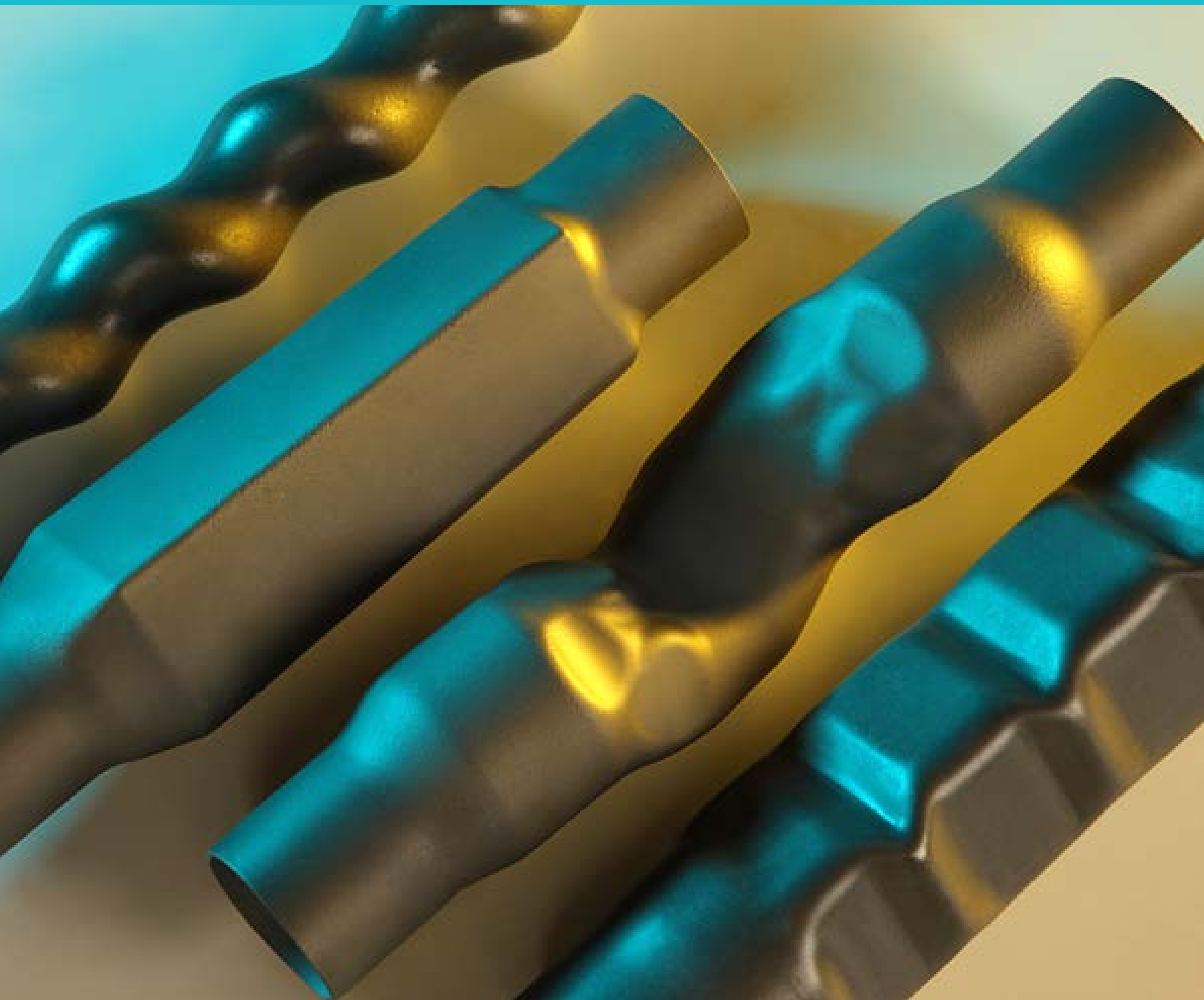
FRAUNHOFER INSTITUTE FOR MACHINE TOOLS AND FORMING TECHNOLOGY IWU

ACTIVE MEDIA-BASED FORMING



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ECONOMICALLY EFFICIENT REALIZATION OF FUNCTION AND SOPHISTICATED DESIGN

Active media-based forming is well established as a means of industrial production of components not just in the automotive industry, but also in the furniture industry or in heating and sanitary engineering applications. This process enables efficient manufacture of industrial goods from tubes, profiles and metal sheets, using liquid or gaseous media.

Sheet hydroforming and the hydroforming of tubes and hollow profiles in particular have been successful areas of research activity for years at Fraunhofer IWU. We have been developing innovative ideas in this field and implementing them in collaboration with industry partners in production-oriented solutions for over twenty years. Currently our focus is on the further development of process combinations such as hydroforming and press hardening as well as hydroforming and injection molding.

We are able to process a wide variety of materials thanks to our excellent technical equipment. In addition to camshafts, exhaust parts and structural components for the automotive industry, we are entering new markets in the furniture industry and in the field of renewable energies. Examples of products include heat exchangers and solar thermal absorbers with bionic channel design as well as steel blades for small vertical-axis wind turbines.

1 *Cross-profiles of possible component geometries*
2 *Process chain of an HF node*

Processing principle for the hydroforming of tubes and profiles (HF)

The hydroforming process uses internal pressure acting in all directions to force closed profiles against a die cavity, thus forming them in a controlled manner. The forming dies usually consist of an upper part and a lower part with a corresponding parting plane. The active medium is introduced via axial sealing punches, which use axial pressure to reliably seal off the component from the environment. Depending on the component shape and sealing concept, additional material can also be forced into the forming zone in order to extend the range of component shape that can be geometrically realized. This process makes it possible to produce unique component geometries that are impossible or extremely complex to produce using other production processes. Although the option of using active media to apply external force to an internal mandrel for forming the semi-finished products is seldom utilized, but does offer interesting prospects for the lightweight construction of complex geometries.

Processing principle for sheet hydroforming (SHF)

In SHF, a variation of HF, either a single blank or a double blank is clamped between two die halves, and high pressure is applied to one side or from the inside. The blank is forced into the opposite cavity in conformity with the forming die shape and sealed off from the environment by the closing force of the two die halves. The process can be viewed as an alternative to deep drawing and stretch drawing, in which the active die components have a much simpler design.

SHF has a high potential for economic efficiency, especially for small quantities, since only one component-specific die is required for production and no shaping punch is needed. By combining SHF with further processes and especially by integrating joining operations, it becomes more economical than ever to produce components and assemblies.

Active medium

The selection of active medium is based primarily on the forming temperature and the forces or internal pressures required for forming. Cold forming is usually carried out using water-oil emulsions. Our system technology enables the realization of internal pressures of up to 400 MPa, and even up to 700 MPa for special applications. Forming temperatures of up to 1100°C can be used for warm and hot forming. The active media used in these processes are gases, especially nitrogen. Hydrothermal forming, using thermal oil and forming temperatures of up to 300°C, has been replaced by hot metal gas forming (HMGF), which uses gaseous active media. Our mobile gas pressure unit enables internal pressures of up to 120 MPa.

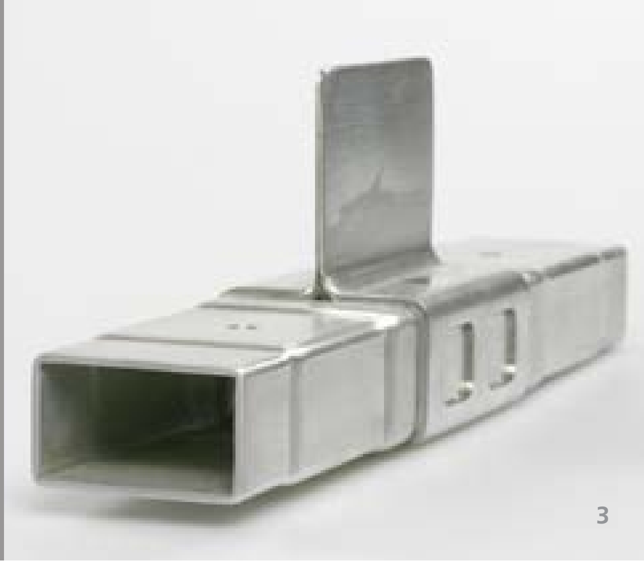
Process parameters

Apart from the active medium used, temperature plays an important role in the forming process. Depending on the requirement profile of the component and material, forming can be carried out either at room temperature, preferably using liquid active media, or at temperatures of up to 1100°C, using gaseous active media. A wide range of materials can be gently formed in both variants. The process combination of HF and press hardening in particular requires special thermal management in order to achieve high cooling rates. HMGF with form quenching (HMGF-Q) combines the hot forming processes and the quenching of the material in the cold or cooled die. The desired microstructural transformation requires cooling rates of up to 100 K/s, which can only be realized by means of adjusted heat dissipation. In addition to shortening the process chain, this also minimizes the distortion associated with conventional heat treatment.

In order to expand the technological limits and application areas, the strain rate is an additional process parameter. In combination with high forming temperatures, low strain rates – as used in super plastic forming – enable effective strains of several hundred percent. High strain rates, in turn, are addressed using high rate forming. We use electromagnetic forming (EMF) for this purpose. Our research does not only examine forming, but also cutting and joining via EMF.

Process advantages

The SHF and HF processes are both gentle to surfaces since the active medium acts on the semi-finished product without friction. Relative movements between the tool and semi-finished product only occur during feeding in the HF process and during sheet draw in the SHF process. The gentle forming makes it possible to use pre-painted semi-finished products without causing the coating system to crack or loosing gloss of the paint. In comparison to deep drawing, another substantial advantage lies in the widespreas homogeneous stressing of the material of the semi-finished product. This typically results in a more homogeneous stretching and thinning compared to the locally thinning in the side wall of drawn parts, for example. Ultimately, this means that the wall thickness of the semi-finished product can be reduced in SHF, resulting in material and weight savings.



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INNOVATIVE TOOL ENGINEERING

Die concepts for HMGF

To further test the limits of active media-based forming, it is required to apply sophisticated process control, and above all to create innovative die solutions including suitable sensors.

Expanding the forming limits of materials by means of hot forming, and the integration of hardening into the forming process, require consideration of the thermal management of a forming die. Although it is relatively easy to determine favourable temperature time cycles, it can often be challenging to implement them in the actual die. In HMGF-Q, various concepts and designs exist for dissipating the heat as close as possible to the cavity contour. The industry standard comprises bored channel systems, but these only achieve a limited cooling effect. One suitable concept that has been employed successfully lies in using thick shells for the cavity contour, with channels milled into the rear of the shells to enable cooling close to the contour. Tests have already been carried out on the application of hollow tool segments in the form of thin-walled cast shells.

Dies are normally heated using heating cartridges and / or heating media. There are also diverse variants for heating semi-finished products outside of the tool. One energy-efficient alternative is local heating of the semi-finished product inside the die. Induction heating is suitable for tubular components, but magnetic flux can also be used to heat profiles of semi-finished products.

The die materials most commonly used are tempered tool steels. Heat-resistant special alloys are required for die temperatures of approximately 800°C. Dies made of plastic, wood and grey cast iron are also suitable for small numbers of pieces or for proving feasibility.

HF joining

The advantage of being able to produce HF components with sophisticated geometries from closed profiles does come with some challenges, as shown by the example of a flangeless B-pillar made from a tube. First, there is a lack of flanges for fastening seals; second, conventional joining processes such as resistance spot welding cannot be used. In these cases, HF joining processes are applied.

No additional joining elements are used for direct joining; the load is transmitted by form and / or force fit. Lightweight camshafts developed at Fraunhofer IWU serve as an example for this method. The advantage lies in the tolerance compensation generated by the inner component, which is applied to the geometry of the outer joining partner via the internal pressure.

Indirect joints are produced using the joining processes of HF self-pierce riveting and HF clinching. In the HF self-pierce riveting process, the self-piercing rivet is supplied to the process in addition to the joining partners and joins them against internal pressure. HF clinching can be passive or active. In the active variant, an additional punch motion produces a better undercut, thus achieving higher torsional strength.

FORMING PROFILES AND FLAT PRODUCTS AT ROOM TEMPERATURE

Metal blades for vertical-axis wind turbines

The traditional cold forming of sheets and profiles at room temperature is still the most commonly used HF process in the sheet-processing industry. The AiF-sponsored “HyBlade” project, which concerns the hydroforming of metal blades for vertical-axis wind turbines, shows that new technological limits can be tested here as well. To ensure the sustainable production of such systems, it will be necessary to rethink conventional production processes. The primary focus lies on blades which, until now, have typically been made of fiber-reinforced plastics. Compared to metal materials, they are more expensive to produce and can only be recycled to a limited extent.

The “HyBlade” project involved the development of a competitive metal blade section, including the complete process chain for economic production. First, a steel sheet strip is bent using a bending punch to attain the typical blade shape. The edges are laser-welded to create a closed profile. This preform is then given its final shape in a die using HF. This calibration compensates all production tolerances of previous production steps and precisely forms the relevant aerodynamic profile. This procedure is also suitable for producing profiles with increasing complexity of cross-sections.

The advantages of steel blades are enormous. Not only is it easier to recycle them, but the cost for series production is also reduced by up to 90 percent compared to fiber-reinforced plastic blades. The accuracy that can be achieved in the production of the blades is significantly higher, and production is much quicker while still being suitable for series production.

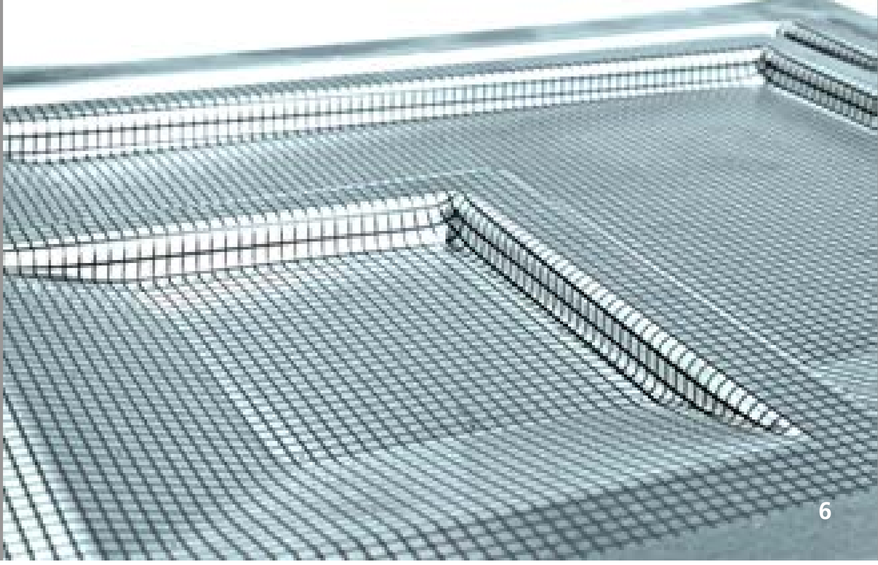
The “HyBlade” project won the Steel Innovation Award 2015 competition in the category climate protection.

Contoured basin floor outlet for a fish-friendly weir

The “fish-friendly weir” was the result of collaboration with Käppler und Pausch GmbH, based in Lausitz. It is intended to maintain the natural living conditions of fish by allowing them to migrate through streams and rivers. The centrepiece of the system is a contoured basin structure with an outlet that generates a powerful vortex. The interplay between turbine and flow duct at the outlet is crucial to the efficiency of the system. For this reason, and to enable economic production of a small number of pieces, the basin floor outlet was formed from stainless steel via SHF. Three innovations were realized in the development of the system. To keep the depth of draw low, the blank holder was designed as double-bent. Wooden tools were used to form a scaled component using SHF in order to validate the simulation model, while a cast iron die was used to produce the actual component.

The fish-friendly weir won an award in the German competition “Landmarks in the Land of Ideas 2014/2015”.

3 *HF-joined frame part*
4 *HF-joined shift fork*
5 *Metal blade section*



EXPANDING THE LIMITS OF FORMING BY USING HOT FORMING

Hot forming of stainless steel exhaust components

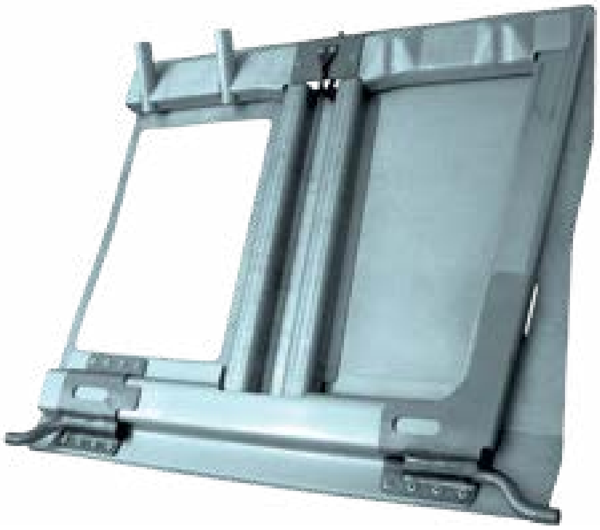
Complex HF components made of stainless steel alloys are conventionally produced in several forming stages with intermediate annealing processes. Due to the limited formability it is impossible to form complex shapes in a single stage. However, these multi-stage process chains are very cost-intensive and error-prone. Using a hot forming process can be a cost-effective way to shorten the process chain. First, the increased forming temperature prevents cold-hardening of the material; second, the forming capacity of the materials is significantly improved by a structural transformation, making HF preform and annealing processes unnecessary. The use of a gaseous active medium also removes the need for a washing process. The forming forces are low thanks to the lower material strength at higher temperatures. This means that smaller presses can be used and, in spite of the additional cost for component heating, the production cost can be significantly reduced.

A process chain to produce a production-oriented exhaust component was developed together with Salzgitter Hydroforming GmbH & Co. KG as part of an industrial project. In the conventional method, the component is preformed in a HF tool and then subjected to an annealing process before receiving its final form in a second HF step. In the new process chain the increase in the forming temperature eliminates the need for the first HF step and the annealing step, and good parts are produced directly with the final component geometry.
To keep the cycle time as low as possible, heating took place outside of the tool by using an induction system.

Super plastic forming of components for consumer electronics (SPF)

When traditional hot forming is no longer sufficient for realizing sophisticated component designs, semi-finished products with super plastic material properties are used. These enable the realization of extremely high effective strains or material strains, thus allowing for very complex geometries. The temperatures required for super plastic forming and the extremely slow strain rates ranging from 10^{-3} to 10^{-5} per second demand high energy input and extremely long process times. Even though the SPF technology requires less component-specific die engineering, components produced by this method are relatively expensive.

This technology is still predominantly used for small-series components for the sectors of aerospace engineering and medical engineering, but it is also suitable for the production of design-oriented sheet metal components for white goods and consumer electronics, as shown by the example of television frames. The latter are increasingly being manufactured from aluminum base alloys to ensure better heat dissipation. Resource-efficient, economic production is ensured when as many frames as possible are formed at the same time from one blank by using SPF. However, the small distances between the frames and the small edge radii result in severe strain on individual sheet areas, making it impossible to implement pure hot forming. Instead, materials with super plastic properties are used. Nevertheless, the process times must be further reduced to enable the economic use of this technology in series production.



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Excursus on the technology platform for magnesium wrought alloys

FROM FEASIBILITY ANALYSIS TO PROTOTYPE

Magnesium wrought alloys are predestined for lightweight construction. Magnesium components are up to 70 percent lighter than conventional solutions made of steel or aluminum. In order to transfer this potential into products ready for series production, the current highly efficient forming technologies established in the automotive industry must be further developed for this material.

Fraunhofer IWU is pursuing this objective together with Saxon companies and research institutions within the technology platform TeMaKplus.

Technology demonstrator convertible car door

The first joint project, TeMaK, examined all relevant processes along the process chain, from magnesium ingots to recycling, for the production of a convertible vehicle door using the forming technologies that are conventionally used in the automotive industry. Forming at elevated temperatures is required because magnesium wrought alloys have a very low forming capacity at room temperature. Therefore all processes were carried out in a temperature range from 220°C to 300°C.

The door frame consists of several parts: a bent frame from an extruded profile as well as a HF frame part with joined hinge reinforcements. Heat was supplied locally in the die in order to achieve the necessary forming temperature while still operating at the highest possible level of energy efficiency. To this end, the forming and joining areas were heated inductively or magnetically. Apart from the significant energy savings compared to a die that has to be fully heated and cooled, the main advantage comprises handling, as the components are inserted cold into the die and the joint assembly can be removed cold after the forming process.

Technology demonstrator rear seat back

The rear seat back is a typical structural component in automotive construction. The joint project TeMaKplus involved the design and production of a demonstrator that shows how approximately 50 percent of the weight can be saved compared to a reference assembly group. To accomplish this, the design was adapted to the specific material characteristics of magnesium. The restrictions regarding the installation space in the vehicle, attachment points and packaging remained unchanged in comparison with the series part. The structural design complied with ECE R17 and was successfully proven in a crash simulation. Apart from HF, the technologies of extrusion, shape rolling, forging and joining were further developed at Fraunhofer IWU and represented in the demonstrator.

The research on the HF process focused on simulation-assisted method planning and die design, including thermal management. The method planning and forming tests concentrated on the pressure build-up rate, which has a decisive influence on the component quality. In addition, various lubricants and die coatings were tested.

6 *Super plastic formed aluminum frame part*
7 *Technology demonstrator rear seat back*


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Excursus on lightweight camshafts

STAGES OF EVOLUTION IN COMPONENT DEVELOPMENT

For over ten years, Fraunhofer IWU has been developing processes to make camshafts lighter and the production process more cost-effective. The separation of functions led to the concept of assembled camshafts. Cam rings handle the stroke, while a tube handles the transmission of torque. The single parts are formed and joined via HF, producing hollow lightweight camshafts. The development path for the assembled camshafts was later followed by the monolithic camshafts. This development was driven by the cost for the precision production of the cam rings. These individual parts are no longer necessary if the cam geometry can be successfully formed from the tubular semi-finished product. All developments share the requirement that essential structural interfaces to the engine peripherals are maintained and the functional requirements of the current series production status are met. Advantages of the hollow lightweight camshafts include the weight, which is at least 50 percent lower, and the significantly reduced production cost.

Assembled HF camshafts

Assembled camshafts are characterized by a tubular semi-finished product and separately produced cams. The cams are joined to the tubular carrier with form and/or force fit. Camshafts of this type have been successfully used in series engines for several years.

8 *Monolithic lightweight camshafts*
9 *Demonstrator for the process combination of HF and plastic injection molding*

Monolithic HF camshafts

In contrast to assembled camshafts, the cams do not need to be joined as individual components in monolithic camshafts. Instead, the cam geometry is formed completely from the tube in the HF process. The necessary wear resistance of the cam surfaces can be ensured, for instance, by hard metal coating applied via flame spraying. For nitrated camshafts, the HF process is followed by a thermal surface treatment to achieve the required wear resistance.

HF press hardening for press-hardened camshafts

Monolithic design characterizes the newest genreation of lightweight camshafts such as nitrated and coated camshafts. Basic materials for the camshafts comprise manganese-boron alloyed steels, such as those used in press hardening of car body components. In HF press hardening, the tube is heated to approximately 1000°C, placed in the die and formed using nitrogen as pressure media. Rapid, targeted cooling of the material is used to trigger martensite formation, allowing the basic strength of approx. 600 MPa to be more than tripled. By implication, the wall thickness can be significantly reduced, thus enabling lightweight construction with steel. The advantages of hot forming, such as low springback and high shape accuracy, also result in a reduction in the grinding stock allowances for the camshafts. The application of this process significantly shortens the process chain and further lowers cost and weight.

Excursus on process combinations

SHEET / TUBE FORMING AND PLASTIC INJECTION MOLDING UNITED

Metal-plastic hybrid components have become established in the field of automotive lightweight design in recent years. They mainly consist of a thin-walled steel sheet structure in combination with suitably formed plastic areas for reinforcement. In conventional processes the metal parts are produced separately from the plastic parts. The injection molding process only includes primary shaping of the plastic parts and joining of plastic and metal components. Therefore, it is always labor- and cost-intensive to produce such components. Research as part of the federal excellence cluster "MERGE – Merge technologies for multifunctional lightweight structures" is examining single-stage processes that enable more cost-effective production of hybrid components. Two such processes are being developed at Fraunhofer IWU.

Additional research focuses on the investigation of metal-plastic joining for steel and aluminum materials in combination with various thermoplastics. In this regard an urgent objective is to replace cost-intensive bonding agents with a suitable surface treatment and surface structuring of the semi-finished products.

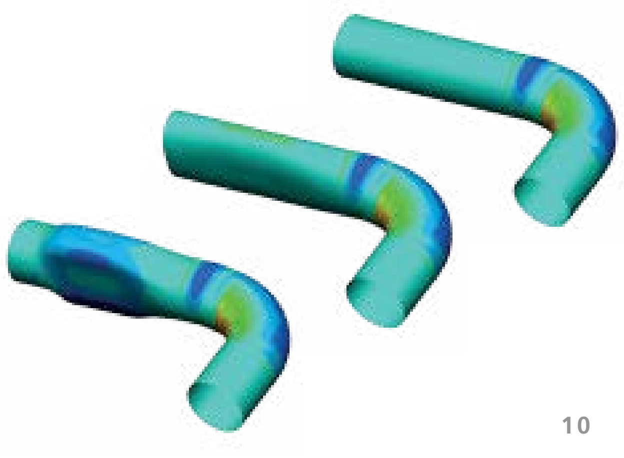
Process combination of deep drawing, injection molding and forming with the melt

The process runs in two sequential process stages in the same die. First, the sheet is formed via deep drawing, and then the injection molding takes place with the die closed. The unique selling proposition of the process developed at Fraunhofer IWU lies in using the plastic melt simultaneously as SHF active medium for advanced metal forming. This allows undercuts and other form elements to be produced, which can be used, for example, for an additional form closure. The combination of deep drawing and SHF combines the advantages of both processes and allows more complex component geometries to be formed than would be possible with the conventional method. Since current plastic injection molding machines do not provide deep drawing, the process combination was realized on a conventional deep drawing press with a connected bolt-on unit for plastic injection.

Process combination of HF and injection molding

Closed profiles offer higher stiffnesses than sheet components of the same weight, and thus holding greater potential for lightweight construction. In contrast to sheet-based metal-plastic hybrid components, encapsulation of thin-walled hollow profiles with plastic is not possible without internal support of the profiles. The profiles would collapse from the high injection pressure. The use of active media does not only provide internal support, but is also used for additional shaping during the HF. This method allows for the production of highly integrated, section-based metal plastic hybrid components in one shot, which implies high lightweight potential.

In both process combinations the challenge lies in combining two different process groups. This affects design and control of the process as well as the die design. Intensive interdisciplinary collaboration with plastics experts led to both processes being successfully proven using demonstrators.



OUR SERVICES – APPROPRIATE SOLUTIONS FOR EVERY APPLICATION

Feasibility analyses

We are happy to advise you on the identification of designs for new components as well as on the evaluation of existing geometries. We offer feasibility analyses and evaluate the technological potential.

Method engineering

The central task for designing the production processes is the method planning. Here we tap into our long-term experience gained in numerous industrial and research projects, supported by the capabilities of our FEM tools. The combination of these two aspects allows us to investigate and evaluate processes virtually, without having to produce dies.

Analysis and comparison of cost-effectiveness

In addition to technological feasibility, it is also necessary to test the economic advantage of a component design and the corresponding production process. We offer you specific support in this regard by using our experience in design, calculation and comparison of a wide variety of process variants. We will find the process that best suits the component and your production environment.

Optimization of design and process

Rarely do the first component draft and method plan represent the optimum. For this reason, we optimize them both until the desired requirements and demands have been achieved.

Depending on the application, we use commercial optimization tools (opti-s-lang) or our own methods and scripts in order to keep the manual effort low.

Simulation

Simulation is an important tool that allows us to examine processes and component designs in advance. In addition to specialized software packages (PAM2G, AutoForm), all-purpose tools (Ansys, Abaqus, LS-DYNA) and experienced staff are available to extend the previous limits.

Die design, production and try-out

We design prototypes and series dies for you according to your ideas (standards and guidelines). The production and try-out of the dies can take place in-house or in collaboration with selected external partners.

Production and analysis of prototypes

Upon request we produce initial prototypes on our systems and provide you with support up to series production of the components.

Process development

New requirements entail the development of new processes or the expansion of existing technologies. Some processes and selected project results are presented in this brochure.

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AVAILABLE SYSTEM TECHNOLOGY

Fraunhofer IWU has two hydraulic presses for active media-based forming as well as the corresponding peripherals for both component handling and component and/or die heating. Using this system technology it is possible to realize a wide range of components, from small components weighing a few grams to large components weighing approximately fifty kilogrammes.

Available presses

HF press DUNKES HS3-1500
– Closing force: 15,000 kN
– Ram stroke: 700 mm
– Work surface: 2.00 x 1.00 m²
– Table cylinder: 800 kN
– Maximum active media pressure:
400 MPa HF system with standard pressure intensifier
700 MPa HF system with additional high-pressure intensifier
120 MPa nitrogen with high-pressure gas system

The modernization of the Dunkes HS3-1500 HF press by AP&T in 2016 provided Fraunhofer IWU with excellent machinery conditions for future research projects. The flexible hydroforming system has a modular control concept that enables the integration of four pressure intensifiers (forming with water or nitrogen) and further auxiliary equipment. The system can also be used to implement cutting or pressing processes with repeating accuracy. Deep drawing processes are possible due to force-controlled displacement of the table axis (die cushion), but super plastic or hybrid forming processes have also been successfully realized and are included in current research projects.

HF press Schuler SHP 50000
– Closing force: 50,000 kN
– Ram stroke: 1500 mm
– Press table: 2.15 x 4.44 m²
– Maximum active media pressure:
400 MPa HF system standard (2 pressure intensifiers)
120 MPa nitrogen with high-pressure gas system

Available peripherals

– Systems for induction heating
– Die heating via heating water
– Power unit for heating cartridges
– Various radiant heating ovens
– Cooling unit
– Robot
– Mobile high-pressure gas system:
70 MPa nitrogen and 20 l pressure volume
120 MPa nitrogen and 10 l pressure volume
– Mobile gas pressure regulator:
10 MPa argon/nitrogen

10 *FEM simulation of the HMGF process of a titanium exhaust component*
11 *Modernized HF press*

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Title
Components produced via HMGF.