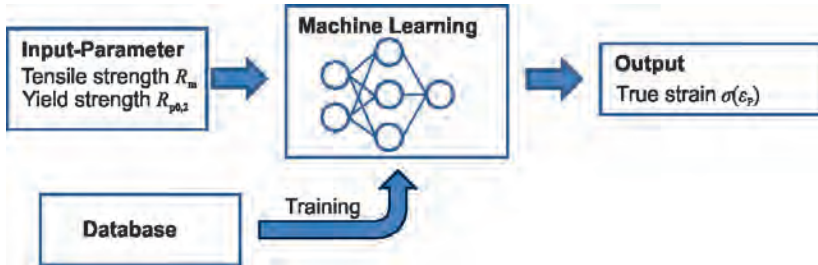
a) Comparison of strain localization, b) Effect of the strain rate sensitivity on forming energy

## 2.4.8 Flow Curve Determination by Machine Learning Algorithms

Funding  
Contact

ReCIMP  
Steffen Grünewald M. Sc.

In the ReCIMP project, which started in May 2023, the Institute of Forming Technology and Lightweight Components together with Forvia-Faurecia investigate the predictability of flow curves using artificial intelligence. Various approaches and strategies are used to solve the regression problem, which are implemented using the Random Forest, Feed Forward Neural Network, and Recurrent Neural Network models. To train the models, flow curves of different steels as well as parameters such as the yield strength and the tensile strength are used. In order to investigate the influence of the amount, scatter, and noise of the available data on the prediction quality and robustness of the different approaches and models, a synthetic data set is created by a perturbation of existing flow curves. In the application the trained model can be used to generate a yield curve from generic or batch-related characteristic values which can be used, for example, within a FEM calculation.



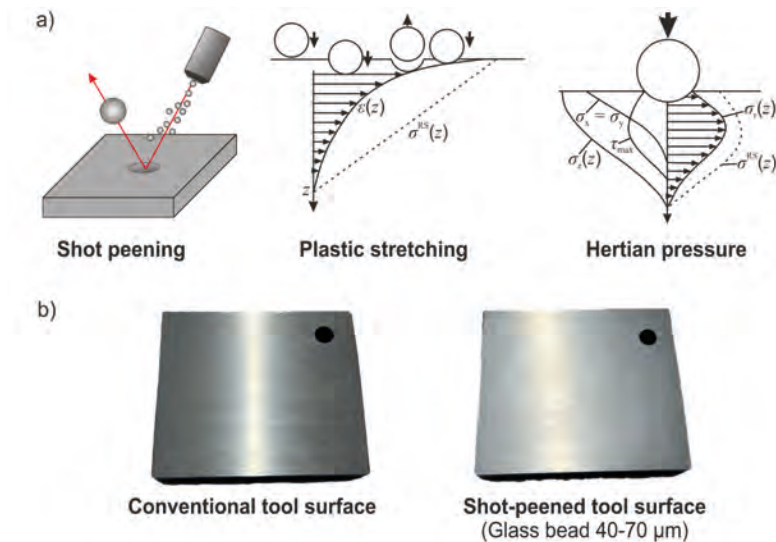
Implementation of Machine Learning in material characterization

## 2.4.9 Reduction of Tool Wear by Shot Peening

Funding  
Contact

Recimp  
Fabian Maaß M. Sc.

In industrial manufacturing processes the functional and guidance surfaces of forming tools are exposed to high loads. An early failure of the tools leads to associated maintenance, consumes additional resources, and affects the production process and product quality. By surface treatment of the tool guidance surfaces in a shot peening process, the service life of the tools can be significantly increased. An analysis of the influence of shot-peened surfaces on the wear resistance of tool surfaces is the subject of this project in cooperation with Faurecia Autositz GmbH. The influence of shot peening on the surface primarily induced near-to-surface compressive residual stresses which suppresses the initiation of cracks as a result of the tool load and significantly increases the service life of the component. In addition to the influence of residual stresses, the influence of the shot peening process on the geometry, surface quality, material hardness, and wear resistance is analyzed as part of the project.



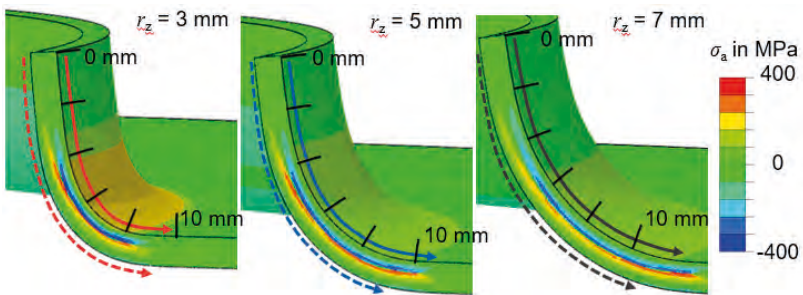
a) Shot peening to generate near-to-surface compressive residual stresses b) Processed tool surfaces

## 2.4.10 Residual Stresses in Welded Connections

Funding  
Contact  
Status

ReCIMP  
Florian Weber M. Sc.  
Completed

Motivated by circumferential cracks in welded sheet-tube joints, this project of the Research Center for Industrial Metal Processing investigated the influence of the manufacturing process on the residual stress state. Simulations of the drawn collars showed a significant influence of the residual stress state by the drawing radius and the collar height. With increasing collar height it was possible to introduce residual compressive stresses that counteracted crack initiation. The numerical results were validated by means of X-ray diffraction (XRD). In addition, a potential application of a component in an exhaust system was analyzed. For this purpose, the welded joints were subsequently heat treated at 800 °C. XRD measurements carried out showed an almost complete reduction of the residual stresses in the material. This made it possible to exclude the forming-induced residual stresses as the cause of the crack formation.



Residual stress in axial direction as a function of the drawing radius

We gratefully acknowledge the funding of our research projects by:



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German Research Foundation

**FORVIA**  
·faurecia



Further Activities

03



## 3 Further Activities

### 3.1 Awards

Chief Engineer Dr. Till Clausmeyer receives the International Karl-Kolle-Prize 2023

The German Metal Forming Association (AGU) honored the Chief Engineer of the Institute of Forming Technology and Lightweight Components, Dr. Till Clausmeyer, with the international Karl-Kolle-Prize 2023 for his many years of research work in forming technology. The prize committee particularly recognized collaborations with scientists and companies from abroad. The prize is endowed by the KARL KOLLE Foundation, which is dedicated to projects in the fields of education and training, science and research, and social welfare.

On August 31, 2023, a ceremony was held to celebrate the awarding of the prize at the IUL. For this joyful occasion, the Rector of TU Dortmund University, Prof. Manfred Bayer, visited the institute. Prof. Winfried Pinninghoff and Benedikt Kummer, members of the foundation's Board of Trustees, Heike Marzen, Managing Director of Wirtschaftsförderung Dortmund, and participants from the KARL-KOLLE-STIFTUNG were among the guests. Prof. Matthias Liewald, Chairman of the AGU in Stuttgart, had handed over the prize in May 2023.



Prof. Tekkaya (Director of the IUL), laureate Dr. Clausmeyer with family, Prof. Pinninghoff (Chairman of the Board of Trustees of the KARL-KOLLE-Stiftung), Prof. Bayer (Rector of TU Dortmund University)

## ICFG International Paper Prize 2023

Robin Gitschel, research associate of the Institute of Forming Technology and Lightweight Components, was awarded the “ICFG International Paper Prize 2023” at the 56th Plenary Meeting of the International Cold Forging Group (ICFG) which took place in Ankara from September 10-13, 2023. Since 1998, the prize has been awarded annually to young scientists for outstanding research results in the field of cold forging.

Mr. Gitschel received the prize for his research on damage evolution in cold forging. Using a novel modeling approach based on evolution equations to describe void nucleation, void growth, and void closure as well as a parameter identification scheme based on scanning electron microscopic measurements on forward rod extruded parts, damage distributions in cold-forged components can be predicted precisely. With the help of this simulation approach, cold forging sequences can be designed in a damage-controlled manner to produce parts with increased product performance during service life.



Robin Gitschel, IUL, and Prof. Dr.-Ing. Thomas Herlan, ICFG President  
Photo: Karl Grötzingler

## Eike Hoffmann receives Young Researcher Award 2023 of the JSTP

During the 14th International Conference on the Technology of Plasticity (ICTP), IUL research associate Eike Hoffmann was awarded the Young Researcher Award (under the age of 35 years) of the Japan Society for the Technology of Plasticity (JSTP) for his excellent publication and presentation on the topic of kinematic profile bending with partial heating. Alongside Mr. Hoffmann, two other international scientists received this award. This year's ICTP took place in Mandelieu-la-Napoule, France, from September.24 – 29. The price was awarded for the first time.



Award winner Eike Hoffmann receiving the Young Researcher Award

The price has been established at the request of Prof. Taylan Altan who gave back his gold medal in order to promote human resources in the field of forming technologies. He had been awarded this medal by the JSTP in 1996 for his work in the field of research and development in the area of precision forging. Due to this, the JSTP established the Young Researcher Award, presenting gold medals to each winner. The gold medals were produced using the gold of Prof. Altan's original medal.

## 3.2 Events

### Launch of the Competence Center for Digital Production Technologies

On March 29, 2023, the Competence Center for Digital Production Technologies at TU Dortmund University was inaugurated during a festive kick-off event. The event took place in the University's Rudolf Chaudoire Pavilion premises on Campus South. In future, the competence center will offer a direct transfer of results from science to industry, a platform for joint research and development as well as numerous networking and training opportunities.

Prof. A. Erman Tekkaya explained at the launch of the competence center: "Companies are dependent on innovation to master current challenges such as those arising from technological change, the climate crisis, and the trend



(from left to right): Prof. Manfred Bayer (Rector of TU Dortmund University), Prof. Norbert Kockmann (Equipment Design - Scientific Advisory Board), Prof. Andreas Hoffjan (Corporate Accounting and Controlling - Scientific Advisory Board), Alessandro Selvaggio (Managing Director of the Competence Center), Wolfgang Heidrich (Aluminium Deutschland - Association Advisory Board), Heike Marzen (Dortmund Economic Development Agency - Association Advisory Board), Prof. A. Erman Tekkaya (Institute for Forming Technology and Lightweight Construction - Scientific Advisory Board), Dr. Lukas Kwiatkowski (Otto Fuchs - Industry Advisory Board), Adolf Edler von Graeve (KIST Germany - Industry Advisory Board), and Frank Grützenbach (Dortmund Economic Development Agency - Association Advisory Board). Photo: Oliver Schaper/TU Dortmund

towards deglobalization. However, they often lack the time and, in some cases, the specialists and technical requirements for development projects. This is where the new competence center for digital production technologies comes into play. Small and medium-sized companies from the region will be particularly targeted.”

In addition to the Institute of Forming Technology and Lightweight Construction (IUL) from the Faculty of Mechanical Engineering, the Chair of Management Accounting and Controlling (Prof. Andreas Hoffjan) from the Faculty of Business Administration and Economics and the Equipment Design working group (Prof. Norbert Kockmann) from the Faculty of Biochemical and Chemical Engineering are the founding institutes of the competence center. The Dortmund Economic Development Agency and Aluminium Deutschland e. V. act as an interface for regional companies. OTTO FUCHS KG and KIST e. V., two partners from this particular field of competence, are also involved. The new competence center is part of TU concept GmbH which, among other things, carries out the university’s economic transfer projects. In addition, TU Dortmund University’s Center for Entrepreneurship & Transfer (CET) supports the competence center with seminars and networking events.

The ceremony was opened by words of welcome from the Managing Director of the Dortmund Economic Development Agency, Heike Marzen, the Rector of TU Dortmund University, Prof. Manfred Bayer, and the Director of the IUL, Prof. A. Erman Tekkaya. Numerous representatives from the local industry, associations, and research community also took part in the event.

## Public relations at the IUL

This year, the IUL took part in numerous activities to increase interest in the subject of mechanical engineering and to communicate current research activities to the public.



IUL public relations activities: MinTU workshop (left) and SchnupperUni (right)

Every year, TU Dortmund University invites interested pupils to have a look at various areas of study at the university as part of the SchnupperUni. In 2023, the IUL participated with an interactive event on the topic of resource-efficient forming technology, which includes an exemplary lecture as well as live experiments on the topic. To increase the interest of young female pupils in STEM subjects, the IUL also takes part in specific measures for this target group. On Girls\*Day, which is organized nationwide, the IUL provided insights into mechanical engineering studies in general, as well as current research topics in the field of production technology. The MinTU (“Mädchen in die TU Dortmund”) initiative is a year-round program in which groups of around 15-20 female pupils take part in specific workshops on various STEM subjects. The three-hour events are both informative and interactive. Participants this year were able to design their own tensile specimens and test them until they broke. Afterwards, they were able to experience the pronounced effect of hardening on the formability of steels for themselves using a demonstrator experiment. Over 60 pupils took part in the events mentioned above.

Around 150 visitors of all ages visited the IUL on this year’s TU Dortmund Open Day. They took part in guided tours of the experimental hall in small groups. The history of forming technology was highlighted and current research in the field of forming technology was illustrated with the help of live experiments. Young visitors were able to experience hands-on forming technology thanks to a blacksmith outside the experimental hall and enjoy face painting for kids.



Participants of the 25th anniversary meeting of the Industrial Advisory Board of the IUL

## Meeting of the IUL Industrial Advisory Board

The IUL Industrial Advisory Board was established in 2010 to exchange experiences and new developments in the field of forming technology and lightweight components with partners from industry and research associations at biannual meetings. The impulses from industry enable us at the IUL to focus our research work on industry-relevant problems. In return, the participants benefit from the exchange of current research results. Starting with 20 members, this committee of experts has grown to a number of 28 members over the past 13 years. We are delighted to have long-term participants, some of whom have been with us from the very beginning, as well as new interesting partners. Except for the first corona virus year, two meetings have been held every year. On May 5, 2023, the Industry Advisory Board met for the 24th time. As usual, the participants were first informed by Prof. Tekkaya about current developments at the IUL. This time, there was a particular focus on our activities in the field of Industry 4.0. Especially the topic of artificial intelligence was discussed extensively with all participants afterwards. In a keynote speech, Dr. Weinrich from the German Spring Industry Association also spoke about current challenges in his field.

The 25th anniversary meeting took place on November 10, 2023. For the first time, the meeting of the Industrial Advisory Board was kicked off the evening before with a welcome dinner at Hövel's Hausbrauerei, providing an opportunity for everyone to get to know our new Prof. Yannis Korkolis in a relaxed atmosphere. Prof. Korkolis' participation also brought a second novelty: the 25th meeting was largely held in English. Prof. Tekkaya reported in detail on material characterization at the IUL and Prof. Korkolis supplemented the presentation with an outlook on planned facilities.

Dr. Hammann from TRUMPF Werkzeugmaschinen GmbH & Co. KG took up the words of a member from the last meeting with the not entirely serious title of his keynote speech "AI is not for engineers" and reported on the industrial application of AI at TRUMPF to disprove the statement. As at this year's first meeting, the topic was once more discussed extensively between the participants. The anniversary meeting ended with an obligatory lunchtime snack and we are already looking forward to the next 25 IUL advisory board meetings.

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

#### Memberships of Research Boards

- acatech – Member of the “German Academy of Science and Engineering” (“Deutsche Akademie der Technikwissenschaften”)
- AGU – Member of the “German Metal Forming Association” (“Wissenschaftliche Arbeitsgemeinschaft Umformtechnik”)
- CIRP – Fellow of “The International Academy for Production Engineering”
- DGM – Member of “German Society of Materials Science” („Deutsche Gesellschaft für Materialkunde“)
- EuraSEM – Council Member der „European Society of Experimental Mechanics“
- FOSTA – Member of the Advisory Board of the “German Steel Federation” (“Forschungsvereinigung Stahlanwendung e. V.”)
- GCFG – Member of the “German Cold Forging Group”
- I<sup>2</sup>FG – Chairman and member of the “International Impulse Forging Group”
- ICFG – Member of the “International Cold Forging Group”
- JSTP – Member of the “Japan Society for Technology of Plasticity”
- ReCIMP – Head of „Research Center for Industrial Metal Processing“
- SME – Member of the “American Society of Manufacturing Engineers”
- WGP – Member of the “German Academic Society for Production Engineering” (“Wissenschaftliche Gesellschaft für Produktionstechnik”)

#### Journals/Editorship

- Chairman of the Advisory Member of the Standing Advisory Board of the “International Conference on Technology of Plasticity” (ICTP)
- Deputy Editor, “Elsevier Series in Plasticity of Materials”
- Editor-in-Chief, “Advances in Industrial and Manufacturing Engineering (AIME)” (Elsevier)
- Member of the Advisory Board, “Journal for Economic Factory Operation” (ZWF) (“Zeitschrift für wirtschaftlichen Fabrikbetrieb“)
- Member of the Editorial Board, “Automotive Innovation” (Springer)
- Member of the Editorial Board, “CIRP Journal of Manufacturing Science and Technology” (Elsevier)

#### Further Activities

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

#### In Scientific Committees

- AiF – German Federation of Industrial Research Associations (“Arbeitsgemeinschaft industrieller Forschungsvereinigungen ‘Otto von Guericke’ e. V.”)
- DFG – German Research Foundation
- ESF College of Expert Reviewers
- The Ohio State University, USA
- University of Duisburg-Essen, Germany
- University of New Hampshire, USA
- University of Waterloo, Canada

#### For Journals

- Acta Materialia
- Additive Manufacturing
- Additive Manufacturing Letters
- Advanced Manufacturing Technology
- Advances in Industrial and Manufacturing Engineering
- Applied Mathematical Modelling
- Archive of Applied Mechanics

- ASME – Journal of Manufacturing Science and Engineering
- Automotive Innovation
- CIRP Annals – Manufacturing Technology
- Computational Materials Science
- Computer Methods in Applied Mechanics and Engineering
- Energy Reports
- Engineering Applications of Artificial Intelligence
- Engineering Computations
- Engineering Fracture Mechanics
- Engineering Research (“Forschung im Ingenieurwesen“)
- Engineering with Computers
- HTM Journal of Heat Treatment and Materials
- International Journal for Numerical Methods in Engineering
- International Journal of Advanced Manufacturing Technology
- International Journal of Damage Mechanics
- International Journal of Machine Tools and Manufacture
- International Journal of Material Forming
- International Journal of Materials and Product Technology
- International Journal of Mechanical Engineering Education
- International Journal of Mechanical Sciences
- International Journal of Mechanics and Materials
- International Journal of Precision Engineering and Manufacturing
- International Journal of Precision Engineering and Manufacturing – Green Technology
- International Journal of Solids and Structures
- Journal Material Characterization – An International Journal on Materials Structure and Behavior
- Journal of Applied Mathematical Methods
- Journal of Computational and Applied Mathematics
- Journal of Manufacturing Processes
- Journal of Manufacturing Science and Engineering
- Journal of Material Engineering and Performance
- Journal of Materials Processing Technology
- Journal of Mechanical Engineering

- Journal of Pressure Vessel Technology
- Journal of Process Control
- Journal of Production Engineering
- Manufacturing Letters
- Materials
- Materials & Design
- Materials and Manufacturing Processes
- Materials Chemistry and Physics
- Materials Science and Engineering A
- Measurements
- 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 - Journal for economic factory operation (“Zeitschrift für wirtschaftlichen Fabrikbetrieb”)



International Exchange

04



## 4 International Exchange

### Chong Zhang

Chong Zhang, PhD student from Xi'an Jiaotong University in China, working in the group of Prof. Yanshan Lou, is visiting the IUL as a guest researcher from February 2023 to January 2024. During his research stay in the Profile and Sheet Metal Forming Department, Mr. Zhang is working on the characterization and modeling of ultra-high-strength steel and high-strength aluminium alloys at different stress states, taking the Bauschinger effect into account. As part of his work, he uses the in-plane torsion test to characterize the flow curves and the Bauschinger effect under simple shear and compares the results with other reverse loading tests such as uniaxial tension-compression



Photo (from left to right): Heinrich Traphöner, Chong Zhang, A. Erman Tekkaya, and Fabian Stiebert

and uniaxial compression-tension tests. The differences in mechanical properties (i.e. Bauschinger effect, permanent softening, etc.) between different load sequences are investigated for both type of materials. Moreover, a comprehensive and user-friendly constitutive model will be developed to model the evolution of yield surface under both proportional and non-proportional loadings.

### Cooperation with the University of Sheffield

As part of a cooperation with the University of Sheffield, Luke Jones, who recently earned his PhD, visited the IUL in Dortmund from May 22-28, 2023. During his stay he carried out high speed blanking experiments (HGSS) on electrical sheets. The experiments aim at determining the influence of the increased cutting speed during HGSS



Luke Jones

(up to 11 m/s) on the fracture behavior, the influence of damage in the region of the cut, and the geometrical quality of the cut edges. Special demands on the process result from the low sheet thickness of 0.2 to 0.5 mm, resulting in only 2-5 grains over the sheet thickness. The stay in Dortmund as well as a one-week research stay in Sheffield were financed by the Royal Society.

## Kaarel Siimut

From June 5 to July 21, 2023, Kaarel Siimut from the DTU (Technical University of Denmark) was a guest at IUL as part of his doctoral exchange program. His Ph.D. is supervised by Prof. Chris Valentin Nielsen at DTU and is being developed in collaboration with the company Grundfos. In the context of his



Kaarel Siimut

doctoral thesis, Kaarel Siimut investigates the closed-loop controlled setting of the height of cups through ironing with a flexible punch. A novel as well as innovative concept here is that the diameter of the flexible punch can be varied during the ironing step. This allows for a targeted variation in the thinning of the cup wall thickness, resulting in different final cup heights after the ironing process. To implement this new technology both control concepts and the implementation of

the actuator, i.e. the flexible punch, need to be developed. For this purpose, Kaarel Siimut was in close contact with Prof. Tekkaya and the IUL's Profile and Sheet Metal Forming Department.

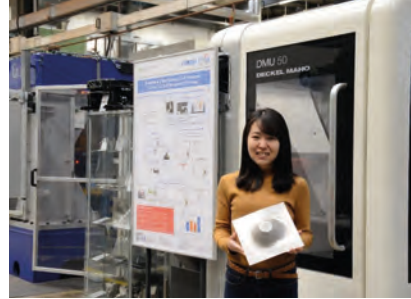
## Prof. Paulo A. F. Martins

Prof. Paulo Martins, Instituto Superior Técnico, Technical University of Lisbon, visited the IUL in June 2023. During his stay he taught analytical methods in forming technology, in particular the application of slip line theory. He consulted the Research Center for Industrial Metal Processing (ReCIMP) with his profound expertise on up-set bulge forming of tubes. Remedies were discussed to avoid initial cracks under pressure, which were caused by the forming operation. Furthermore, he worked with the IUL staff on a method for the analytical prediction of the part geometry in continuous composite extrusion of aluminum and polymer.

## Alexander von Humboldt Fellowship Holder Dr. Shiori Gondo

Granted by the Alexander von Humboldt Foundation (AvH), Dr. Shiori Gondo from the National Institute of Advanced Industrial Science and Technology (AIST) is conducting postdoctoral research at IUL from July 1, 2023, until June 30, 2025. Her research focuses on Incremental Sheet Forming (ISF) with the

aim of suppressing void formation and enhancing the formability and product performance of high-strength steel components. During her doctoral research at Waseda University in Tokyo she developed expertise in forming technologies by investigating the wire drawing process. Subsequently, she continued her research career at AIST where she conducted investigations into the spinning process. Due to her remarkable work she is an established

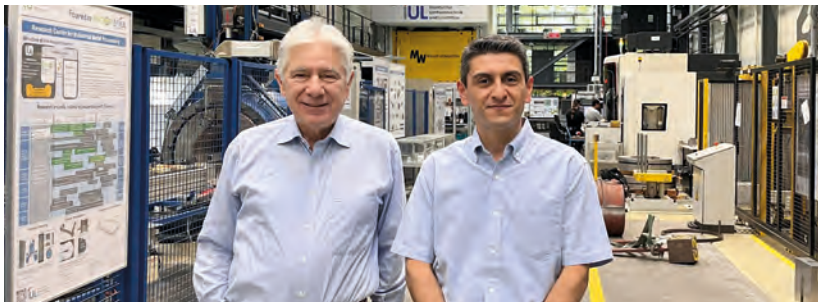


Dr. Shiori Gondo

and well-known expert in the scientific forming community. Currently, she is carrying out her research in close collaboration with IUL members of the Department of Non-Conventional Processes

### Prof. Saeed Farahani

Prof. Saeed Farahani from Clemson University (formerly Cleveland University) visited the IUL from July 3 to August 16, 2023. Prof. Farahani is an expert in supercritical fluids, plastics, and composite materials. His travel and stay was granted by the German Research Foundation (DFG) according to project number 528238310 for establishing the collaborative project on 3D-Multi-functional Sandwich Structures. During his stay in Dortmund he held three workshops on the 'principles of supercritical fluid-assisted injection molding', 'hybrid manufacturing', and 'networked manufacturing'. Several preliminary experiments for ongoing cooperation ideas were successfully carried out during his fruitful visit and new ideas for further cooperation and investigations were also initiated.



Prof. A. Erman Tekkaya and Prof. Saeed Farahani

## Visit of Prof. Yoshinori Yoshida at the IUL

From September 18 to 22, 2023, Prof. Yoshinori Yoshida, Gifu University, Japan, was a guest at the IUL. Prof. Yoshida is the director and coordinator of the exchange program “G-CADET”. The aim of this program, which was presented during his visit to the IUL, is to expand international cooperation in engineering sciences with Japan. This was also implemented in concrete terms so that at the turn of the year two mechanical engineering students of TU Dortmund University traveled to Japan for a 2-month research stay and also a Japanese student could visit the IUL for two months to conduct research in the field of additive manufacturing.



Presentation of the G-CADET program by Prof. Yoshida on September 21, 2023 at the IUL

## Prof. Kaan Inal

Prof. Kaan Inal, head of the Computational Mechanics Research Group at the University of Waterloo in Canada, continued his group’s collaboration with the IUL. He contributes to the topics of modelling and characterization of damage in forming technology as a Mercator Fellow in TRR 188. During two visits in spring and winter 2023, Prof. Inal presented his latest research results on modeling manufacturing processes with machine learning and the failure behavior of aluminum alloys. IUL co-workers Jan Gerlach, Dr. Till Clausmeyer, and Prof. A. Erman Tekkaya published a joint article in the journal “Manufacturing Letter” on the prediction of the influence of voids on the stiffness and strength of bent sheet metal components. Research in this area will continue during further visits in 2024



Prof. Kaan Inal and Prof. A. Erman Tekkaya during his first visit in 2023

## Théo Duchateau

Over Christmas 2023 (December-January), Mr. Théo Duchateau from the French National Centre for Scientific Research in France visited the IUL. As part of his doctorate, Mr. Duchateau is investigating the influence of preceding heat treatment and temperature evolution on the oxidation of aluminum chips during chip extrusion. The resource-efficient process is used to recycle aluminum chips directly into profiles without the energy-intensive step of remelting. The aim is to determine the effects of the temperature history on the formation of different oxide phases such as aluminum oxide or magnesium oxide, which influence the welding of the chips during the process. The tests were carried out on a 2.5 MN extrusion press. Subsequently, the resulting oxide concentration is evaluated by means of electron probe microanalyser (EPMA) and scanning electron microscope (SEM). The knowledge gained can be used to explain the physical mechanisms that take place during the welding of the aluminum chips and the process can be designed with regard to improved product properties.



Guest scientist Théo Duchateau pressing chip-based profiles on the 2.5 MN press.

Moreover, the IUL welcomed the following international students in 2023:

- Erin Weiss, University of Tulsa, USA
- Carter Taylor, Ohio State University, USA
- Ian Campbell, Ohio State University, USA
- Shuma Minoura, Gifu University, Japan



Technical Equipment

05



## 5 Technical Equipment

### Presses

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

### Further Forming Machines

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

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

### Additive Manufacturing Machines

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

### Material Testing Machines

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

### Measurement Technique and Electronics

- 2D laser position sensor, scanCONTROL 3012-50/BL by Micro-Epsilon
- 3D coordinate measurement machine, PRISMO VAST 5 HTG by Zeiss (in cooperation with the Institute of Machining Technology, TU Dortmund University)
- 3D profilometer, VR-5200 by Keyence
- 3D video measuring system, A250 by Optomess

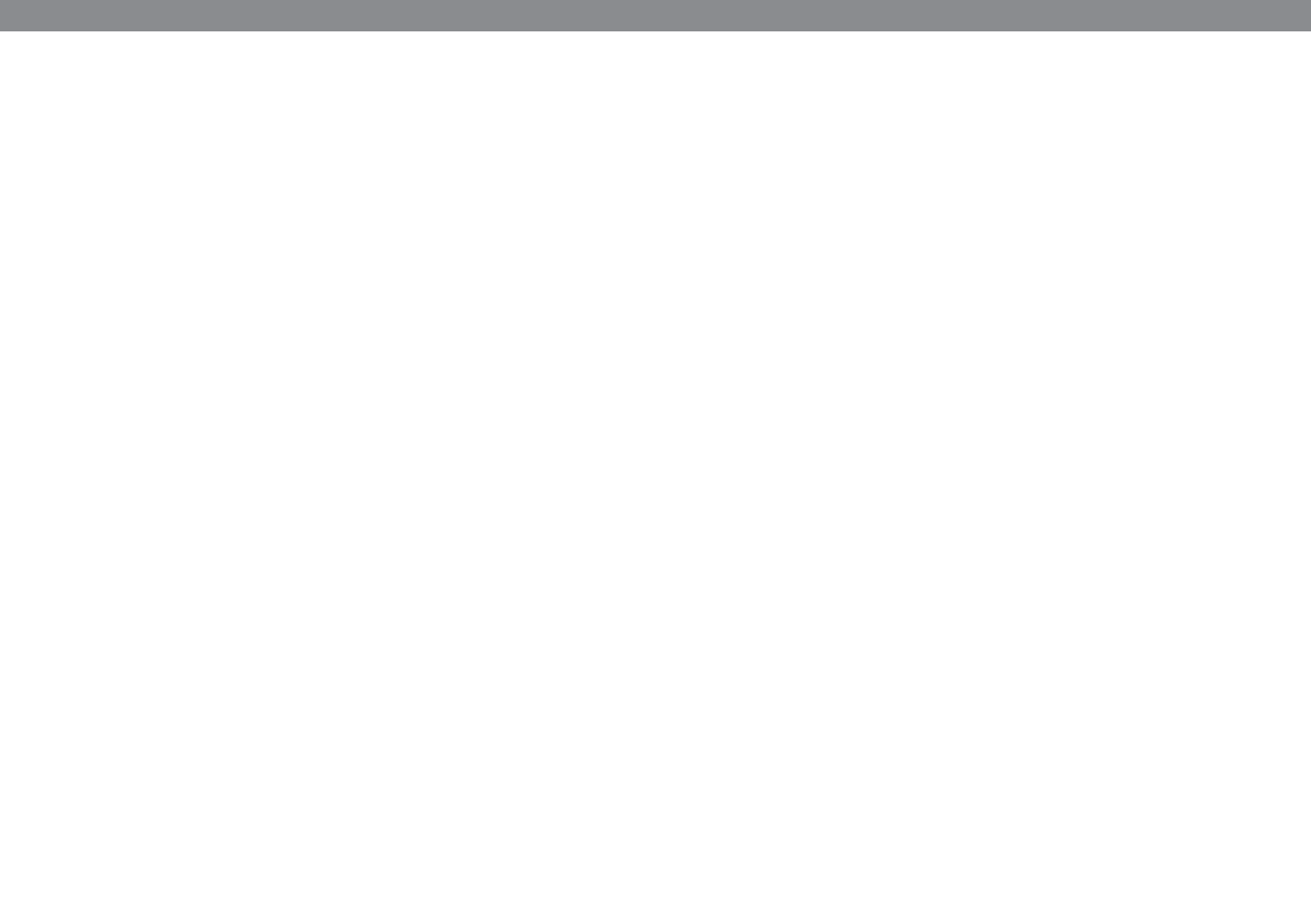
- 3MA-II measurement system by Fraunhofer IZFP
- Density measurement system, IMETER V6 by MSB Breitwieser MessSysteme
- Digital oscilloscopes with 4 channels (HDO6104A and Waverunner 104 MX by LeCroy, TDS420A by Tektronix)
- Hardness tester, Diatestor 2 RC/S by Wolpert
- Infrared camera, Infratec VarioCam HD head 680 S by Infratec
- Infrared measuring device, PYROSKOP 273 C
- Large volume SEM, Mira XI by Visitec (in cooperation with the Institute of Machining Technology and the Chair of Materials Technology, TU Dortmund University)
- Laser extensometer for universal testing machines, laserXtens 2-120 HP/TZ by ZwickRoell
- Laser-based photon doppler velocimeter for the measurement of high workpiece velocities RIO1074-8-00-3 by Rio
- Laser surface velocimeter for non-contact velocity measurement, LSV-200 by Polytec
- Light optical microscope, adapted for polarization, Axio Imager.M1m by Zeiss
- Optical 3D deformation analysis: 4x ARAMIS (2x 5M + 1x 4M + 1x 2M) and 1x ARGUS by GOM
- Optical 3D digitizer: 2x ATOS Triple Scan and 1x TRITOP by GOM
- Optical 3D motion analysis, 1x PONTOS 4M by GOM
- Optical frequency domain reflectometer, space- and time-resolved measurement of temperature and strain, ODISI-B10 by Polytec
- Pressure measurement system using thin film tactile pressure sensors, I-Scan System by Tekscan
- Pyrometer, near infrared and multi-wavelength, 3 pc. (Metis M308, Metis M316 and Metis M318) by Sensortherm
- Residual stress measurement by means of hole drilling technique and Electronic Speckle Pattern Interferometry (ESPI), Prism by Stresstech
- Residual stress measurement by means of hole drilling technique and strain gauge measurement, Milling Guide RS-200 by Micro-Measurements
- Tabletop SEM-EDX: Coxem EM-30 PLUS by RJL Micro & Analytic
- Thermal imaging camera, thermoIMAGER TIM M-1 by Micro-Epsilon
- Thickness measuring device, CL 304 by Krautkramer
- Ultrasonic thickness sensor, 38DLPLus by Olympus

- X-ray diffractometer for measuring residual stresses, Xstress 3000 by Stresstech

## Miscellaneous

- Autonomous mobile robot, LD-90 by Omron
- Belt grinding machine, PB-1200-100S by Baier
- CNC turning machine, NEF 400 by DMG MORI
- DC-power supply, LAB/HP 4020 by ET-System
- Electrolytic polishing and etching machine, Kristall 650 by Stresstech
- Encapsulated postprocessing cabin for additive manufactured parts, ENESKApostpro by joke Technology
- Etching and polishing station, LectoPol-5 by Struers
- High-frequency generator, 10 kW, Axio 10/450 by Hüttinger
- High-performance metal circular saw, AL 380 by Häberle
- High-temperature chamber furnaces, up to 1200 °C and 160 l volume, N60/65 HA, N120/85 HA and N161 by Nabertherm
- Hydraulic power units and pressure intensifiers up to 4000 bar (3x)
- Hydrostatic roller burnishing tools with and without couplings for automatic tool change, HG6, HG13 and HG19 by Ecoroll
- Industrial robots, 3x 6-axes robot (KR 5 sixx R650, KR 90 R3700 prime K and KR 30-3) by KUKA
- Laser processing center, LASERCELL TLC 1005 by Trumpf
- Measuring rack, HP-4-2082 by Boxdorf
- Medium-frequency generator, 40 kW with coax transformer, TruHeat 3040 and 7040 by Trumpf
- Mitring band sawing machines, HBS 265 DG by Klæger
- Power source for resistance welding, 500 kW, Genius HWI436WA by ProCon / Harms & Wende
- Roll seam welding machine, UN 63 pn by Elektro-Schweißtechnik Dresden
- Several machines for machining purposes
- Tabletop cut-off machine Discotom-100 by Struers (in cooperation with the Institute of Machining Technology, TU Dortmund University)
- Tensile testing punch press, 1200 kN, ZS1200CN by Schütz + Licht
- Tensile test specimen grinder, PSM 2000 by Schütz + Licht





Kooperationen | Cooperations

06

## Kooperationen | Cooperations

Auf diesem Wege möchten wir uns für die vielfältige Zusammenarbeit im Jahr 2023 bedanken, ohne die unser gemeinsamer Erfolg nicht möglich wäre.

### Industriebeirat des IUL | IUL Industrial Advisory Board

Das Gremium des Industriebeirates vermittelte auch im Jahr 2023 wichtige Impulse hinsichtlich des industriellen Forschungsbedarfes. An dieser Stelle möchten wir uns für diese wertvolle Zusammenarbeit bedanken.

*In 2023, the Industrial Advisory Council provided yet again significant input regarding the need for research from an industrial point of view. We would like to take this opportunity to express our gratitude for this valuable cooperation.*

- Dr. Eisso Atzema (Hans Mulder), Tata Steel Research & Development Product Application Centre
- Dr. Denise Beitelschmidt, Zwick GmbH & Co. KG
- Dr. Nicolas Berger, Festo SE & Co. KG
- Gerhard Bürstner, Ing.-Büro Gerhard Bürstner
- Marius Fedler, Kunststoff-Institut für die mittelständische Wirtschaft NRW GmbH
- Patrick Großhaus, Egon Grosshaus GmbH & Co. KG
- Dr. Gerhard Hammann, TRUMPF Werkzeugmaschinen GmbH & Co. KG
- Dr. Sebastian Heibel, Mercedes-Benz AG

*At this point we would like to express our gratitude to the large number of various cooperation partners in 2023 which have added to our joint success.*

- Dr. Jens Heidenreich, PHOENIX FEINBAU GmbH & Co. KG
- Wolfgang Heidrich, Aluminium Deutschland e. V.
- Jörg Höppner, Verband Metallverpackungen e. V.
- Daniel Hornauer, Faurecia Emissions Control Technologies, Germany GmbH
- Bernhard Jacobs, Industrieverband Blechumformung e.V. (IBU)
- Dr. Stefan Keller, Speira GmbH
- Dr. Lutz Keßler, ThyssenKrupp Steel Europe AG
- Dr. Thomas Kloppenborg, OTTO FUCHS KG
- Bob Knauff, CTM-do GmbH
- Dr. Roald Lingbeek, Autoliv Inc.
- Dr. Ingo Neubauer, simufact engineering GmbH
- Franz-Bernd Pauli, Franz Pauli GmbH & Co. KG
- Rainer Salomon, Forschungsvereinigung Stahlanwendung e. V. (FOSTA)
- Prof. Karl Schweizerhof, DYNAmore GmbH
- Dr. Hosen Sulaiman, Faurecia Autositze GmbH

- Mario Syhre, GKN Driveline Deutschland GmbH
- Adolf Edler von Graeve, KIST Kompetenz- und Innovationszentrum für die StanzTechnologie Dortmund e. V.
- Patrick Vonmüllenen, Feintool Technologie AG
- Dr. Andres Weinrich, Verband der Deutschen Federnindustrie e. V. (VDFI)

## Universitäre Kooperationen auf nationaler Ebene | University cooperations at national level

- Fachgebiet Metallische Werkstoffe, Institut für Werkstoffwissenschaften und -technologien, Technische Universität Berlin
- Fachgebiet Werkstoffprüftechnik, Technische Universität Dortmund
- Fachhochschule Südwestfalen
- Fraunhofer-Institut für Werkstoffmechanik, Chemnitz
- Fraunhofer-Institut für Werkzeugmaschinen und Umformtechnik, Chemnitz
- Fraunhofer-Institut für Werkstoffmechanik, Freiburg
- Gemeinschaftslabor für Elektronenmikroskopie, Rheinisch-Westfälische Technische Hochschule Aachen
- Institut für Angewandte Materialien – Werkstoffkunde, Karlsruher Institut für Technologie (KIT)
- Institut für Aufbereitungsmaschinen und Recyclingsystemtechnik, Technische Universität Bergakademie Freiberg
- Institut für Bildsame Formgebung, Rheinisch-Westfälische Technische Hochschule Aachen
- Institut für Eisenhüttenkunde, Lehr- und Forschungsgebiet für Werkstoff- und Bauteilintegrität, Rheinisch-Westfälische Technische Hochschule Aachen
- Institut für Leichtbau und Kunststofftechnik, Technische Universität Dresden
- Institut für Mechanik der Bauwissenschaften, Universität Duisburg-Essen
- Institut für Mechanik, Technische Universität Dortmund
- Institut für Produktionstechnik und Umformmaschinen, Technische Universität Darmstadt
- Institut für Umformtechnik, Universität Stuttgart
- Institut für Werkzeugmaschinen und Betriebswissenschaften, Technische Universität München
- Laboratorium für Werkstoff- und Fügetechnik, Universität Paderborn
- Lehrgebiet Konstruktions- und Fertigungstechnik, Hochschule Hamm-Lippstadt
- Lehrstuhl für Automatisierungs- und Regelungstechnik, Christian-Albrechts-Universität zu Kiel
- Lehrstuhl Baumechanik, Technische Universität Dortmund
- Lehrstuhl Fertigungstechnik, Universität Duisburg-Essen
- Lehrstuhl für Konstruktion und Fertigung, Brandenburgische Technische Universität Cottbus-Senftenberg

- Lehrstuhl für Reliability Engineering, Technische Universität Dortmund
- 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
- Leibniz-Institut für Polymerforschung Dresden
- Max-Planck-Institut für Eisenforschung GmbH, Düsseldorf
- Professur für Baumechanik, Universität der Bundeswehr München
- Professur Virtuelle Fertigungstechnik, Technische Universität Chemnitz
- Professur Werkstoff- und Oberflächentechnik, Technische Universität Chemnitz
- Professur Werkstoffwissenschaft, Technische Universität Chemnitz
- wbk Institut für Produktionstechnik, Karlsruher Institut für Technologie
- Werkzeugmaschinenlabor, Rheinisch-Westfälische Technische Hochschule Aachen

### Universitäre Kooperationen auf internationaler Ebene | University cooperations at international level

- Department of Automotive Engineering, Clemson University, USA
- 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 Engineering, University of Sheffield, UK
- Department of Mechanical Science and Engineering, Hiroshima University, Higashi-Hiroshima, Japan
- École Nationale Supérieure d'Arts et Métiers (ENSAM), ParisTech, Paris, France
- George W. Woodruff School of Mechanical Engineering, Georgia Tech, Georgia, USA
- Institut de Chimie et des Matériaux Paris-Est, Paris, France
- KAIST – Korea Advanced Institute of Science and Technology, Daejeon, Republic of Korea
- Laboratory of Microstructure Studies and Mechanics of Materials, Arts et Métiers ParisTech (Metz campus), France

- Mechanical Engineering College of Tongji University, Jiading Campus, Shanghai, China
- Nagoya University, Nagoya, Japan
- School of Mechanical Engineering, Xi'an Jiatong University, Xi'an, China
- School of Mechatronics Engineering, Harbin Institute of Technology, Harbin, Heilongjiang, China
- University of Waterloo (Mechanical and Mechatronics Engineering), CA
- Türkisch-Deutsche Universität, Istanbul, Turkey

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

- ACS
- alutec metal innovations GmbH & Co. KG
- apt Extrusions GmbH & Co. KG
- AUDI AG
- AutoForm Engineering Deutschland GmbH
- Autoliv Inc.
- Baoshan Iron & Steel Co. Ltd.
- Benteler International AG
- Bilstein GmbH & Co. KG
- BMW AG
- BÖHLER-UDDEHOLM Deutschland GmbH
- borit Leichtbau-Technik GmbH
- Brand KG
- Bulten AB
- CARL BECHEM GMBH
- CENIT AG
- Centroplast Engineering Plastics GmbH
- C-TEC Constellium Technology Center
- Daimler AG
- Deutsche Edelstahlwerke Specialty Steel GmbH & Co. KG
- DYNAmore GmbH
- ElringKlinger AG
- Erichsen GmbH & Co. KG
- F. W. Brökelmann Aluminiumwerk GmbH & Co. KG
- Festo SE & Co. KG
- Fischerwerke GmbH & Co. KG
- FLORA Wilh. Förster GmbH & Co. KG
- Forvia Faurecia
- Franz Pauli GmbH & Co. KG
- Freudenberg Sealing Technologies GmbH & Co. KG
- FRIMO Group GmbH Composites & Tooling Technologies
- Gebr. Wielpütz GmbH & Co. KG
- Gerhardt AluTechnik GmbH
- GKN Driveline Deutschland GmbH
- Goekeler Messtechnik GmbH
- GSU Schulungsgesellschaft für Stanz- und Umformtechnik mbH
- HAI Extrusion Germany GmbH
- Heggemann AG
- HELLA GmbH & Co. KGaA
- Hexagon AB
- HMT Höfer Metall Technik GmbH & Co. KG
- HoDforming GmbH
- HUECK Extrusion GmbH & Co. KG

- Hydro Aluminium Deutschland GmbH
- Ingenieurbüro Peter Baumgart
- ISPT
- Kirchhoff Automotive GmbH
- Kistler Instrumente AG
- KODA Stanz- und Biegetechnik GmbH
- Kunststoff-Institut Lüdenscheid (KIMW GmbH)
- MATFEM Partnerschaft Dr. Gese & Oberhofer
- MK Metallfolien GmbH
- Mubea Unternehmensgruppe
- NETZSCH – Pumpen & Systeme GmbH
- Novelis Deutschland GmbH
- Otto Fuchs KG
- Outokumpu Nirosta GmbH
- Poynting GmbH
- PWF Aerospace GmbH
- S+C Extrusion Tooling Solutions GmbH
- Salzgitter Mannesmann Forschung GmbH
- Salzgitter Mannesmann Precision Tubes GmbH
- Schnupp GmbH & Co. Hydraulik KG
- Schondelmaier GmbH Presswerk
- Schuler AG
- Schüco
- simufact engineering gmbh
- SMS Group

- SoluteriAL
- SSAB Svenskt Stål AB
- Steitz Präzisionstechnik GmbH
- STURM GmbH
- Tata Steel
- thyssenkrupp Federn und Stabilisatoren GmbH
- thyssenkrupp Nucera
- thyssenkrupp Rasselstein GmbH
- thyssenkrupp Steel Europe AG
- TK Oberfläche GmbH
- TM Lasertechnik GmbH
- transfluid Maschinenbau GmbH
- transvalor S.A.
- Trimet Aluminium SE
- TRUMPF Hüttinger GmbH + Co. KG
- TRUMPF Werkzeugmaschinen GmbH + Co. KG
- Uddeholms AB
- Viessmann Werke GmbH & Co. KG
- voestalpine AG
- voestalpine High Performance Metals Deutschland GmbH
- Vossloh AG
- wefa Westdeutsche Farben GmbH
- Welser Profile Deutschland GmbH
- Weseralu GmbH & Co. KG
- Wilke Werkzeugbau GmbH & Co. KG

- WILO SE
- Zapp Precision Metals GmbH

- ZWEZ – CHEMIE GmbH

In addition, several companies with disclosure agreements.

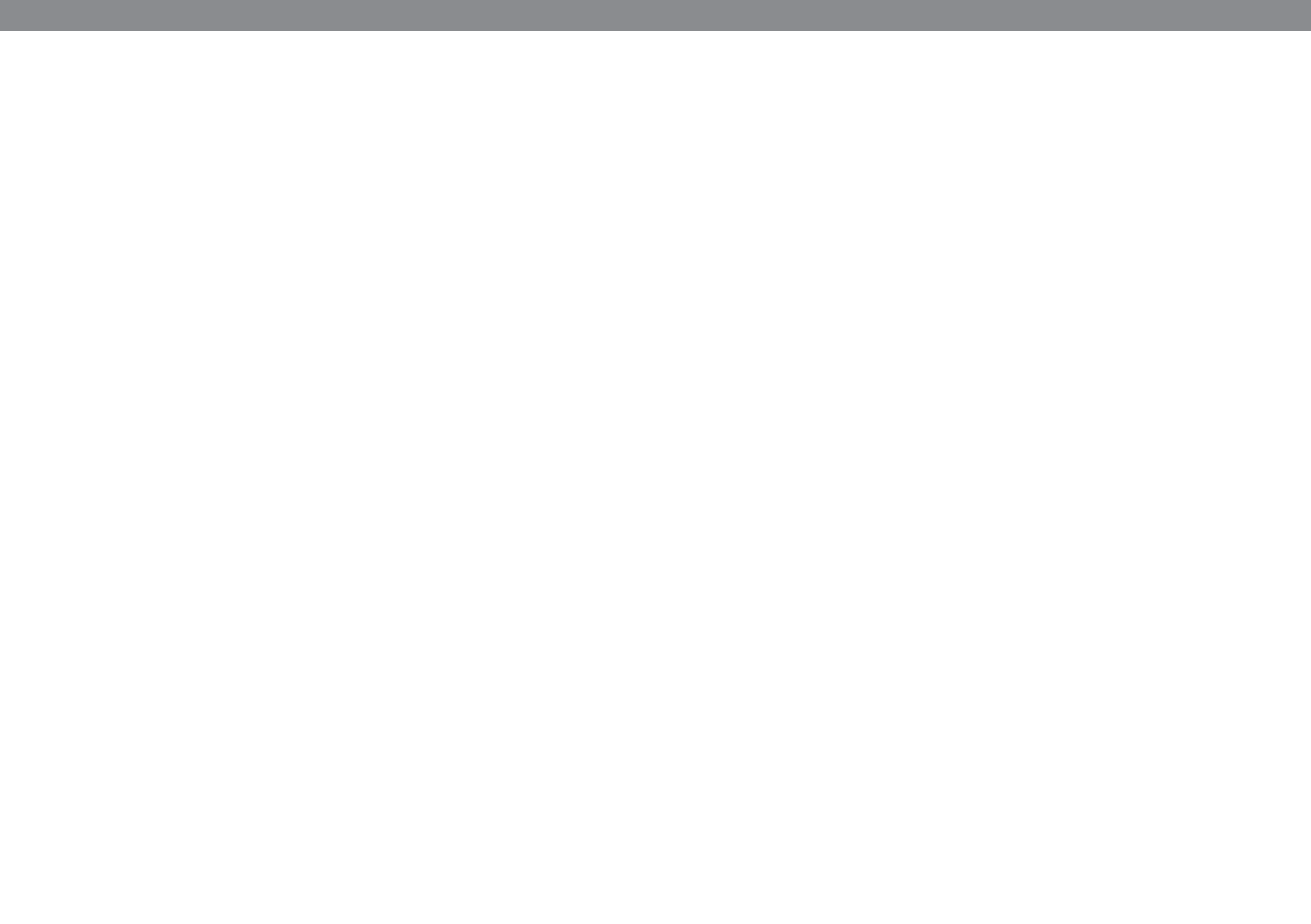
## Verbände | Associations

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

## Stiftungen | Foundations

- Alexander von Humboldt-Stiftung
- KARL-KOLLE-Stiftung
- Stifterverband Metalle e. V.
- Wilo-Foundation





Abgeschlossene Arbeiten | Completed Theses

07

## Abgeschlossene Masterarbeiten<sup>1</sup> | Completed Master of Science Theses<sup>2</sup>

**Agboola, Ololade Emmanuel**

Tekkaya, A. E.; Dardaei, H.

Realisierung von Heißprägestempeln mithilfe eines optimierten hybriden additiv laminierten Werkzeugs

**Realization of Hot Stamping Dies Using an Optimized Hybrid Additive Laminated Tool**

**Badroosian, Darwin**

Tekkaya, A. E.; Stennei, M.

**Simulationsgestützte Untersuchung zur gezielten Eigenschaftsgradierung pressgehärteter Bauteile mit der TemperBox®**

Simulation-based Investigation for Targeted Property Grading of Press-hardened Components with the TemperBox®

**Bazargan, Pedram**

Tekkaya, A.E.; Clausmeyer, T.

Bewertung und Klassifizierung von ultrahochfesten Stählen mit einer Festigkeit von mehr als 0,8 GPa für Anwendungen in der Rohkarosserie

**Evaluation and Classification of Ultra-high-strength Steels with Strength Larger than 0.8 Gpa for Applications in Body-in-white**

**Caspari, Fabian**

Tekkaya, A. E.; Kotzyba, P.

**Untersuchung des Strangpressens mit Aluminium-Polymer-Verbundblöcken**

Investigation of Hot Extrusion with Aluminum-Polymer-Composite billets

**Dobrowolski, Fabian**

Tekkaya, A. E.; Martschin, J.

**Numerische Abbildung des mehrstufigen Presshärtens von 22MnB5 in einem Folgeverbundwerkzeug mit erweiterter Aktorik**

Numerical Simulation of Multi-stage Press Hardening of 22MnB5 in a Progressive Die with Extended Actuator Design

**Gawali, Aniket**

Tekkaya, A. E.; Gitschel, R.

Einfluss anisotroper Verfestigung auf die Leistungsfähigkeit fließgepresster Befestigungselemente

**Anisotropic Strain Hardening Effect in Cold-Forged Fasteners**

**Gerlach, Torben**

Tekkaya, A. E.; Gitschel, R.

**Einfluss von Wärmebehandlungen auf umforminduzierte Schädigung und die resultierende Leistungsfähigkeit**

Effect of Heat Treatment on Forming-induced Damage and Resulting Product Performance

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1 Originaltitel ist fett gedruckt.

2 Original title written in bold.

**Hainmann, Till Sebastian**

Tekkaya, A. E.; Rosenthal, S.

**Eigenstressanalyse an Bauteilen mit verschweißten Blechdurchzügen**

Residual Stress Analysis of Components with Welded Flanged Holes

**Helmus, Philippa**

Tekkaya, A. E.; Rosenthal, S.

**Widerstandsschweißen hybrider Sandwichbleche mit additiv gefertigtem Kern - Herstellung und Charakterisierung**

Resistance Welding of Hybrid Sandwich Sheets with Additively Manufactured Core - Manufacturing and Characterization

**Kandemir, Bünyamin**

Tekkaya, A. E.; Kockmann, N (Fak. Bio- und Chemieingenieurwesen)

**Entwicklung von additiv gefertigten Wärmeübertragern mit numerischer Strömungsuntersuchung und experimenteller Modellvalidierung**

Development of Additively Manufactured Heat Exchangers with Computational Fluid Dynamics and Experimental Model Validation

**Kumar, Aakash Chandra**

Tekkaya, A. E.; Lennemann, P.

Schädigungsmechanismen in Mangan-Bor-Stahl beim Presshärten

**Damage Mechanisms in Boron Steel during Hot Stamping**

**Lashkari, Mohammedjavad**

Tekkaya, A. E.; Hahn, M.

Entwicklung eines numerischen Modells für das Magnetimpulsschweißen von Rohrgeometrien in FORGE

**Development of Numerical Model for Magnetic Pulse Welding of Tubular Geometries in FORGE**

**Lütticke, Tobias**

Tekkaya, A. E.; Martschin, J.

**Prozessnahe Charakterisierung von 22MnB5 durch Warmzugversuche für das mehrstufige Presshärten**

Process-related Characterization of 22MnB5 by Hot Tensile Tests for Multi-stage Press Hardening

**Potnis, Namrata**

Tekkaya, A. E.; Flesch, J.

Walzsimulation mithilfe der „Generalized Plane Strain“-Elementformulierung

**Rolling Simulation with the Aid of „Generalized Plane Strain“ Element Formulation**

**Rennar, Yannik**

Tekkaya, A. E.; Martschin, J.

**Einfluss der thermo-mechanischen Historie beim mehrstufigen Presshärten von 22MnB5 auf die Mikrostruktur und die Produkteigenschaften**

Effect of thermo-mechanical history in multi-stage press hardening of 22MnB5 on microstructure and product properties

**Sapre, Aditya Mahesh**

Tekkaya, A. E.; Kneuper, F.

Auswirkungen der Wärmebehandlung auf die mechanischen Eigenschaften von fließgepressten Bauteilen

**Effects of Heat Treatment on Mechanical Properties of Cold-forged Parts**

**Schaumburg, David**

Tekkaya, A. E.; Martschin, J.

**Entwicklung eines Softsensors zur Vorhersage der Mikrostruktur beim mehrstufigen Presshärten**

Development of a Soft Sensor for Predicting the Microstructure during Multi-stage Press Hardening

**Sundarajan, Praveen Kumar**

Tekkaya, A. E.; Clausmeyer, T.

Analyse des Werkzeugverschleißes und der Schnittkantenqualität beim Stanzen von Elektroblechen

**Analysis of Tool Wear and Sheared Edge Properties in Banking of Electrical Steel**

**Tonfack-Tsobeng, Ramsay Noel**

Tekkaya, A. E.; Martschin, J.

**Regelungsorientierte Berechnung der Abkühlung beim mehrstufigen Presshärten unter Berücksichtigung der Blechdicken- und Temperaturverteilung**

Control-oriented Computation of Quenching in Multi-stage Press Hardening Considering Sheet Thickness and Temperature Distribution

**Yilmaz, Emre**

Tekkaya, A. E.; Martschin, J.

**Mechanische Kennwerte von 22MnB5 nach dem Presshärten mit Kurzzeitaustenitisierung**

Mechanical Properties of 22MnB5 after Press Hardening with Short-term Austenitization



## Abgeschlossene Bachelorarbeiten | Completed Bachelor of Science Theses

**Alattar, Mohamad**

Tekkaya, A. E.; Rethmann, P.

**Quantifizierung des Dehngrenzenabfalls beim Flügelrichten von Ti-6Al-4V Titanstäben**

Quantification of the Yield Point Drop During Wing Straightening of Ti-6Al-4V Titanium Rods

**Gusseck, Lukas**

Tekkaya, A. E.; Martschin, J.

**Regelungsorientierte Berechnung des Gesenkbiegens beim mehrstufigen Presshärten**

Control-oriented Calculation of Die Bending in Multi-stage Press Hardening

**Keyk, Simon**

Tekkaya, A. E.; Traphöner, H.

**Untersuchungen zur Korrelation von Härte und Festigkeit bei hochlegierten Stählen**

Investigations on the Correlation between Hardness and Strength in High-alloyed Steels

**Krimphoff, Dennis**

Tekkaya, A. E.; Kneuper, F.

**Bestimmung des druckabhängigen Fließverhaltens von Mischungen aus Quarzsand und Zirkoniumdioxidgranulat**

Determination of the Pressure-dependent Flow Behavior of Mixtures of Quartz Sand and Zirconium Dioxide Granulate

**Polec, Lenard Adam**

Tekkaya, A. E.; Maaß, F.

**Untersuchung der Martensitumwandlung in SS304 & SS316L mit temperaturgesteuertem kontinuierlichem Biegen unter Spannung**

**Examination of Martensite Transformation in SS304 & SS316L with Temperature-controlled Continuous Bending under Tension**

**Scholz, Linus Adrian**

Tekkaya, A. E.; Hoenen, N.

**Untersuchung des Einflusses von Umformschmierstoffen auf das Verschleißverhalten von Werkzeugen im Stanzprozess**

Investigation of Different Lubricants Regarding the Wear Behavior of Tools in Blanking

**Stegemann, Tim**

Tekkaya, A. E.; Stennei, M.

**Industriennahe Kalibrierung und Validierung des GISSMO-Versagensmodells für den hochfesten niedriglegierten Werkstoff CR800LA zur Prognose von Biegerissen**

Industry-based Calibration and Validation of the GISSMO Failure Model for the High-strength Low-alloyed material CR800LA

**Tunc, Thomas**

Tekkaya, A. E.; Hoenen, N.

**Optimierung von Umformwerkzeugen bezüglich der Spanbildung beim Umformen von Aluminium**

Optimization of Forming Tools Regarding Chip Development during Forming of Aluminum

**Weinert, Ben Farin**

Tekkaya, A. E.; Komodromos, A.

**Numerische Untersuchungen zur Temperaturverteilung bei der Kühlkanalfertigung mittels Laserpulverauftragungsschweißens**

Numerical Investigations on the Temperature Distribution during Cooling Channel Manufacturing by Directed Energy Deposition

## Abgeschlossene Projektarbeiten | Completed Project Theses

**Agboola, Ololade Emmanuel**

Tekkaya, A. E.; Dardaei Joghhan, H.

Einfluss von Prozessparametern des Laserpulverauftrags-schweißens und Laserpolierens auf flache Oberflächen

**Effect of Process Parameters of Laser Metal Deposition and Laser Polishing on Flat Surfaces**

**Araripe Maia, Marina**

Schrage, O.; Grodotzki, J.

Entwicklung einer neuen Methodologie zur Bestimmung der Kantenrissempfindlichkeit bei adiabatisch schwergeschnittenen Blechen

**Development of a New Methodology for Edge Crack Sensitivity Characterization of Adiabatically Blanked Sheets**

**Arslan, Oguzhan**

Tekkaya, A. E.; Grodotzki, J.

**Misconceptions in der Umformtechnik**

Misconceptions in Forming Technology

**Brock, Thorben**

Tekkaya, A. E.; Stiebert, F.; Schulz, O.

**Experimentelle Umsetzung und Bewertung der Spannungsüberlagerung im ebenen Torsionsversuch**

Experimental Implementation and Evaluation of Stress Superposition in the In-plane Torsion Test

**Dickhaus, Friedrich Daniel**

Tekkaya, A. E.; Lennemann, P.

**Spannungsüberlagerung beim Rollformen**

Stress Superposition in Roll Forming

**Elbahbishy, Mohamed**

Tekkaya, A. E.; Hoffmann, E.

Entwicklung einer kyrogenen Kammer für die Materialprüfung bei tiefen Temperaturen

**Design of a Cryogenic Chamber for Material Testing at Low Temperatures**

**Gawali, Aniket**

Tekkaya, A. E.; Bechler, J.

Anwendbarkeit von analytisch bestimmten FLC auf unterschiedliche Stahlfamilien

**Applicability of Analytically Determined FLC to Different Steel Families**

**Gusseck, Lukas**

Tekkaya, A. E.; Weber, F.

**Konstruktion eines Fügwerkzeuges mit integrierter Funktionsüberprüfung zum Innenhochdruckfügen**

Design of a Joining Tool with Integrated Functionality Check for Joining by Hydroforming

**Hanl, David**

Tekkaya, A. E.; Bechler, J.

**Analyse des Einflusses der Mikrostruktur auf die Lebensdauer beim Knickbauchprozess**

Analysis of the Influence of the Microstructure on the Service Life in Upset Bulging

**Hasenau, Alexander**

Tekkaya, A. E.; Dardaei Joghhan, H.

**Ermittlung der Oberflächeneigenschaften von hybriden, additiven gefertigten Lamellenwerkzeuge**

Determination of the Surface Properties of Hybrid Additively Manufactured Laminated Tools

**Kaup, David**

Tekkaya, A. E.; Kamaliev, M.

**Tribologische Bedingungen und deren Einfluss beim kontinuierlichen IH-Aufweiten**

Tribological Conditions and Their Influence During Continuous Internal Pressure Expansion

**Krimphoff, Dennis**

Tekkaya, A. E.; Kneuper, F.

**Steigerung der Verschweißqualität beim Späneextrusionsprozess durch gezielte Werkzeuganpassung**

Increase in Welding Quality during Chip Extrusion through Targeted Tool Customization

**Kropf, Juliana Xenia**

Grodzki, J.; Stennei, M.

**Entwicklung eines numerischen Modells zur Berechnung der Biegesteifigkeit eines Hohlimplantates**

Development of a Numerical Model to Calculate the Bending Stiffness of a Hollow Implant

**Kruip, Theresa**

Tekkaya, A. E.; Grodzki, J.

**Umformtechnische Missverständnisse in den Themengebieten Spannung, Dehnung und Volumenkonstanz**

Forming Technology Misconceptions Related to Stress, Strain, and Volume Constancy

**Kurmangaliev, Sergej**

Tekkaya, A. E.; Bechler, J.

**Erarbeitung eines Prozessfensters für flexible Werkzeuge mit vaporisierenden Aktuator Folien**

Development of a Process Window for Flexible Tools with Vaporizing Actuator Foils

**Polec, Lenard**

Tekkaya, A. E.; Stiebert, F.

**Wirtschaftlichkeitsbetrachtung des ebenen Torsionsversuchs**

Economic Analysis of the In-plane Torsion Test

**Pontis, Namrata Nitin**

Tekkaya, A. E.; Weber, F.; Marín, G.

Numerische Untersuchung zum Innenhochdruckfügen von Aluminium (AA6061) und Polyetheretherketon (PEEK)

**Numerical Investigation on Joining Aluminium (AA6061) to Polyetheretherketone (PEEK) by Hydraulic Expansion**

**Rose, Jan Philipp**

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**Konstruktion eines Fügwerkzeuges mit integrierter Funktionsüberprüfung zum Innenhochdruckfügen**

Design of a Joining Tool with Integrated Functionality Check for Joining by Hydroforming

**Simon, Jakob**

Tekkaya, A. E.; Bechler, J.

**Entwicklung einer zyklischen Prüfvorrichtung knickbauchumgeformter Rohre**

Development of a Testing Device for Up-set Bulge-formed Tubes

**Uyar, Berk**

Tekkaya, A. E.; Lennemann, P.

**Prozessentwicklung zum Rotationszugbiegen von L-Profilen**

Development of a Rotary Draw Bending Process for L-sections

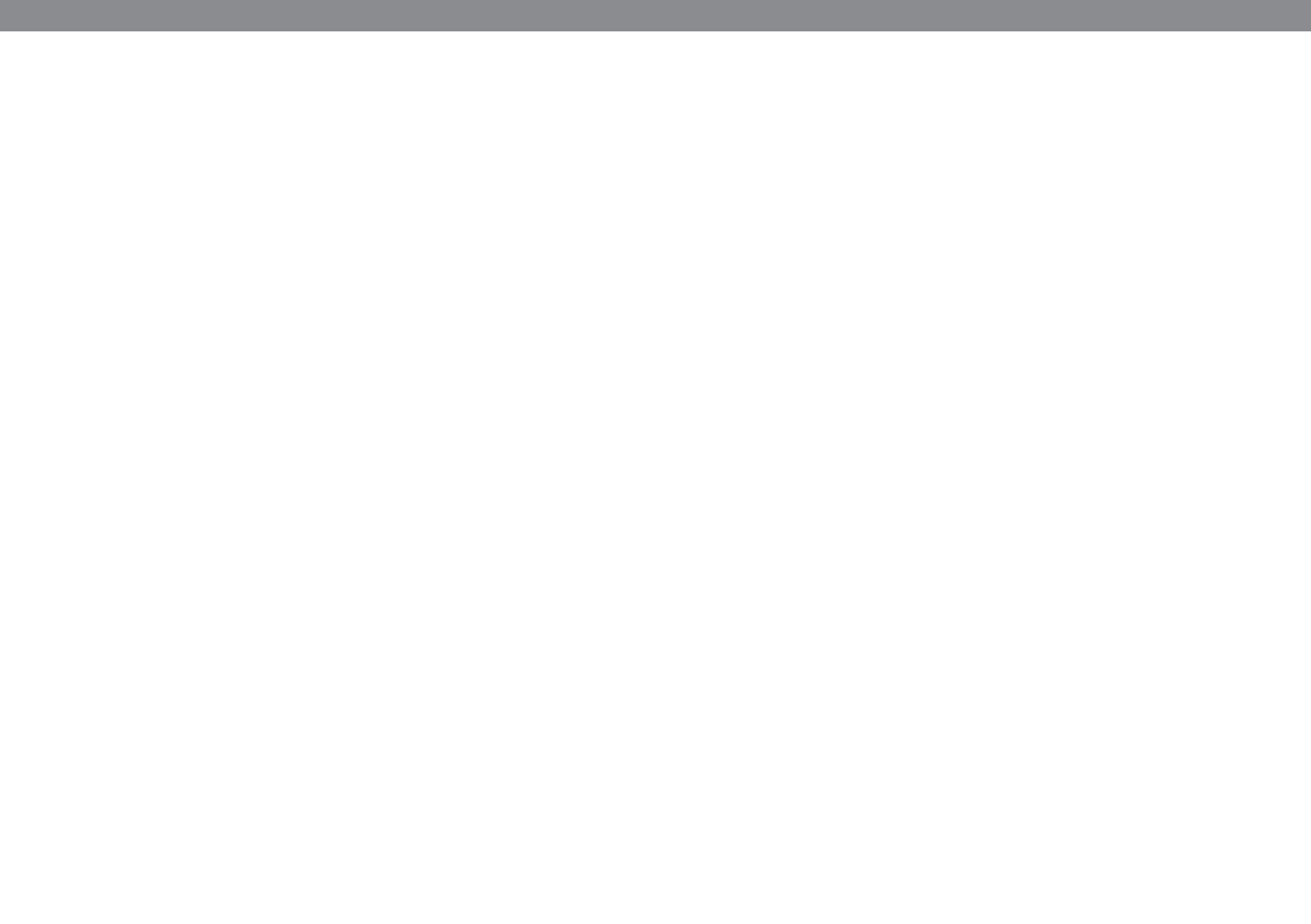
**Yie, Kay-Long Alex**

Tekkaya, A. E.; Grodotzki, J.

**Misconceptions in der Umformtechnik**

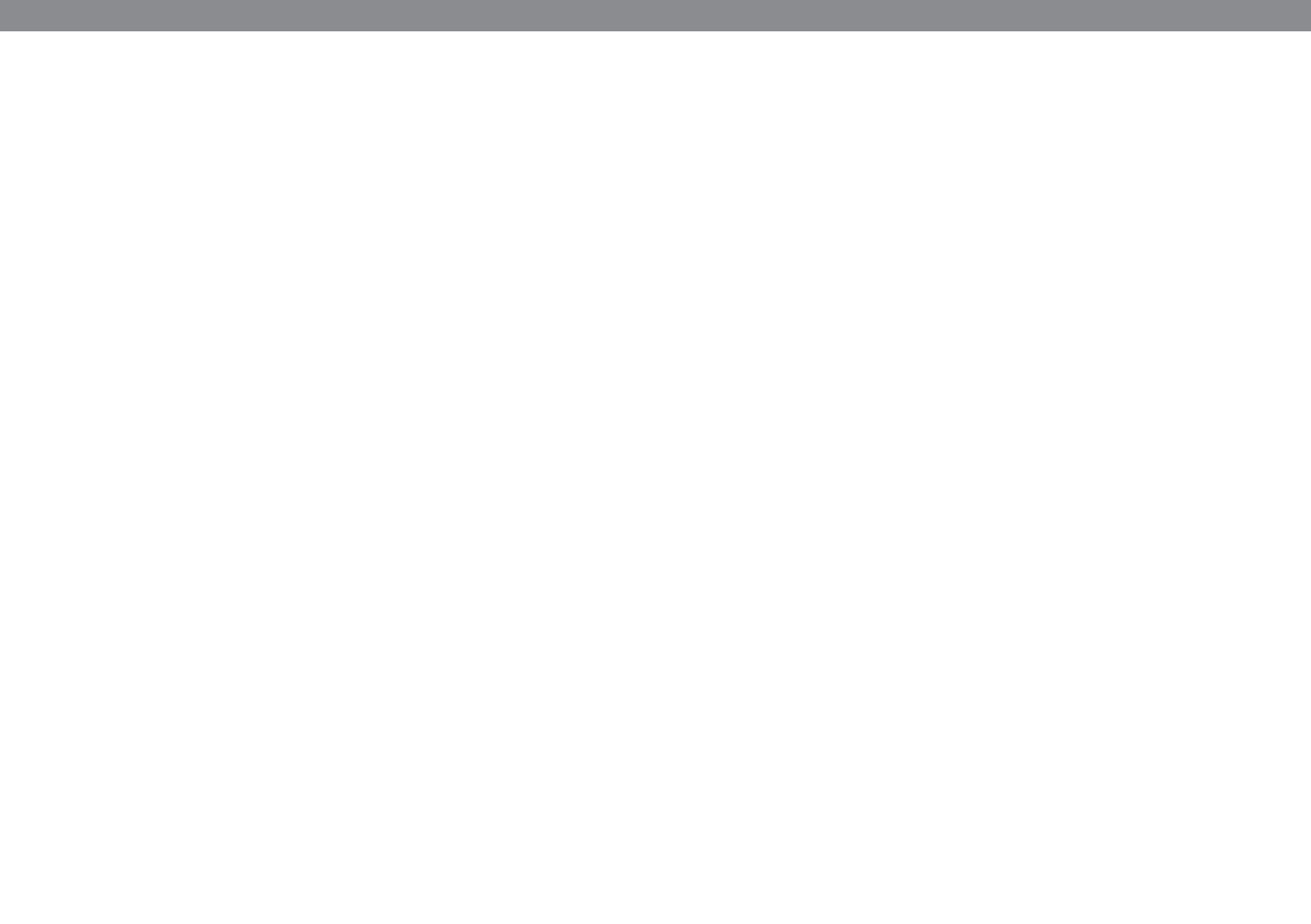
Misconceptions in Forming Technology





Ausgewählte Veröffentlichungen und Vorträge |  
Selected Publications and Lectures

08



## Zeitschriftenbeiträge | For SCI-Journals

**Gebhard, J., Schulze, A., Clausmeyer, T., Tekkaya, A. E., 2023.** Continuous Hot Extrusion with a Stationary Valve. CIRP Annals - Manufacturing Technology, DOI: 10.1016/j.cirp.2023.03.003.

**Kamaliev, M., Flesch, J., Grodotzki, J., Tekkaya, A. E., 2023.** Numerical and Experimental Analysis of the Isothermal High Temperature Pneumofforming Process. International Journal of Material Forming 16, DOI: 10.1007/s12289-023-01767-y.

**Komodromos, A., Grodotzki, J., Kolpak, F., Tekkaya, A. E., 2023.** Characterization of Tool Surface Properties Generated by Directed Energy Deposition and Subsequent Ball Burnishing. Journal of Manufacturing Science and Engineering, DOI:10.1115/1.4063736.

**Rosenthal, S., Hahn, M., Tekkaya, A. E., 2023.** Deep Drawability of Additively Manufactured Sheets with a Structured Core. International Journal of Material Forming 16, DOI: 10.1007/s12289-023-01739-2.

**Tekkaya, A. E., Groche, P., Kinsey, B.L., Wang, Z. G., 2023.** Stress Superposition in Metal Forming, CIRP Annals 72 (2), pp. 621–644, DOI: 10.1016/j.cirp.2023.04.090.

**Dardaei Joghhan, H., Hölker-Jäger, R., Komodromos, A., Tekkaya, A. E., 2023.** Hybrid Additive Manufacturing of Forming Tools. Automotive Innovation 6, pp. 311-323. DOI: 10.1007/s42154-023-00239-y.

**Gerlach, J., Clausmeyer, T., Schowtjak, A., Muhammad, W., Brahme, A. P., Koppka, L., Inal, K., Tekkaya, A. E., 2023.** Data-driven Ductile Damage Model for Damage-induced Material Degradation in Forming. Manufacturing Letters 35, pp. 1097-1102. DOI:10.1016/j.mfglet.2023.08.092.

**Gitschel, R., Schulze, A., Tekkaya, A. E., 2023.** Void Nucleation, Growth and Closure in Cold Forging: An Uncoupled Modelling Approach. Advances in Industrial and Manufacturing Engineering 7, DOI: 10.1016/j.aime.2023.100124.

**Grodotzki, J., Müller, B. T., Tekkaya, A. E., 2023.** Enhancing Manufacturing Education Based on Controller-free Augmented Reality Learning. Manufacturing Letters 25, pp. 1246-1254, DOI: 10.1016/j.mfglet.2023.08.068.

- Grodotzki, J., Müller, B. T., Tekkaya, A. E., 2023.** Introducing a General-purpose Augmented Reality Platform for the Use in Engineering Education. *Advances in Industrial and Manufacturing Engineering* 6, DOI: 10.1016/j.aime.2023.100116.
- Hahn, M., Bechler, J., Tekkaya, A. E., 2023.** Modeling and Validation of Forming by Vaporizing Foil Actuators. *Manufacturing Letters* 35, pp. 132-140, DOI: 10.1016/j.mfglet.2023.07.002.
- Homberg, W., Arian, B., Arne, V., Borgert, T., Brosius, A., Groche, P., Hartmann, C., Kersting, L., Laue, R., Martschin, J., Meurer, T., Spies, D., Tekkaya, A. E., Trächtler, A., Volk, W., Wendler, F., Wrobel, M., 2023.** Softsensors: Key Component of Property Control in Forming Technology. *Production Engineering - Research and Development*, DOI: 10.1007/s11740-023-01227-1.
- Langenfeld, K., Lingnau, L., Gerlach, J., Kurzeja, P., Gitschel, R., Walther, F., Kaiser, T., Clausmeyer, T., 2023.** Low Cycle Fatigue of Components Manufactured by Rod Extrusion: Experiments and Modeling. *Advances in Industrial and Manufacturing Engineering* 7, DOI: 10.1016/j.aime.2023.100130.
- Laurent-Brocq, M., Lilensten, L., Pinot, C., Leroy, E., Tekkaya, A. E., 2023.** Solid State Recycling of Aluminium Chips: Multi-technique Characterization and Analysis of Oxidation. *Materialia* 31, DOI: 10.1016/j.mtla.2023.101864.
- Martschin, J., Wrobel, M., Grodotzki, J., Meurer, T., Tekkaya, A. E., 2023.** Soft Sensors for Property-Controlled Multi-Stage Press Hardening of 22MnB5. *Automotive Innovation* 6, pp. 352-363, DOI: 10.1007/s42154-023-00238-z.
- Min, J., Tekkaya, A. E., Li, Y., Korkolis, Y. P., Zhao, Y., 2023.** Preface for Feature Topic on Environmentally Benign Automotive Lightweighting. *Automotive Innovation* 6, pp. 297-299, DOI: 10.1007/s42154-023-00236-1.
- Rosenthal, S., Bechler, N., Hahn, M., Tekkaya, A. E., 2023.** Large Sandwich Sheets Enabled by Joining Rolled Sheets and Additively Manufactured Core Structures for Forming. *Manufacturing Letters* 35, pp. 249-257, DOI: 10.1016/j.mfglet.2023.08.034.
- Selvaggio, A., Tekkaya, A. E., 2023.** Identification of Factors Influencing the Quality of Extruded Profiles Using Aluminum Recyclate-Based Billets. *Manufacturing Letters* 35, pp. 1326-1335, DOI: 10.1016/j.mfglet.2023.08.076.

**Stebner, S. C., Martschin, J., Arian, B., Dietrich, S., Feistle, M., Hütter, S., Lafarge, R., Laue, R., Li, X., Schulte, C., Spies, D., Thein, F., Wendler, F., Wrobel, M., Vasquez, J. R., Dölz, M., Münstermann, S., 2023.** Monitoring the Evolution of Dimensional Accuracy and Product Properties in Property-controlled Forming Processes. *Advances in Industrial and Manufacturing Engineering* 8, DOI: 10.1016/j.aime.2023.100133.

**Weber, F., Lu, Y., Peterschilka, F. J., Hahn, M., Tekkaya, A. E., 2023.** Electromagnetic Joining of Aluminum and Polycarbonate Tubes. *Advances in Industrial and Manufacturing Engineering* 6, DOI: 10.1016/j.aime.2022.100109.

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

**Dardaie Joghhan, H., Hahn, M., Agboola, O., Tekkaya, A. E., 2023.** Resources and Manufacturing Technology Evaluation of Hybrid Additive Metal Laminated Tooling for Forming. 26th International Conference on Material Forming (ESAFORM), Krakow, Poland. Materials Research Proceedings 28, pp. 21-30, DOI: 10.21741/9781644902479-3.

**Dardaie Joghhan, H., Hölker-Jäger, R., Hahn, M., Tekkaya, A. E., 2023.** Verfahrenskombination aus inkrementeller Blechumformung und Laserpulverauftragsschweißen. ZWF - Zeitschrift für wirtschaftlichen Fabrikbetrieb 118 (7-8), pp. 481-485, DOI: 10.1515/zwf-2023-1101.

**Gebhard, J., Schulze, A., Tekkaya, A. E., 2023.** Comparison of Stationary and Movable Valves for Continuous Hot Extrusion. In: 14th International Conference on the Technology of Plasticity (ICTP), Cannes, France. Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-3-031-41023-9\_46.

**Gitschel, R., Gebhard, J., Tekkaya, A. E., 2023.** Modelling Void Area Fractions in Cold Forged Parts. In: Proceedings of the 56th Plenary Meeting of the International Cold Forging Group (ICFG), Ankara, Turkey, pp. 161-171.

**Grodotzki, J., Tekkaya, A. E., 2023.** Comparative Analysis of Remote, Hands-on, and Human-remote Laboratories in Manufacturing Education. In: 2023 American Society for Engineering Education (ASEE) Annual Conference & Exposition, Baltimore, Maryland, USA.

**Guhr, F., Gitschel, R., Barthold, F.-J., Tekkaya, A. E., 2023.** Numerical Optimisation of Damage in Extrusion Processes. In: 93rd Annual Meeting of the International Association of Applied Mathematics and Mechanics (GAMM). Proceedings in Applied Mathematics and Mechanics 23, Art. Nr. e202300199, DOI: 10.1002/pamm.202300199.

**Hoffmann, E., Grodotzki, J., Tekkaya, A. E., 2023.** Investigation of Warping and Springback in Kinematic U-Profile Bending with Partial Heating. In: 14th International Conference on the Technology of Plasticity (ICTP), Cannes, France. Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-3-031-42093-1\_33.

**Kneuper, F., Grodotzki, J., Tekkaya, A. E., 2023.** Process Development for Passive Granular Media-Based Tube Press Hardening. In: 14th International Conference on the Technology of Plasticity (ICTP), Cannes, France. Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-3-031-41023-9\_56.

**Komodromos, A., Marín, G., Grodotzki, J., Tekkaya, A. E., 2023.** Investigation of Hot Stamping with Cooled and Textured Tools Manufactured by Directed Energy Deposition. In: 14th International Conference on the Technology of Plasticity (ICTP), Cannes, France. Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-3-031-40920-2\_19.

**Kotzyba, P., Gebhard, J., Schulze, A., Günther, F., Stommel, M., Tekkaya, A. E., 2023.** Novel Extrusion Process for the Production of Aluminum-Polymer-Composites. In: 14th International Conference on the Technology of Plasticity (ICTP), Cannes, France. Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-3-031-41023-9\_47.

**Lennemann, P., Grodotzki, J., Tekkaya, A. E., 2023.** Controlling the Damage Evolution in Roll Forming of a V-Section by Elastomer Rollers. In: 14th International Conference on the Technology of Plasticity (ICTP), Cannes, France. Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-3-031-42093-1\_26.

**Maaß, F., Hahn, M., Tekkaya, A. E., 2023.** Controlling Product Properties by Compressive Stress-Superposed Incremental Forming. In: 14th International Conference on the Technology of Plasticity (ICTP), Cannes, France. Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-3-031-41023-9\_73.

**Mamros, E. M., Polec, L. A., Maaß, F., Clausmeyer, T., Tekkaya, A. E., Ha, J., Kinsey, B. L., 2023.** Examination of Bending Stress Superposition Effect on Martensite Transformation in Austenitic Stainless Steel 304. In: 14th International Conference on the Technology of Plasticity (ICTP), Cannes, France. Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-3-031-40920-2\_49.

**Martschin, J., Wrobel, M., Grodotzki, J., Tekkaya, A. E., 2023.** Tailoring the Hardness in Multi-stage Press Hardening of 22MnB5 Sheet Material in a Progressive Die. In: 14th International Conference on the Technology of Plasticity (ICTP), Cannes, France. Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-3-031-40920-2\_10.

**Rakshit, T., Dunlap, A., Kraemer, S., Schulze, A., Aretz, A., Schwedt, A., Tekkaya, A. E., 2023.** Damage Evolution in Axial Forming of External Splines and Quenching Operation of the Tubular Gear Shafts. In: 14th International Conference on the Technology of Plasticity (ICTP), Cannes, France. Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-3-031-42093-1\_21.

**Rakshit, T., Gebhard, J., Tekkaya, A. E., 2023.** Influence of Die Parameters on the Damage Evolution in Axially Formed Gears. In: Proceedings of the 56th Plenary Meeting of the International Cold Forging Group (ICFG), Ankara, Turkey, pp. 233-242.

**Rethmann, P., Grodotzki, J., Tekkaya, A. E., 2023.** Berücksichtigung der Umformhistorie gezogener Drähte bei der Simulation des Federwindens. In: 6. Biegeforum, Siegen, Germany, DOI: 10.25819/UBSI/10397.

**Stennei, M., Grodotzki, J., Tekkaya, A. E., 2023.** Analyse der Biegeeigenschaften verschiedener Stähle zur Anwendung beim Presshärten. In: 6. Biegeforum, Siegen, Germany, DOI: 10.25819/UBSI/10397.

**Stennei, M., Clausmeyer, T., Grodotzki, J., Rosenthal, S., Stiglmaier, M., Tekkaya, A. E., 2023.** Prediction Strategy for the Forming and Stuffing of Non-circular Tube. In: 42nd Conference of the International Deep Drawing Research Group (IDDRG), Luleå, Sweden. IOP Conference Series: Materials Science and Engineering, DOI: 10.1088/1757-899X/1284/1/012084b.

**Stiebert, F., Traphöner, H., Tekkaya, A. E., 2023.** In-Plane Torsion Test - Analysis of the Tool Design. In: 14th International Conference on the Technology of Plasticity (ICTP), Cannes, France. Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-3-031-40920-2\_57.

**Weber, F., Hahn, M., Tekkaya, A. E., 2023.** Joint Strength Determination by a Resistance-Based Sensor in Metal-Polymer Joining by Hydraulic Expansion. In: 14th International Conference on the Technology of Plasticity (ICTP), Cannes, France. Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-3-031-41341-4\_4.

**Wrobel, M., Martschin, J., Meurer, T., Tekkaya, A. E., 2023.** Data-driven Temperature Estimation for a Multi-Stage Press Hardening Process. 22nd World Congress of the International Federation of Automatic Control (IFAC), Yokohama, Japan. IFAC-PapersOnLine 56 (2), pp. 4252-4257, DOI: 10.1016/j.ifacol.2023.10.1785.

## Keynote/Invited-Vorträge | Keynote/Invited Presentations

**Tekkaya, A. E., 2023.** Nonconventional Hot Aluminium extrusion. Invited presentation, ALUMIL A.S., Thessaloniki, 19.05.2023, Thessaloniki, Greece.

**Tekkaya, A. E., 2023.** Effect of Loading Path on Damage in Metal Forming: Experimental Findings from IUL. Invited keynote presentation. Numisheet/FTF Technical Meeting, 06.-08.06.2023, Zurich, Switzerland.

**Tekkaya, A. E., Groche, P., Kinsey, B. L., Wang, Z. G., 2023.** Stress Superposition in Metal Forming. Keynote presentation, 72nd CIRP General Assembly, 20.-26.08.2023, Dublin, Ireland.

**Tekkaya, A. E., 2023.** Two Innovative Profile Forming Processes. Invited presentation, ERC HAMMER Online Seminar, 02.10.2023, Columbus (Ohio), USA.

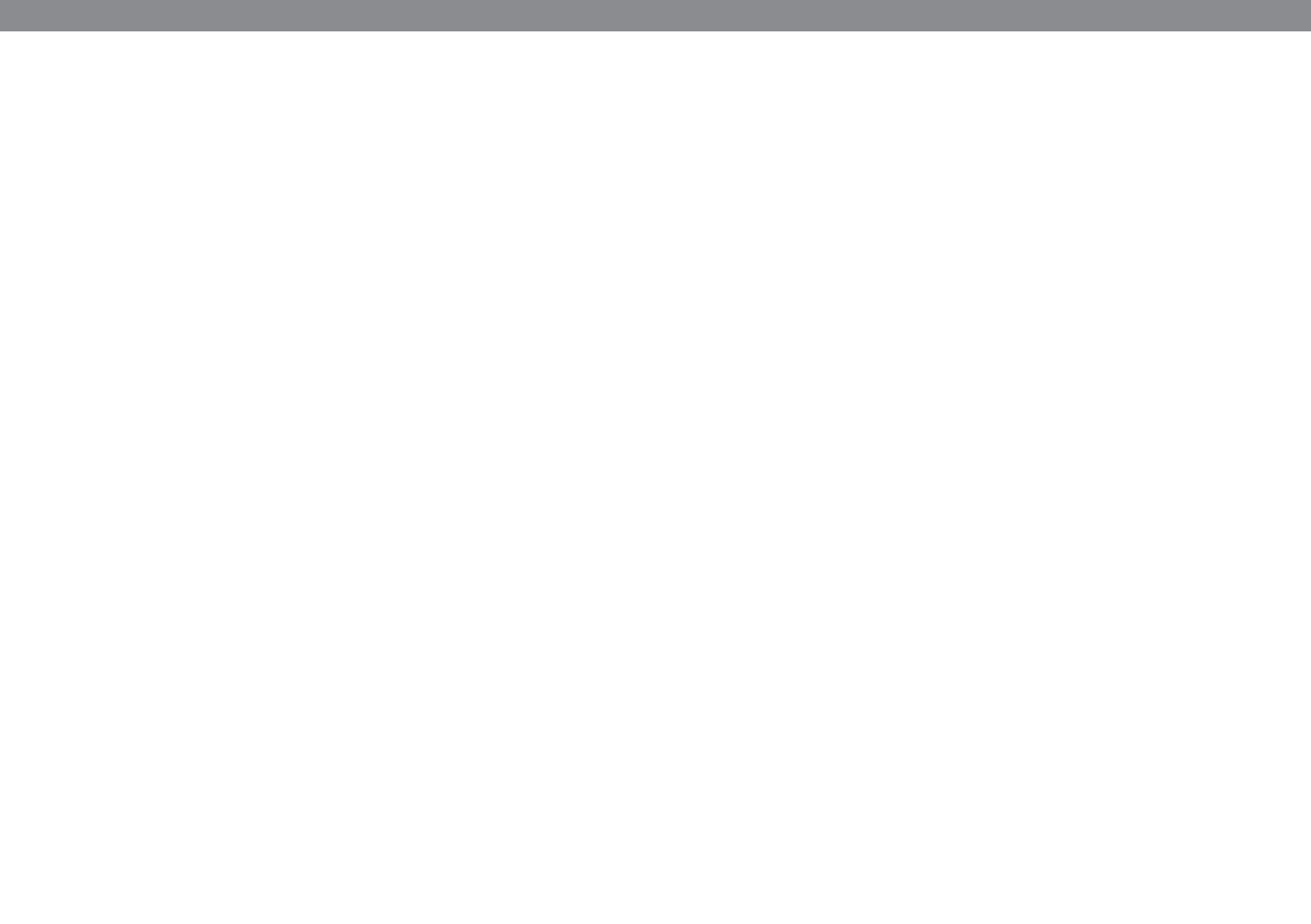
**Tekkaya, A. E., 2023.** Hot Extruded Sheets from Aluminium Chips. Invited keynote presentation, Frontiers in Automotive Materials and Manufacturing Research, 17.-18.10.2023, Hamilton (Ontario), Canada.

**Tekkaya, A. E., 2023.** Stress Superposition in Metal Forming. Invited presentation, Baosteel, 27.10.2023, Shanghai, China.

**Tekkaya, A. E., 2023.** Aluminium Sheets Made of Chips. Invited presentation, Baosteel, 27.10.2023, Shanghai, China.

**Tekkaya, A. E., 2023.** Damage Under Strain Path Changes. Invited presentation, Tongji University, 27.10.2023, Shanghai, China.

**Tekkaya, A. E., 2023.** Advanced Material Characterisation. Invited presentation, Tongji University, 27.10.2023, Shanghai, China.



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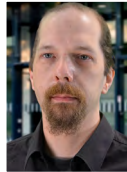
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