ICFG National Report 2015

GERMANY

The German Cold Forging Group (GCFG)

Established in September 2003 to support and develop the national cold forging technology and the research work in this field, the German Cold Forging Group (GCFG) experienced a significant growth and a good and considerable development. Four working groups, chaired by renowned university institutes, provide a platform for experts from industry and academia permitting an intensive exchange of knowledge and experience and for triggering scientific studies and new research programs. Further GCFG activities are the cooperation in common research projects and the support of young scientific researchers.

Actually, the GCFG consists of **79 members:**

Cold forgers:	39 companies
Service providers / suppliers:	19 companies
Universities:	16 institutes
Organizations:	1 (VDI)
Personal members:	4

More than 75% of the members are OEM suppliers or otherwise linked to the automotive industry.

The steering committee consists of:

Prof. Dr.-Ing. Mathias Liewald, Institut für Umformtechnik (IfU), Universität Stuttgart
Tillmann Fuchs, Fuchs Schraubenwerk GmbH, Siegen
Dr.-Ing. Rainer Neher, Wezel GmbH, Kaltumform-Technik, Frickenhausen

Additional advisory members are:

Prof. Dr.-Ing. habil. Ulf Engel, Lehrstuhl für Fertigungstechnologie (LFT), Universität Erlangen
Prof. Dr.-Ing. Dipl.-Wirtsch.-Ing. Peter Groche, Institut für Produktionstechnik und Umformmaschinen (PtU), Technische Universität Darmstadt
Dr.-Ing. Gunther Hartmann, KAMAX Automotive GmbH, Homberg/Ohm
Prof. Dr.-Ing. Prof. E.h. Rudolf Kawalla, Institut für Metallformung, TU Bergakademie Freiberg
Prof. Dr.-Ing. Mathias Liewald, Institut für Umformtechnik (IfU), Universität Stuttgart
Dr.-Ing. Markus Meidert, ThyssenKrupp Presta AG, Eschen (Liechtenstein)
Dr. Ing. Rainer Neher, Wezel GmbH, Kaltumform-Technik, Frickenhausen
Dipl.-Ing. Oliver Oehler, Schondelmaier GmbH Presswerk, Gutach/Schwarzwald
Dr.-Ing. Hans-Willi Raedt, Hirschvogel Umformtechnik GmbH, Denklingen

In the following the highlights of the actual research work at the GCFG member institutes 2015 are presented.

M. Liewald, A. Felde
Institute for Metal Forming Technology (IFU)
University of Stuttgart / Germany – Status report July 2015

Working group for cold forging of aluminium alloys

The working group called "Cold Forging of Aluminium Alloys" has been established at the IFU in October 2006 due to the encouragement of nine industrial organisations. Group meetings are held at least twice a year and within the teamwork it has been strongly focused on various research tasks since 2006:

- Practical testing of a newly developed raw material test
- Forming of aluminium alloys at elevated temperatures, like at heat treatment condition T6, to investigate the increase of mechanical strength and to avoid deviations due to heat treatment after cold forging
- Investigating tribology of aluminium cold forging processes using special tool materials, tool coatings or multifunctional tool surfaces on the tribological system of spike test
- Investigating the influence of slug preparation process (shot material, blasting time, and type of lubricant) on slug surface characteristics (topography, skin hardness, and lubricant entrainment)
- Optimising specific models for FEA purposes
- Simulating multi-step forming processes of aluminium alloys.

Control of material flow during combined cold forging of aluminium components using a moving die

Exact knowledge about parameters which are influencing the flow of material is an important factor to design combined cold forging processes. Within the project it is focused on manufacturing processes of double-cup-shaped components having one or more branches. The main idea is to move the die with specific kinematics. By moving the die with a certain velocity profile induced by frictional forces, the material flow can be controlled within certain limits. Software for FEA forming simulation and for CAE multi-objective optimisation were combined to determine an optimal and robust process design which was in accordance with the predefined work piece geometry.

In experimental tests the movement of the tool part was automatically controlled along with kinematics which had been optimised in advance.

Failure prediction during flange upsetting at hollow cold forged parts

Hollow drive shafts having circumferential flanges can be manufactured by upsetting tubular parts. This provides both: high material efficiency and strong potential of lightweight design. Occurring instability of tubular parts due to high free upsetting heights during flange upsetting is known as a significant process limit. This kind of failure extensively decreases component strength, especially when having alternating loads. Within the scope of this project, technological measures are examined by using a wide range of parameters to classify and to avoid folding as well as to exceed actual process limits. Besides, the instability occurrence of two further mechanisms leading to annular folding during upsetting could be determined. Influence parameters on fold formation without previous buckling behaviour of tubular parts are the local strain hardening during upsetting in connection with reducing the inner lateral surface as well as the surface quality of inner lateral surface of semi-finished parts. Instability occurrence and critical local strain hardening can be counteracted by applying a multistage upsetting process with intermediate annealing for example. Moreover, it is focused on process combinations avoiding buckling and providing optimised material flow in experimental investigations. Numerical prediction of so called folds of 2nd order is only possible by means of a developed fold criterion implemented into commercial FE software. Satisfying agreements of numerically determined fold depth as well as fold position and measured fold depth and fold position have been achieved using the proposed fold criterion. Following the numerically and experimentally derived results, a revision of existing working limit diagrams has been carried out.

System development for automatically controlled (AC) cold forging processes

The increasing diversity of variations within part families demands high flexibility of bulk metal forming processes. Moreover, flexible fabrication means quick reaction to production defects and design changes. Approaching forming limits and proceeding of cold forging processes often requires process combinations which lead to a necessary additional moveable tool axis. Furthermore, an automatically controlled tool axis provides the possibility of reacting to unexpected process variations during serial production which leads to net-shape manufacturing. Main objective of this project is developing a modularly designed control system of material flow for cold forging applications. It should be possible to control (combined) cold forging processes when a hydraulic system adapted to the specific reqirements is used. Required additional movement of certain components or additional tool axes are dependent or independent from press movement. For this purpose a tool rack with an automatically controllable servo-hydraulic movement axis was built up at IFU for using it in single-acting presses. Using the previous experiences of the tool rack with one additional controllable axis, a second tool rack with two additional servo-hydraulic axes was designed and tested for applying it during cold forging. Optimised set point curves of additional tool axes have been determined by using CAE based optimisation and numerical simulation. Aim of this project is the further control of axes of motion integrated in a cold forging tool for controlling the material flow of complex cold forging parts during forging. Despite the enormous scatter of mechanical properties (AA1050 vs. 16MnCrS5), optimised control parameters lead to acceptable cup bottom heights and deviations, causing a reduction in speed difference between punch and counterpunch. Using this system is a possibility to improve process robustness immensely. Moreover, it has been shown that using a controllable counterpunch during backward cup extrusion led to significantly reduced punch loads. Pre-set velocity ratios of $V \geq 0.85$ allow manufacturing of cups made of steel with wall thicknesses of $s = 0.875$ mm. Achieved experimental results correlate with numerically determined Metamodel of Optimal Prognosis. Investigations for controlling material flow during combined cold forging of aluminium alloys showed that tribological conditions and therefore material flow can be affected by a co-moving die. By using the AC system, process time and cost inefficient trial and error method can be coped with.

Bulk metal forming at elevated temperatures – Extrusion of steel in a range from room temperature to 500°C

By forming within the temperature range up to the (industrial) warm forming temperature, a combination of advantages of cold and warm forming under economically optimal conditions is intended. Temperature range of blue brittleness between 300 °C and 500 °C for steel, which is characterised by low ductility and low yield stresses, is of particular interest. In addition to an increase of formability, forming at elevated temperatures results in a decrease of tool load and an increase of tool life. Due to lacking experiences within forming at elevated temperatures this study is based on the three work packages tribology, technological material properties, and process investigations.

Improvement of positional accuracy of hollow semi-finished products

For the production of geometrically demanding hollow parts transmission shafts with finally pressed gearings using the cold extrusion technology were selected. A manufacturing chain for producing such components by using metal forming could include a cup-extrusion process. However, this method has certain limitations regarding the geometric part design.

Further investigations will help to identify and to improve the positional accuracy of hollow semi-finished parts for the forming production of hollow gear shafts. Error propagation and loss of accuracy in the whole series forming technology from the production of hollow semi-finished parts due to a cup extrusion to the gearing forming using a combined hollow-forward-hollow-backward extrusion is the focus of interest.

Manufacturing of a shaft-hub-connection by lateral extrusion

Nowadays, the design of positive locking shaft-hub-connections is often limited due to machining of shaft and hub because of manufacturing tolerances. Especially new outlines based on complex cycloids, which show a high potential in numerical analysis, cannot show this potential in the experiments due to manufacturing tolerances and assembling clearance. The final machining of the shaft geometry is no longer necessary by joining a shaft-hub-connection using lateral extrusion.

As part of this investigation, a hub of tempered 42CrMo4 and a shaft of 16MnCrS5 (GKZ annealed) are joined by lateral extrusion of the shaft. Besides tribology conditions and the internal profile type of the hub, the radial preload of the hub is investigated with regard to high mould filling of hub along its length. First results using a polygonal hub profile (P3G) show that high friction leads to an increase of radial material flow and thus to a higher mould filling. Unfortunately, the increase of mould filling causes higher radial deformation and higher residual stresses of hub. The properties of the manufactured joints are checked by carrying out static and dynamic investigations.

Form- and force-closed shaft-hub-connections showing different profile parameters were joined by using lateral extrusion and punch force. Roundness deviation and cavity filling were determined for finding a suitable internal hub profile. Table 1 shows the identified optimal profile parameters and performance requirements. In numerical and experimental investigations it has been found out that the smaller the profile eccentricity is the lower are punch force, roundness deviation, and radial gap. From process point of view, low teeth numbers are striven for and epitrochoid profiles are preferable based on the performed studies. However, this profile type leads to a strong notch effect within the shaft and therefore it has to be replaced by complex trochoid.

Investigations on hollow lateral extrusion without a lateral mandrel of tubular billets

Cold forged hollow components with similar hollow branches possess an enormous potential of lightweight design. Areas of application for such geometrically complex forming parts are automotive industry as well as machine and plant construction. Fundamental investigations of hollow lateral extrusion without a lateral mandrel were carried out by combining experimental examinations and Finite-Element-Analysis regarding the geometrical parameters of sound part forming. However, geometrical properties are not the only factor, which have an influence on the quality of the forming part. The shape deviation can be improved by increasing the hydrostatic pressure in the forming zone as well. A further positive aspect is the expansion of the specific process limits that have limited the product range before. This project is a mutual project of the Institute for Metal Forming Technology (IFU), University of Stuttgart and Institute of Forming Technology and Lightweight Construction (IUL), University of Dortmund.

Development of new equipment to improve the cutting quality in high-speed cutting process

The high-speed cutting process is a chipless cutting method. The material will be separated in the shearing zone by two blades which move past each other. The objective of this method is to manufacture raw products which can be used without any necessary post-processing in the following process steps. Unfortunately, the application of this production method has been very limited so far. To compensate for the geometrical derivation (burr and edge entering) a setting process is used. Improving the cutting quality is another aim of this development.

The scope of this work is to create new equipment for high-speed cutting processes. The equipment is supposed to stabilise the work piece and to make it possible to transfer additional forces (tensile, torsional, and bending forces). The superposition of forces should reduce the extent of burrs, minimise deformation and make it thus possible to omit a setting process .

Production of extremely deep sleeves by backward cup extrusion

Limits of production of deep sleeves have been a major topic of numerous studies of researchers for many years. Bottomed sleeves are often used as finished products or semi-finished products.

They are intended for manufacturing hydraulic cylinders which are designed for operations under extreme temperatures or pressure level conditions. Since there are several ways of manufacturing such sleeves or can shaped work pieces, the first criterion of choosing a suitable production technology depends on the desired properties and dimensions of the final product. Currently, the most commonly adopted technique for producing smaller dimensions of sleeves is backward cup extrusion which belongs to cold forging in general.

The primary goal of this research project consists of designing a new tool set for producing deep sleeves (H/d>3) in one process step by backward cup extrusion. The main feature of this tool for the backward extrusion process are special guided components of working punches which were designed in a way where the free length of punch never exceeds its two diameters including the beginning of the process. Due to this feature, the buckling effect of the punch can be avoided throughout the forming process. The application of this working tool will offer the possibility of extending the limitations and thereby reducing the production and energy costs for manufacturing pressed components. Simultaneously, main advantages which pressed parts possess after normal backward extrusion can be maintained.

Lightweight Forging

Automotive engineering has been of economic importance since decades and is currently facing a big challenge regarding the reduction of CO^2 emission. The Lightweight Forging Initiative “massiverLEICHTBAU”, funded by AiF (an alliance of research associations) and BMWi (Bundesministerium für Wirtschaft und Energie) was set up to highlight the contributions which the forging industry makes to the automotive megatrend of lightweight design and make it accessible for the professional world. Nine steel manufacturers and eleven companies of the bulk metal forming industry have joined this initiative. From a forging perspective point of view, primarily parts from the powertrain (injection, engine, transmission, transfer gearbox, drive shafts) and the chassis are suitable for lightweight design ideas. The project is subdivided into five groups of which the IFU Stuttgart participates in three. In sub-project two, a gear will be built using a multi component manufacturing process to manufacture a built gearwheel. It will be manufactured by simultaneously forging and joining the gearwheel body and a gear ring, respectively a gear ring and a shaft. In sub-project three where the IFU Stuttgart takes the lead, local part properties will be investigated. By building a virtual process chain, which includes the forming analysis, metal cutting analysis, and structural analysis, a CAE-based optimised procedure will be carried out. The performance of this tool will be defined with regard to two demonstration parts in order to downsize lighter forged parts which have equal properties without necessary heat treatment targeting the adjustment of local part properties. Sub-project four will focus on the optimisation of forged components with regard to lightweight constructions and expansion of technological limits during the forging production.

Cold forging extrusion of metal and plastic

The combination of different materials allows a broad range of functionality and applicability for the production of high performance parts. Thus, the use of metals and plastics for hybrid structures has grown more and more important within the last years, as their respective complementary characteristics can be exploited in the fields of lightweight construction, acoustic damping and others. However, the number of production processes allowing a common manufacturing of both materials is limited. Therefore, the potential of metal-plastic-hybrids has not been fulfilled yet.

The scope of this research project is to develop a new way for processing metal and plastic in one single production step by using cold forging extrusion. This kind of process does not exist yet. The general feasibility of this concept has already been shown in a preceding experimental study. The first steps within this research project will be to further explore single aspects of the process e.g. the input of mechanical energy for the plasticisation of the polymer phase and its flow behaviour during the deformation. The results of these investigations will be the basis for deducing the design for the cold forging extrusion die. In a repeating loop, parts will be produced and analysed in regard to their properties. The findings will be used to further optimise the process and to define its potentials and limitations. Finally, metal-plastic-hybrid parts will be produced with optimised process parameters and their weight specific mechanic properties and damping characteristics will be determined.

Publications:

- T. Schiemann, M. Liewald, Flange upsetting of tubular components: 47th ICFG Plenary Meeting 2014; Ankara 2014 (Paper Prize Winner)
- T. Schiemann, M. Liewald, C. Mletzko: Automatically Controlled (Cold-) Forging Processes, Procedia CIRP, Vol. 18, 2014, pp. 39-44, doi:10.1016/j.procir.2014.06.104
- Schiemann, T., Liewald, M., Beiermeister, C., Till, M., 2014, Influence of Process Chain on Fold Formation during Flange Upsetting of Tubular Cold Forged Parts, Procedia Engineering, Vol. 81, 2014, pp. 352-357, http://dx.doi.org/10.1016/j.proeng.2014.10.005
- Dörr, F.; Funk, M.; Liewald, M.; Binz, H.: Investigations on the influence of hub internal profile on joining process of hub and shaft by lateral extrusion. ICTP 2014, Nagoya, Japan
- Mletzko, C.; Liewald, M.: Verbesserung der Vorhersagegenauigkeit des Werkstoffflusses bei der Simulation von kombinierten Fließpressverfahren durch inverse Parameterkalibrierung. XXXIII. Verformungskundliches Kolloquium, 15.-18. März 2014, Zauchensee (Österreich)
- Liewald, M.; Felde, A.; Schiemann, T.; Dörr, F.; Kannewurf, M.; Labanova, N.; Mletzko, C.: Current Research Activities along the Process Flow for Manufacturing of Hollow Lightweight Components at University of Stuttgart/Germany. 34th SENAFOR, Porto Alegre, RS, Brazil, 2014
- Liewald, M.; Felde, A.: Lagegenauigkeit von Verzahnungen an kaltgepressten hohlen Getriebewellen. Umformtechnik, Ausgabe November 2014
- Dörr, F.; Funk, M.; Liewald, M.; Binz, H.; Savino, M.: Determination of friction coefficients of interstice of a shaft-hub-connection manufactured by lateral extrusion. 6th International Conference on Tribology in Manufacturing Processes & Joining by Plastic Deformation, 22. - 24. Juni 2014, Darmstadt
- Schiemann, T.; Liewald, M.; Mletzko, C.; Wälder, J.: Automatically controlled (cold-) forging processes – equipment and application examples. In: Liewald, M. (Edit.), New Developments in Forging Technology, MAT INFO Werkstoffinformationsgesellschaft mbH, Frankfurt/M., 2015, pp. 257-282
- Dörr, F.; Kannewurf, M.; Liewald, M.: Investigations of joining by Forming by means of lateral extrusion. In: Liewald, M. (Edit.), New Developments in Forging Technology, MAT INFO Werkstoffinformationsgesellschaft mbH, Frankfurt/M., 2015, pp. 331-350
- Liewald, M.; Felde, A.: Research activities and new dewelopements in bulk metal forming at the Institute for metal Forming Technology. In: Liewald, M. (Edit.), New Developments in Forging Technology, MAT INFO Werkstoffinformationsgesellschaft mbH, Frankfurt/M., 2015, pp. 1-34
- Henry, R.; Liewald, M.: High-Speed Cropping of Rods and Wire with Superposition of Various Stress Conditions. 18th International ESAFORM Conference on Material Forming, 15th- 17th April 2015, Graz

Institute for Production Engineering and Forming Machines (PtU) Technical University of Darmstadt

Development of flexible processes on a multiple point servo press

Cold forging is mainly applied if high production volumes and narrow tolerances are required. Since the properties of semi-finished parts are exposed to fluctuations, a quality control is required to achieve the desired properties of the products. This requires appropriate sensors to measure the

product properties during the process and a controller logic as well as flexible actors, which are able to influence the process.
If sensor integration is not possible or not economic, models can be used to predict the current state of the product properties during the process. These models are fed by easily measureable values, like machine and tool parameters, as well as the properties of the semi-finished part or material.
The 3D Servo Press can be utilized as a flexible actuator, driving tool systems with up to three degrees of freedom. Servo presses in general can combine a flexible ram movement, known from hydraulic presses, with the advantages of mechanical presses with respect to speed and accuracy. Adjusting the ram speed and the stroke length during a ram stroke offers possibilities for improvements in productivity and part quality. The 3D Servo Press was designed based on the advantages of servo and multiple point servo presses. It provides a flexible ram motion with three degrees of freedom (DoF). The layout of the 3D Servo Press enables processes with 1-DoF ram motion, like in forging or extrusion, as well as processes with more than one DoF, like in orbital forming. Thus, the concept of the press can be used to realize forming processes with influence on product properties during the process. (Contact: Dipl.-Ing. Daniel Hesse, M.Sc. Florian Hoppe)

Investigation and enhancement on bonding by cold bulk metal forming processes

Cold bulk metal processes provide high dimensional accuracy and good material utilization. The manufactured components are featuring a high surface quality and a low machining allowance, while requiring only low energy consumption for the forming. Because of the cold hardening at low forming temperatures and high strains, cold bulk metal formed components are favorable for high mechanical loads.
The high tribological loads occurring during cold bulk metal forming can be used to bond two work pieces, enabling the possibility to combine the advantages of cold bulk metal forming with a functional material compound. The potential of this material compound comes along with the opportunity to combine high strength material with lightweight material for weight reduction. Further, expensive corrosion resistant materials can be used to cover surfaces of cheaper, corrosion-prone materials. This technique can also be used to include magnetic properties in a component locally.
The aim of this research project is to investigate the bonding surfaces and the conversion of the inner and outer boundary layer in interdisciplinary cooperation with the methods of surface analysis to deepen the understanding of the bonding mechanism. Methods will be established to strengthen or promote the bonding of steel to material combinations, which are traditionally seen as non-bondable during cold bulk metal forming. The effect of the oxide layer thickness is investigated on the resulting bond strength. Beside the effect of heavy work hardening of the boundary layers by mechanical processes, the effect of tempering the billets and varying the geometrical surface structure regarding the bond strength is analyzed. Especially the effect of the billet temperature is investigated intensely to promote bonding and to generate compressive stress due to shrinkage. Furthermore, strategies for post forming heat treatment will be developed in order to obtain an optimized ratio of bond strength to the material strength itself. Further emphasis is put on a subsequent forming of the bonded cups in order to weld previously unbonded areas and to further enhance the overall bond strength. Based upon the results of the research project, design criteria for the production of compound specimen will be derived and evaluated by potential applications like shaft-hub connections. (Contact: M.Sc. Simon Wohletz)

Magnetic materials

Modern high-performance permanent magnets represent a key component for the continuously growing electric mobility such as hybrid or electric drives. They are also important components in alternative energy generation methods such as wind power generators. To achieve a particularly high energy density, magnets are used with a large amount of rare earths, which have unique electronic, magnetic and optical properties. Compared to rare earth-based materials, classical magnetic materials have only one-fifth of the energy density. However, the extraction of rare earths is highly energy-intensive due to geological deposits as well as the chemical similarity and causes intense pollution of the environment. At the same time rare earths are subjected to big market

dependencies. The use of rare earths will increase with further development of alternative energy generation methods which include these high-performance permanent magnets.
This research project has two main objectives. On the one hand, the aim is to reduce or to substitute the proportion of rare earths in the strongest rare earth magnets without having significant performance losses. The use of these magnets will focus further on high performance applications in electric motors and generators for wind turbines. The second objective is to develop new magnets of the next generation without rare earths with much higher energy density than conventional magnetic materials. These magnets are expected to be used in small electric motors in a medium to high temperature range.
In cooperation with the Fraunhofer Project Group and the Technische Universität Darmstadt in the fields of materials science, chemistry, physics and engineering, methods for the achievement of the described project objectives are developed. The focus of the project "New methods of synthesis" is to develop a process chain that enables grain refining and continuous production of highly textured magnetically anisotropic samples. For grain refinement and induction of high defect densities in soft and hard magnetic materials, the continuous ECAS process (Equal Channel Angular Swaging) is intended to be used. This process will produce a nanocrystalline isotropic preform with high coercive field strength. A texture in the material is realized by a downstream rotary swaging process and/or by a magnetically enhanced heat treatment. (Contact: Dipl.-Ing. Lennart Wießner)

Industry 4.0

Cold forging processes are usually part of longer manufacturing chains. Wire drawing or cutting processes often take place prior to forming operations. Calibrations or heat treatments, for instance, are typical operations performed after many metal forming processes. In order to counteract the influences of fluctuating material, tool or process conditions it seems to be reasonable to use knowledge gained in preceding process steps for the adaption of an actual manufacturing operation. So far, this is hardly realized in industrial manufacturing chains. Main reasons are given by the difficulties to collect the relevant data and to use them intelligently.
For the realization of that, four different challenges have to be achieved. The first challenge is already mentioned through the intelligent use of relevant data. For an intelligent use, correlations between measured values and process or material parameters have to be identified. Those correlations can be used to influence and control upstream or downstream processes within the process chain. The second challenge is the intelligent integration of sensors at appropriate positions in the process tools. In this case, sensors which resist the difficult environment conditions in the cold forging processes have to be developed and integrated. The third challenge is the robust data management and the interpretation of the gained data. Thus, an intelligent database structure and preparation plus the preprocessing of measured data have to be carried out. As fourth and last challenge an appropriate control algorithm has to be implemented in the process chain control. In further steps the mentioned database will be integrated into the system control.
If all challenges are met, an adaptive process control of any processes can be realized. Also, an online process optimization can be realized. (Contact: M.Sc. Johannes Hohmann, M.Sc. Johanna Schreiner)

Improvement of the numerical simulation of profile rolling processes by consideration of friction

The modeling of friction within numerical simulations of cold forming operations is nowadays mostly carried out by an arbitrary definition of a global friction coefficient before conducting the simulation. However, it is known that the friction coefficient is not constant but dependent on multiple mechanisms within the work piece/tool interface. Friction modeling is especially significant when considering profile rolling operations of symmetric grooves with flat dies. Process feasibility is dependent upon the friction in this process setup, since the lateral translation of the work piece in between the dies relies only on friction.
The goal of this research project is the improvement of the quality of the numerical simulation so as to aid in the process design. To aid this goal, experimental investigations as to the acting friction conditions are carried out with the help of the sliding compression test. These findings will be

considered in the to be developed 2D and 3D numerical simulations. Additionally, the profile rolling process will be experimentally analyzed with high-precision sensor technology. This empirically gathered data will, on the one hand, aid the verification of the numerical simulations as well as further the improvement and optimization of the numerical models. On the other hand, the experiments will serve to evaluate different tribological systems that are commonly used for profile rolling operations. Combined with experimental tribological investigations and numerical simulations, the understanding of the profile rolling process is aimed to be increased. (Contact: Dipl.-Ing. Philipp Kramer)

Process optimization in cold forging due to oscillating tool movements

Forming longitudinal toothings with an oscillating ram movement is used to produce high precision toothings and thin walled profiles from tubes. High forming forces in conventional forming of longitudinal toothings lead to buckling when forming thin walled work pieces. Due to the oscillating ram movement the forming force can be reduced by up to 40%. This leads, amongst others, to an extension of the forming limits and enables e.g. the forming of toothings with smaller wall thicknesses. The reason for the reduction of the forming force is not clarified yet. Two theories are encountered in literature: One is the "friction theory" which attributes the force reduction to the rebuilding of the lubricating film during the back stroke. On the other hand the "softening theory" attributes the force reduction to softening effects like the Bauschinger-Effect due to the alternating load when using oscillating ram motion.

To identify the reason for the force reduction and to implement that reason in commercial FE-Systems the process is experimentally und numerically investigated. To separate the two theories experimentally a tool with a container was produced which enables the adjustment of the radial stress on the tooth forming die. Therewith the back stroke can be executed without any load. Hence softening effects like the Bauschinger-Effect can be excluded. With the help of that tool and the numerical investigations the mechanisms of the friction theory have been identified as the reason for the force reduction. (Contact: Dipl.-Ing. Benjamin Heß)

Integration of smart materials by cold forging

To handle the uncertainty of load-carrying systems safety factors are used for a systematic oversizing during the design process. This causes additional energy consumption and opposes the principle of lightweight construction. Therefore, the aim is to produce active components which react to external influences while being used.

With incremental bulk forming processes, it is possible to impose forces locally and thus to generate stress in the work piece at the location where it is required for a joining operation. This ability is needed, in case the properties of the parts to be joined differ strongly. In the project "integration of functional materials in metallic carrying structures" a process control is developed to integrate piezoceramics coaxially into tubes. The fusion of carrying structure and smart materials with actuatory and sensory capabilities enables new product architectures and the possibility of a cost-effective production by a joining operation which takes place simultaneously with the manufacturing process. Incremental forming methods in the focus of the studies of this project are roller spinning, rotary swaging and orbital forging. (Contact: M.Sc. Martin Krech)

Environmentally friendly process chains in cold forging by abdication of zinc phosphate conversion layers

Cold forging processes provide a high dimensional accuracy and a good material utilization. Due to high tribological loads, which occur during forming, complex separation and lubrication layers are used to prevent wear and failure of expensive forming tools. Hence, zinc phosphate coatings as separation layers and soap as a lubricant are used for the forging of steel, though the application and use of zinc phosphate coatings comes along with several environmentally drawbacks. Objective of this research project is to gather basic knowledge for the zinc phosphate-free, multistage cold forging of billets. New single layer lubricants have been developed and successfully applied for cold bulk metal forming of steel. The use of fast applicable single layer lubricants permits innovative process sequences. An inline-surface treatment interlinked with a multistage forming process of billets has been designed and realized within this project. The inline-surface treatment in combination with the developed environmentally benign lubricants will enable shorter treatment times, lower buffer volumes and a higher grade of flexibility for manufacturers. (Contact: Dipl.-Ing. Sebastian Zang).

Publications:

- Altin, A.; Wohletz, S.; Krieger, W.; Kostka, A.; Groche, P.; Erbe, A.: Nanoscale understanding of bond formation during cold welding of aluminum and steel. Advanced Materials Research, 2014, 966-967, 445-452
- Brenneis, M.; Ibis, M.; Duschka, A.; Groche, P.: Towards Mass Production of Smart Products by Forming Technologies. Advanced Materials Research, Trans Tech Publications, Switzerland, 2014, 907, 113-125
- Freund, T.; Würtenberger, J.; Calmano, S.; Hesse, D.; Kloberdanz, H.: Robust design of active systems - An Approach to Considering Disturbances within the Selection of Sensors. International Symposium on Robust Design - ISoRD14, Copenhagen, Denmark, 2014
- Groche, P.; Brenneis, M.: Manufacturing and use of novel sensoric fasteners for monitoring forming processes. Measurement, 2014, 53, 136-144
- Groche, P.; Calmano, S.; Felber, T.; Schmitt, S. O.: Statistical analysis of a model based product property control for sheet bending. Production Engineering Research and Development, Vol. 9, 2015, 25-34
- Groche, P., Heß, B: Friction control for accurate cold forged parts. CIRP Annals - Manufacturing Technology, Elsevier, Manchester, 2014, 63, 285-288
- Groche, P.; Schreiner, J.; Hohmann, J.; Birkhold, M.; Lechler, A.: Industry 4.0 – An opportunity also for metal forming?, VDI-Z 156, 2014 (in German)
- Groche, P.; Wiessner, L.: High Performance Permanent Magnets by Cold Forming. 60 Excellent Inventions in Metal Forming, 2015, 343-348
- Groche, P.; Wohletz, S.; Brenneis, M.; Resch, F.: Joining by forming - A review on joint mechanisms, applications and future trends. Journal of Materials Processing Technology, 2014, 214, 1972-1994
- Groche, P.; Wohletz, S.; Erbe, A.; Altin, A.: Effect of the primary heat treatment on the bond formation in cold welding of aluminum and steel by cold forging. Journal of Materials Processing Technology, 2014, 214, 2040-2048
- Groche, P.; Zang, S.; Müller, C.: Influence of the relative sliding velocity on tribological systems for cold massive forming. Tribologie und Schmierungstechnik, expert Verlag, Renningen, 02/14, 2014, 26-32 (in German)
- Groche, P.; Zang, S.; Kramer, P.; Müller, C.; Rezanov, V.: Influence of a heat treatment prior to cold forging operations on the performance of lubricants. Tribology International 92, 2015, 67-71
- Heß, B.; Übelacker, D.; Groche, P.: Influence of the stroke progression on shape and forming forces during the oscillating tooth forming process. VDI Wissensforum 2014 – Veranstaltungsunterlagen (in German)
- Krech, M.; Groche, P.: Integration of functions through rotary swaging – New possibilities for the monitoring of states and loads in tubular machine elements. Control loops in forging technology, 2015, 247-255

- McBain, G.; Wohlmuth, M.; Calmano, S.; Stahlmann, J. Groche, P: Considerations on the utilization of forming simulations for process control and process monitoring. Tagungsband 29. Jahrestreffen der Kaltmassivumformer, VDI, 2014 (in German)
- McBain, G.; Wohlmuth, M.; Calmano, S.; Stahlmann, J. Groche, P: Little to do with Industry 4.0? Mit Industrie 4.0 wenig zu tun?. UMFORMtechnik, 4/2014, 2014, 40-43
- Schmitt, S. O.; Scheitza, M.; Groche, P.: A model for improving the applicability of design methodologies to mechanical engineering design routines. Journal of Engineering Design, 2015, 1-19
- Schoppe, J.; Zang, S.: The possibility of using lubricants for process monitoring in cold massive forming. 12. Umformtechnisches Kolloquium Darmstadt, 2015, 5-13 (in German)
- Wiessner, L.; Gröb, T.; Bruder, E.; Groche, P.; Müller, C.: Severe plastic deformation and incremental forming for magnetic hardening. Advanced Materials Research, 2015, accepted
- Wohletz, S.; Groche, P.: Material Adherence in Cold Welding by Cold Forging. The 20th International Symposium on Plasticity and Its Current Applications, Numerical Engineering Analysis and Testing Inc., 2014, 34-36
- Wohletz, S.; Groche, P.: Forming joining processes for dissimilar connections. DGM-Fortbildungsseminar Fügen hybrider Verbindungen 19.11.2014-20.11.2014 (in German)
- Wohletz, S.; Groche, P.: Temperature Influence on Bond Formation in Multi-material Joining by Forging. Procedia Engineering, 81, 2014, 2000-2005.
- Wohletz, S.; Groche, P.: Metallic bonds generated by extrusion. 30. Jahrestreffen der Kaltmassivumformer, 2015, 87-98 (in German)
- Zang, S.; Müller, C.; Bodenmüller, D. & Groche, P.: Influence of Temperature on Environmentally Benign Tribological Systems in Cold Forging Operations. Proceedings of NAMRI/SME, 2014, 42

Institute of Manufacturing Technology (LFT)
Friedrich-Alexander-Universität Erlangen-Nürnberg

Collaborative Research Centre SFB/TR73 (www.tr-73.de)

Subproject A1 - Process combination for manufacturing of teethed, thin-walled functional components out of tailored blanks

The aim of the Collaborative Research Centre Transregio 73 (www.tr-73.de) is the investigation and further development of the manufacturing technology sheet-bulk metal forming. Applying bulk forming operations on sheet metals combines the advantages of conventional sheet and bulk metal forming processes in terms of product quality and flexibility.

The main focus of subproject A1 is the realization and understanding of the complete process chain. The first stage is the manufacturing of process-adapted tailored blanks from conventional thin sheet. Subsequently those semi-finished products are processed in a combined single-stage deep drawing and upsetting process to form thin-walled components. As different functional elements, for example gear teeth or open and closed carriers, lead to varying requirements on the semi-finished products, fundamental knowledge how to produce parts which meet those demands has to be build up. For realizing the required local properties of semi-finished components depending on the diverse features, two different forming processes are used: orbital forming and flexible rolling. Regarding the rolling process, a new rolling concept which uses a die mold was realized. This concept enables manufacturing of different, more complex geometries. The use of orbital forming enables the adaption of the mechanical properties of the semi-finished parts in addition to the adjustment of a defined material distribution. The application of those tailored blanks in subsequent forming operations improves the mold filing behavior due to fewer defects such as forging laps caused by uncontrolled material flow. In addition, the material efficiency rises and the required forming forces are decreased. Beside the forming processes sub-processes along the process chain like trimming operations are analyzed regarding the dimensional accuracy of the manufactured components. A trimming operation after the last forming process has no significant influence on the dimensional accuracy caused by springback, whereas a trimming operation before the forming process leads to an improvement of the geometrical properties of the parts. All investigations are carried out using a mild deep drawing steel. Additionally a high-strength dual phase steel is used to investigate the effects of a higher strength level and differing hardening behavior.

Subproject A2 - Forming of complex functional elements on sheet metal

Objective of subproject A2 is the fundamental analysis of the effects and interactions between workpiece and forming zone in sheet-bulk metal forming. By means of a process that allows forming of functional elements by forging, the complex interaction between regions of high and low strains have been investigated using a sensitivity analysis. Furthermore, the examination is extended to research the interaction of geometrically varying structures on the material flow. For that purpose cavities of different geometrical shape have been selected and are subsequently investigated by the use of statistical methods in simulations as well as in experiments. As a result, an advanced understanding of the process is achieved which will finally lead to the development of measures with the objective to control the material flow during the forming operation. One approach in this regard is the application of tailored surfaces on tool and workpiece. By this means, the material flow has been locally modified and mold filling could be improved. Another promising approach for process adaption is given by the use of tailored blanks with alternating sheet thicknesses. Analogous to the application in subproject A1, this method has been proven as effective for the improvement of mold filling by provision of additional material in the cavity area. As another central topic, current research involves the improvement of the tooling system with respect to the expected distinctive high tool stresses due to the asymmetrical material flow. For this purpose, a non-circular die reinforcement has been developed in order to raise stiffness of the tooling system and therefore improving accuracy of formed parts as well as tool life.

Subproject C1 - Constitutive friction law for the description and optimization of tailored surfaces

Due to locally varying load conditions regarding stress and strain states the tribological conditions are of major importance for sheet-bulk metal forming operations. The main focus of this subproject is on the investigation of the tribological conditions in sheet-bulk metal forming, the qualification of tailored surfaces and the development of a friction law.
A focal point of subproject C1 is the investigation and further development of tribological systems. One focus is on the investigation of conventional lubricants known from sheet and bulk-metal forming. Additionally, tailored surfaces are qualified with regard to the applicability in forming processes in sheet-bulk metal forming. The investigation of the tribological conditions is done by the use of different laboratory friction tests which have been adapted to the process conditions in sheet-bulk metal forming. Current results reveal that workpiece-side tailored surfaces in terms of surface adjustments by micro structuring and abrasive blasting are suitable methods for influencing the friction factor and thus, to control the material flow in SBMF processes. These results have been proven for different sheet-bulk metal forming processes.

Fine Machining of Tool Surfaces

Due to the high stresses in cold forging, high speed steels (HSS) and cemented carbides (CC) are often used as tool materials. In many cases, complex tool geometries are hard machined by electrical discharge machining (EDM). For improvement of surface properties the white layer caused by EDM is usually removed by cost intensive polishing. For reduction of polishing effort as well as for improvement of ED machined surfaces different post machining methods after EDM are available. In this project, the fatigue behavior of tools made of HSS and CC manufactured by the process chain “EDM - post machining - polishing” has been investigated. The results of rotating bar bending fatigue tests show a strong influence of tool manufacturing and resulting surface properties on the fatigue strength. In this regard, the integration of combined blasting and peening improves the fatigue behavior. The transferability of laboratory results to industrial cold forging could be proven in serial production tests.

Microforming of bulk metal components from band material

The complexity of microcomponents is an increasingly required feature, especially to satisfy the needs of industrial fields like electronics and micromechanics. In order to manufacture such metal components with high production rates, the knowledge of bulk forming is adapted to these fields. In microforming, besides the so called “size effects”, more complex forming processes have to be realized because of handling difficulties caused by small workpieces. A promising approach to simplify the multi-step production of complex microcomponents is given by bulk microforming from metal strip. The positioning problematic can be extremely simplified by using the metal strip as raw material and support of the workpiece through the different forming stages. The results of these studies will lead to a definition of the achievable geometries and a review of further one- and more step forming processes from the strip plane. A tooling system has been designed on the basis of a numerical study, realizing an experimental set up that allows the study of single forming steps as well as an entire forming chain. The design and validation of a 3D simulation model together with the analysis of the experimental results support the optimization of the metal flow during single as well as multiple step bulk forming processes. The second phase of the project focusses on two main topics. The strip deformation and the possibilities to control the material flow will be studied, focusing the research in particular on tribology and blank-holder design. Simultaneously, a cup extrusion process from metal strip will be analyzed as single and as multi-step microforming, studying size effects and comparing the two approaches. The identification of the best solution for a more effective process with minor consequences on the handling is expected.

Manufacturing error-free goods at first time (http://www.megafit-project.eu)

The reduction of the number of defects in the manufacturing of complex workpieces cannot always be achieved in the design of a robust process. Another approach is seen in in-line measurement and real-time adaptive process control, supported and interfaced by a metamodel, result of an in-depth process knowledge. This methodology is developed within the EU-project MEGaFiT (Manufacturing Error-free Goods at First Try), applied to two different production technologies: additive manufacturing and multi-step microforming. The subproject of the LFT is focusing on numerical and experimental studies of a microcoining process which is part of the multi-step microforming. After the design of the microcoining step on the basis of a first numerical study, the FE model was further developed and validated by a simplified experimental set up, providing the necessary database for the design of the interface between on line measurement and on line control of the microforging process. Within the project the validated model has been also integrated with the other simulations representing each step of the microforming process. This solution enabled also the study of the interactions between forming stages and the conduction of a sensitivity analysis on the whole manufacturing chain. Finally, the designed process control has been successfully implemented on the demonstrator process, proving the increased quality of the produced workpieces.

Reduction of friction in EHD-contacts by microstructured surfaces of components – design, layout and manufacturing by forming

Subproject within the Priority Program 1551 “Resource efficient design elements”
In highly loaded revolving sliding contacts, like cam follower matchings, specifically inserted defined microstructures have the potential to reduce friction in the contact zone of components. Likewise, the wear behavior of such microstructured surfaces determines the durability of components. Within the first phase of this project a simulation based method was developed in collaboration with a partner institute in Erlangen that allows the design of microstructures adapted to the individual tribological load collective. The focus of the LFT was on the elaboration of the technological basis

for structuring of components by a combined extrusion micro coining process coping with the demands of large-scale production. After confirmation of the feasibility of the combined process in the first phase, the second phase aims to determine the potentials and limits of microstructuring in dependence of the applied manufacturing technology. Due to its filigree geometries, the production accuracy of the micro coining punch by micro electrical discharge machining plays a significant role. In addition interdependencies of the different technologies being used will be examined. For an overall view of the product life cycle the characterization of microstructured surfaces is of vital importance as a junction between design and manufacturing of the components. Furthermore the analysis of wear behavior in operation will be covered by this investigation. In cooperation with several subprojects within the Priority Program 1551 the results will be summarized in a manufacturing matrix.

Mechanical joining of dissimilar materials by shear clinching processes without pre-punching (shear clinching)

Subproject B5, Priority program 1640 - “joining by plastic deformation”
An efficient use of energy and raw materials requires the design of components based on lightweight structures. One possible approach is the use of different metallic materials or metals and polymers in composite construction. By suitable combinations of materials functional performance, operational safety and resource efficiency can be improved. Therefore, it is essential to establish a reliable component connection by means of adequate joining technologies. This project focuses on the research of an innovative joining operation of different materials without additional aids. The process is based on a clinching process, where the connection results from a material flow of the upper joining partner behind the pre-cut bottom partner. In contrast to this method, the mechanical joining is performed without pre-cut operation in the investigated shear clinching process. This leads to a reduction of steps in the process chain. A great potential in this development is the identification of the relevant parameters of the process and the development of a process window. Another aim of the project is the adjustment of the tool components. Therefore recent work focuses on the definition of characteristics for a suitable shear-clinching joint and the strength of the connection could be improved. Further a damage based numerical model for parameter studies was qualified.

Individualized forming tools by additive manufacturing

Subproject BFS 1117-14 TP1, Cooperative project “ForNextGen – Next Generation Tools”
By taking the costumers requirements more into consideration, the variation of products increases. Thus, the companies need to investigate flexible processes to guarantee an easy product change. Advantages in additive manufacturing processes allow the production of unique customized parts. As the trend of individualization of products is not just limited on design parts, but also for highly loadable parts, for example produced by forging, flexible manufacturing processes have to be developed. In this project the Laser Metal Deposition (LMD) is qualified for the production of forging tools. Process windows for high-carbon tool steels are investigated by measuring the shape of single welding tracks to delimit the process parameters. After identifying the best settings in order to build three dimensional parts, one layer is welded and the waviness of the surface is measured to classify optimized parameters. Subsequently several layers are welded on top of each other to build a three dimensional cube. To isolate the ideal parameters the density and the inner structure of the cubes are analyzed. The investigations have shown that even with high-carbon tool steels three dimensional structures can be produced by LMD without cracks by using a high energy density. Further investigations will focus on manufacturing of hot and cold forging tools by LMD. These tools will be tested within the forming process.

Stress adapted design of reinforcement system

Study, funded by the German Cold Forging Group (GCFG)
The aim of the study is the description of the current state of knowledge for reinforcement systems in cold forging under the consideration of security issues. Special interest is put on the development of approaches for the realization of increased prestress by means of numerical simulation. For this

study a literature review and a survey among the members of the GCFG was conducted and supplemented by recommendations of the tool steel manufacturers. In addition, numerical calculations are carried out in order to identify factors influencing the magnitude and distribution of prestresses and to identify levers for realizing increased prestresses.

Catalogue for cemented carbides

Study, funded by the German Cold Forging Group (GCFG)
Aim of this study was the development of a catalogue which recommends WC-Co-based cemented carbides for tooling applications in cold forging industry. Within the study, typical applications of cemented carbide based tools were identified by a survey among the members of the GCFG. The tool stresses for those standard tool applications were determined by means of numerical simulation. For the load cases and the corresponding requirements the cemented carbide manufacturers suggested favorable cemented carbide grades. Beside these recommendations, the catalogue includes knowledge which is relevant for tool application. In this context, the catalogue summarizes relevant information regarding properties, machining and design of cemented carbide based forming tools.

Publications:

- Andreas, K.; Kiener, C.; Engel, U.; Merklein, M.: Smart FE-Based Tool Design in Cold Forging. Advanced Materials Research 1018(2014), pp. 309-316
- Andreas, K.; Merklein, M.: On the tribological influence of coatings in cold forging. In: Bouzakis, K.-D.; Bobzin, K.; Denkena, B.; Merklein, M. (Edtrs.): Proc. 11th Int. Conf. THE "A" Coatings in Manufacturing Engineering, 2014, pp. 23-32
- Andreas, K.: Einsatz des Hochleistungswerkstoffes Hartmetall in der Umformtechnik - Hartmetall als Werkzeugwerkstoff. Zeitschrift Konstruktion 5/12(2015), pp. IW5-7
- Andreas, K.: Beeinflussung der Werkzeuglebensdauer durch werkzeugseitige Anpassungen. In: Buchmayr, B. (Edtr.): Proc. of XXXIII. Verformungskundliches Kolloquium, Lehrstuhl für Umformtechnik, Montanuniversität Leoben, 2015, pp. 158-163
- Gröbel, D.; Hildenbrand, P.; Engel, U.; Merklein, M.: Influence of tailored blanks on forming of cold forged functional elements in a sheet bulk metal forming process. In: Stahl-Institut VDEh (Edtrs.): Proceedings METEC & 2nd ESTAD, 2015
- Gröbel, D.; Koch, J.; Vierzigmann, U.; Engel, U.; Merklein, M.: Investigations and approaches on material flow of non-uniform arranged cavities in sheet bulk metal forming processes. Procedia Engineering 81(2014), pp. 401-406
- Gröbel, D.; Merklein, M.; Schneider, T.: Sheet-Bulk Metal Forming. In: Tekkaya, A.E.; Homberg, W.; Brosius, A. (Edtrs.): 60 Excellent Inventions in Metal Forming, Springer, 2015
- Hildenbrand, P.; Schneider, T.; Merklein, M.: Flexible Rolling of Process Adapted Semi-finished Parts and its Application in a Sheet-Bulk Metal Forming Process. Key Engineering Materials 639(2015), pp. 259-266
- Hildenbrand, P.; Sieczkarek, P.; Matthias, S.; Löffler, M.; Besserer, H.: Inkrementelles Umformen dünnwandiger Funktionsbauteile unter Einsatz prozessangepasster Halbzeuge durch Verfahren der Blechmassivumformung. In: Tekkaya, A. E.; Liewald, M.; Merklein, M.; Behrens, B.-A. (Edtrs.): Tagungsband zum 18. Workshop Simulation in der Umformtechnik & 3. Industriekolloquium Blechmassivumformung 2015 - DFG Transregio 73, Shaker Verlag Aachen, 2015, pp. 149-170
- Löffler, M.; Gröbel, D.; Engel, U.; Andreas, K.; Merklein, M.: Analysis of Effectiveness of Locally Adapted Tribological Conditions for Improving Product Quality in Sheet-Bulk Metal Forming, 2015, accepted

- Löffler, M.; Schneider, T.; Vierzigmann, U.; Engel, U.; Merklein, M.: Locally Adapted Tribological Conditions as a Method for Influencing the Material Flow in Sheet-Bulk Metal Forming Processes. Key Engineering Materials 639(2015), pp. 267-274
- Löffler, M.; Freiburg, D.; Gröbel, D.; Loderer, A.; Matthias, S. ; Stangier, D. ; Weikert, T.: Untersuchung von Tailored Surfaces hinsichtlich ihres tribologischen Einflusses auf Prozesse der Blechmassivumformung. In: A.E. Tekkaya, M. Liewald, M. Merklein, B.-A. Behrens (Edtrs.): Tagungsband zum 18. Workshop Blechmassivumformung & 3. Industriekolloquium Blechmassivumformung 2015 - DFG Transregio 73, Shaker Verlag Aachen , 2015, pp. 132-146
- Merklein, M.; Löffler, M.; Schneider, T.: Plastic flow and its control in sheet-bulk metal forming of thin-walled functional components. CIRP Annals - Manufacturing Technology 64(2015)1, accepted
- Merklein, M.; Hildenbrand, P.; Schneider, T.: Application of Process adapted semi-finished Parts for the Production of Thin-walled Components via Sheet-Bulk Forming. In: Kawalla, R. (Edtr.): AutoMetForm / SFU 2014, ACATRAIN e.V., 2014, pp. 58-66
- Müller, M.; Vierzigmann, U.; Hörhold, R.; Meschut, G.; Merklein, M.: Development of a testing method for the identification of friction coefficients for numerical modeling of the shear-clinching process. Key Engineering Materials. 639(2015), pp. 469-476
- Müller, M.; Hörhold, R.; Meschut, G.; Merklein, M.: FE-based study of the cutting operation within joining by forming of dissimilar materials using shear-clinching technology. Adv. Mater. Res. (2015), accepted
- Schneider, T.; Merklein, M.: Sheet-bulk metal forming - potential and challenges of a new class of forming processes. In: Khan, A.; Yu, H.Y. (Edtrs.): Proceedings of PLASTICITY '15: The Twenty First International Symposium on Plasticity and its Current Applications, 2015, pp. 169-171
- Stellin, T.; Engel, U.; Merklein, M.: Experimental Study of a Microforging Process of Parallel Ribs from Metal Strip. In: Annoni, M.; Fassi, I.; Wiens, G.J.; Dimov, S. (Edtrs.): Proc. 4M/ICOMM2015 Conf., Research Publ., 2015, pp. 218-221
- Stellin, T.; van Tijum, R.; Merklein, M.; Engel, U.: Study of Microforging of Parallel Ribs from Metal Strip. In: Larkiola, J. (Edtr.): Material Forming - ESAFORM 2014, 2014, pp. 565 – 572
- Stellin, T.; Merklein, M.; Engel, U.: Investigation on a Microextrusion Process of Parallel Protrusions from Metal Strip.In: M. Jun, S. Park (Edtr.): Proc. 8th Int. Conf. Micro Manufacturing, 2013, pp. 169-174
- Weschta, M.; Schrader, T.; Tremmel, S.; Merklein, M.; Wartzack, S.; Engel, U.: Mikrostrukturierung von Tassenstößeln zur Reibungsreduzierung im Ventiltrieb – Herstellung, Simulation und tribologische Charakterisierung. Tribologie und Schmierungstechnik 61(2014)1, pp. 21-28

Institute for Metal Forming (IMF)
TU Bergakademie Freiberg

GCGF Working Group "Materials"

The working group was founded in 2009 and is one of four GCFG working groups. Currently, working group meetings take place twice a year in spring and autumn. The working group **"**Materials**"** deals with topics in the fields of materials quality, process safety, and materials development. In addition, external lectures will be organized at the group meetings. These are thematically selected in such a way that the group will be informed of recent developments from the side of the steel manufacturers and to exchange information between steel producers and steel processors.

Integrative process and material development of a hardenable AFP-steel for energy-efficient and distortion-reduced manufacturing for cold formed high-strength massive components

The projects aim is the development of a novel precipitation-hardened steel including a production and application technology. The steel shall be quite soft during cold forming as well as getting higher strength in a subsequently low temperature annealing due to fine precipitations. Therefore, hardening and tempering will be unnecessary and so the saving of time and costs are possible. The recent development covers two different alloying concepts and three laboratory ingots. Therefore, the IMF Freiberg and the IEHK Aachen collaborate closely with several companies of the cold forming and steel production industry. This research project is accompanied and funded by the AiF.

During the first period simulations were executed at IEHK Aachen to identify the optimal composition of micro alloying elements (Nb, V). Then, the steels were produced at the IEHK. The IMF Freiberg has executed a limited test matrix to investigate the fundamentally effectiveness of the two different alloying systems which are based on ultra-fine Cu precipitations and the hardening through micro alloying elements. The three test steels have the same alloying mixture, except of Cu and the micro alloying’s for a proper comparison. The microstructure and precipitation characterisation will be done by the IEHK. After that, a wider test matrix will be conducted at the IMF and one steel will be chosen.

The 2nd period contains the development of a deformation strategy close to the industrial processing at the IMF Freiberg. In the third period, the industrial project partners will produce a batch of the developed steel processing in accordance with the investigated processing route. They will manufacture various parts to proof the reliability of the small-scale former results. All results will be available to the industrial project partners and should give them an advantage to produce larger cold forged parts and the ability of cost savings.

Development of a method to characterize the workability in the cold forging

There is a need for research in the GCGF Working Group "Materials" to a process-oriented evaluation of the formability in cold forging. The study aims to develop new suitable method for the rapid assessment of the workability of various materials and material charges. The research activities include the development, manufacturing and subsequent testing of an experimental tool. An important criterion in the tool development is a simple to use as possible and a compact design, so that the tool can be effortlessly integrated into a laboratory.

Sintering, hot forming and characterization

Subproject A6, Collaborative Research Centre CRC-799 “Design of tough and transformation toughened composite materials and structures based on Fe-ZrO_2”

The subproject A6 involved with the study of conventional sintering route, the Spark Plasma Sintering (SPS) technology as well as the rolling of sintered material with a final sheet forming. The goal is to analyze the relationship between the material condition, the process parameters and the compaction and the material flow with the elucidation of mechanisms. Based on the research results, it will be possible to systematically set materials properties through the processing and shaping.

Manufacture of fasteners from magnesium alloys with improved properties

Project content includes the technology and tool development for the production of fasteners, mainly of screw, from caliber-rolled, drawn and scalped drawn high quality magnesium wires. These Mg-screw connectors require an optimized performance in terms of their mechanical, static and dynamic characteristics. Mg-screw can't be purchased at the time in the world market. Compared to the currently applied screws made of aluminium alloys, and due to elimination of material mixes, the electrochemical potential and the weight shown benefit. Also favourable performance characteristics and cost efficiency to manufacture and application are noticeable.

Development of a method for low-temperature testing of wire materials and fundamental investigations on materials behavior in the temperature range -50 to -80°C

The aim of the project is the development of increased potential applications for steel wire materials in products, being exposed to -80°C operating temperature. To investigate the material behavior at low temperatures and the suitability of certain wire materials for such applications, initially an appropriate test method has to be developed. This method reflects the expected loads in the application close to reality. In addition to simple tensile and torsional loads especially multiaxial stress states as well as different forms of load dynamics are taken into account. To perform such tests a suitable experimental setup need to be developed, technically implement and tested.

Another object is to enhance the general state of knowledge on the behavior of steel wire materials, at temperatures ranging from -50 to -80°C. For this purpose, selected investigated wire materials and their behavior as a function of the temperature, the type of load and the material properties are modeled. The results of these studies provide an indication of the specific wire materials, which are suitable for low temperatures use. Otherwise, they allow us to derive starting points for the development of special steel wire materials with improved low temperature properties.

Manufacture of fasteners from bainitic steels

Currently, bainitic steels are gaining popularity in the field of forging. Therefore, at the Institute of Metal Forming different types of bainitic steels have been investigated. Starting with the chemical analysis, over hot forming and cold forming to final analysis, several process chains for these steels have been developed and patented. The portfolio of the Institute of Metal Forming contains as well low carbon steels as also high carbon steels. Both materials were part of investigations concerning deformation behavior in cold and warm forging. As could been demonstrated, increased temperature improves the workability and reduces the resistance to deformation. Therefore cold forming of bainitic steels at elevated temperatures becomes more attractive. Based on these findings, new technologies of forging for bainitic steels were developed.

New approach of void closure in large ingots

At present, voids in casted ingots are still a challenge in bulk metal forming. A lot of researcher investigated the closing behavior during the open die forging process and try to find new models for a correct void closure prediction. There are two main problems. On the one hand, artificial pores were analyzed in the most publications, mostly regular voids, for example spherically. But normally the structure is more a fractal one. On the other hand, a challenge is the inner surface of the pores. That means based on the cooling process and the forming of inner voids dendrites shape the form of inner pore surface. Especially at the end of void closing process the dendrites influence the end of closing process and the recrystallization behavior. The aim is to find a new global empirical approach to combine the macroscopic closing behavior and the microscopic behavior on dendrites level.

Hot forming with oscillating tools: Effect on tool load and temperature distribution in workpiece

The pre-studies on hot forging with an oscillating tool, carried out at the Institute of Metal Forming back in the ´90s, have shown, that a work reduction up to 30% is possible. Due to a shorter contact duration between tools and workpiece the heat loss in the workpiece can be reduced. Furthermore due to the non-continuous deformation a static recrystallization occurs in workpiece. This leads to a lower flow stress during the whole deformation process, which results in a decreased tool wear and load. In addition the overlapping of the interrupted deformation and static recrystallization should lead to noticeable microstructure changes within the workpiece, which are to be investigated.

DFG Research Group: Low loss electrical steel sheets for highly efficient electrical drives

The aim of the proposed research group is to expand the scientific knowledge and to improve understanding of the dependence of the electromagnetic losses on the process parameters of the production, processing and operation of electrical steels used in electrical drives. The interdisciplinary nature of the research group enables a holistic and systemic view of the entire process chain, from the materials production to their final application in the electric drive. In terms of a continuous process and property modeling and taking into account the latest technological developments in the field the existing interdependencies between material properties, manufacturing and processing technologies as well as the specific conditions of application are taken into account. In two steps covering a total time frame of six years, the existing gaps in the virtual process chain will be closed to develop an integrated process model. Within the project, the theoretical basis for explaining the behavior and properties of electrical steel-based materials should be extended significantly. In particular, new scientific models regarding the dependence between electromagnetic losses and microstructural properties developed within production and processing of the electrical steels will be developed.

Substitution of Rare Earth Elements in High-strength Wrought Magnesium Alloys – SubSEEMag

The project aims to develop new Magnesium strip and sheet materials which exhibit high strength and ductility, low flammability and improved creep resistance without using rare earth alloying elements. The research involves the use of magnesium alloys containing calcium as well as improvements regarding the technological process chain of twin-roll casting, hot rolling, forming, joining and surface treatment. The project consortium includes two research institutes, six industrial enterprises and three more companies as associated partners.

Hybrid Compound Materials for Lightweight Car Bodies – LEIKA

This project involves the development of new hybrid compound materials combining CFRP with layers of steel respectively magnesium sheet. Task of the IMF within the project is to develop efficient rolling technologies for the production of thin magnesium strip with suitable surface properties and good processability.

Multi Material Lightweight Constructions for Electro Mobility – SMiLE

The projects overall target is to develop a car body for an electrical vehicle using different lightweight materials (CFRP and light metals) in an intelligent mixture. Task of the IMF is to develop production technologies for magnesium sheet and strip materials with improved formability in order to allow the use of highly productive processing technologies.

Development of Magnesium Wire Reinforced Plastic Compounds

The target is here to develop a new hybrid compound material using thin Magnesium wire and wire structures in combination with a thermoplast matrix. The new material should show an improved crash performance compared to conventional plastics because of the ductility provided by the wire structure. The task for the IMF is to develop a calibre rolling technology for the production of small diameter rolled wire down to below 5 mm.

Publications:

- R. Kawalla, A. Nam, S. Guk: “Technological methods to control the final properties of rolled product”. International conference "The modern metallurgy at the beginning of the new millennium", 17-21.11.2014 in Lipetsk T. 1, S. 36-43, ISBN 978-5-88247-675-4
- S. Guk, W. Müller, K. Pranke, R. Kawalla: “Mechanical Behaviour Modelling of an Mg-Stabilized Zirconia Reinforced TRIP-Matrix-Composite under Cold Working Conditions”. Materials Sciences and Applications, No. 5 (2014), pp. 812-822
- S. Guk, K. Pranke, W. Müller: “Flow Curve Modelling of an Mg-PSZ Reinforced TRIP-matrix-composite”. ISIJ International, Vol. 54 (2014), No. 10, pp. 2416–2420
- S. Guk, A. Yanina, R. Kawalla, H. Berek, J. Räthel: “Densification and properties of an Mg-PSZ reinforced TRIP-Matrix-Composite produced by hot pressing: Comparison with other

powder metallurgy techniques". International Science & Technology Congress OMD-2014, Hrsg.: MISIS, Moskau, ISBN: 978-5-905714-27-6, pp.364-369

- S. Guk, K. Pranke, W. Müller, A. Yanina: „Development of High-Strength TRIP-Matrix-Composite Materials", in: Proc. of the Int. Conf. of production and processing of cladded materials and metal matrix composites MEFORM 2014, ISBN 978-3-86012-481-9, Altenberg 26.03.-27.03.2014, Herausg.: ACATRAIN e.V., Verein für Weiterbildung an der TU Bergakademie Freiberg, Institut für Metallformung, pp. 149-159.

Institute of Forming Technology and Lightweight Construction (IUL)
TU Dortmund University

Systematic Process Control in Cold Forging and Heat Treatment for Minimizing Distortion

The aim of this research project, which is performed in cooperation with the IWT Materials Science, Bremen, is the specific adjustment of process parameters in cold forging and subsequent heat treatment in order to reduce the distortion of the formed components. On the basis of experimentally conducted results in the previous project "Analysis of the Active Correlation between Heat Treatment and Distortion of Cold Forging Workpieces", the influence of further factors on the distortion mechanisms, like the hardening behavior of the material or the anisotropy due to perlite banding, are investigated. A coupled simulation of the process steps cold forging, ejection, and heat treatment is performed in order to detect potential influencing factors of distortion in advance. Based on these results, process parameters can be changed to finally reduce the distortion. This analysis of the residual stresses is highly relevant, as their release during the heat treatment can cause distortion.

Manufacture by Forming and Characterization of Actuator Profiles Based on Shape-Memory-Alloys

The aim of the research project is to manufacture structural components made of shape-memory metal matrix composites (SM-MMC) with an actuator function by composite extrusion and further forming processes. The mechanical and technological fundamentals of this approach are analyzed. Furthermore, the process limits of SM-MMCs are investigated. For achieving the shape-memory effect, NiTi wires are embedded into an aluminum matrix under different temperature and stress conditions in order to achieve a defined mechanical response of the produced profile. First investigations have shown a gapless embedding of the NiTi wires in the aluminum matrix, which is a significant requirement for using the full potential of SM-MMCs.

Basic Investigations on Hollow Lateral Extrusion of Additional Shape Elements

The aim of this joint project between the IUL and the Institute for Metal Forming Technology at the University of Stuttgart is to investigate the basics of the manufacturing process "Hollow Lateral Extrusion" without a lateral mandrel. The identification and analysis of the interaction of geometry and process parameters by numerical simulations and experiments are two of the main aspects of this project. In initial studies the influence of the main process parameters, like number and position of the lateral shape elements, on the dimensional accuracy of the lateral shape elements was investigated. Based on these results, new tool concepts that can directly influence the material flow and improve the dimensional accuracy will be developed and tested.

Optimization of Workpieces by Forging of Composite Aluminum Extrudates

In this project, the specific strength of aluminum extrudates is further improved by a combination of composite extrusion with discontinuous reinforcement elements (RE) for local reinforcement and composite extrusion with continuous RE, such as high-strength steel wires. The produced semi-finished products are subsequently forged in this cooperative research project to reinforced finished parts at the Institute of Forming Technology and Machines of the Leibniz University Hannover. For this approach, different types of reinforcing elements with varying size, shape and materials were embedded into the aluminum matrix during the extrusion process. In addition to this variation, the RE were positioned centrically as well as eccentrically in the prepared billet in order to define the radial and axial position of the RE within the reinforced profile.

Extrusion Dies with Local Internal Cooling Channels Manufactured by Additive Manufacturing Technologies for Extending the Process Limits in Hot Extrusion

The fundamentals of applying dies manufactured by rapid tooling with conformal cooling channels for the extension of the process limits in hot extrusion of aluminum were investigated. Tools based on the layer-laminated manufacturing method and laser melting were developed and their performance explored. The interactions between the workpiece, the die, and the main process parameters were analyzed by experimental, analytical, and numerical investigations. Experimentally, by applying the inner local die cooling during hot extrusion of the hard-to-extrude alloy EN AW-7075, an increase in productivity of up to 300 % could be achieved.

Expanding Technological Horizons when Forging in Different Temperature Ranges

In this collaborative project, embedded into the Pre-Competitive Cooperative Industrial Research Project “Lightweight Forging – Innovation Network for Technological Progress in Part, Process and Material Design for Forged Parts in Automotive Technology”, the IUL is investigating the influence of different process strategies for forward rod extrusion for the processing of high strength material. Besides multi-stage extrusion, the design of the extrusion die is altered in terms of cone angle and extrusion ratio. Additionally, the produced rods are further treated by a furnishing process in order to increase the surface hardness and to induce compressive residual stresses into the surface of the rods. This approach is also applied for heat treated rods in order to further increase the strength of the material.

Lightweight Design through Targeted Generation of Local Part Properties

In this collaborative project, embedded into the Pre-Competitive Cooperative Industrial Research Project “Lightweight Forging – Innovation Network for Technological Progress in Part, Process and Material Design for Forged Parts in Automotive Technology”, the IUL is investigating a material model for numerical simulations, which is capable to predict the final mechanical properties of the processed material after various forming and machining operations.

Publications (excerpt):

- Ben Khalifa, N., Foydl, A., Pietzka, D., Jäger, A., Tekkaya, A. E., 2014. Extrusion of Multi-Material Components. In: Proceedings of the ASME 2014 International Manufacturing Science and Engineering Conference MSEC2014, Keynote Speech, Detroit, Michigan, USA, (CD).
- Dahnke, C., Pietzka, D., Haase, M., Tekkaya, A. E., 2014. Extending the Flexibility in the Composite Extrusion Process. In: Procedia CIRP Vol. 18, International Conference of Lightweight Components, ManuLight 2014, Dortmund, Germany, pp. 33-38.
- Hölker, R., Haase, M., Ben Khalifa, N., Tekkaya, A. E., 2014. Increased Productivity in Hot Aluminum Extrusion by Using Extrusion Dies with Inner Cooling Channels Manufactured by Rapid Tooling. In: Key Engineering Materials 611-612, Esaform 2014, Espoo, Finland, pp. 981-988.
- Schwane, M., Dahnke, C., Haase, M., Ben Khalifa, N, Tekkaya, A. E., 2014. Composite Hot Extrusion of Functional Elements. In: WGP Kongress 2014, Erlangen, Germany, pp. 223-228.
- Tekkaya, A. E., Ben Khalifa, N., Grzancic, G., Hölker, R., 2014. Forming of lightweight metal components: Need for new Technologies. In: 11th International Conference on Technology of Plasticity, ICTP, Keynote Speech, Nagoya, Japan, pp. 28–37.

Fraunhofer Institute for Mechanics of Materials IWM, Freiburg

Activities of the IWM group *Forming Processes*

- Forming process simulation (sheet metal forming, bulk metal forming, forging, specialized processes)
- Calculation of microstructural development (e.g. textures)
- Development of material models and their numerical translations
- Description of the thermodynamics and kinetics of phase formation processes
- Identification of material properties, thermophysical parameters and thermomechanical properties.

Micromechanical material models for prediction of damage and failure in cold forging processes

In frames of the AiF project a practically relevant extension of the known modelling methods with regard to the description of forming limits of steels typically used in cold forging is developed and implemented in a commercial finite element code. The modeling approach is based on the micromechanical damage concept which represents the microstructure evolution more detailed than phenomenological models and provide better prediction of damage during the forming process. In this project the well-known damage model of Gurson-Tvergaard-Needleman was essentially extended and applied to the numerical simulations of industrial forging processes. It is shown that in combination with coalescence criteria this model is able to accurately describe material failure in cold forging. In future an integrated concept to the enhanced computer-aided design of forming processes through the advanced material modeling and prediction of damage will help the forging industry to avoid cost- and time-consuming testing cycles during the tool design and to apply complex component geometries more easily.

Publications:

- Helm, D.; Butz, A.; Raabe, D.; Gumbsch, P.: Microstructure-based description of the deformation of metals: theory and application, JOM – Journal of the The Minerals, Metals & Materials Society (TMS) 63/4, 26-33 (2011)
- Kadkhodapour, J.; Butz, A.; Rad, S.Z.: Mechanisms of void formation during tensile testing in a commercial dual-phase steel, Acta Materialia 59/7, 2575-2588 (2011)
- Zapara, M.; Tutyshkin, N.; Müller, W.H.: Growth and closure of voids in metals at negative stress triaxialities, Key Engineering Materials 554-557, 1125-1132 (2013)
- Zapara, M., Augenstein, E., Helm, D.: Prediction of damage in cold bulk forming processes, Proc. Appl. Math. Mech. 14, 1037 – 1040 (2014)