INNOVATIVE FORMING TECHNOLOGIES IN CAR BODY STRUCTURES

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Abstract

Ecological and economic reasons are forcing industry to improve efficiency and to save energy and resources. Especially for the automotive and transport industry - but also for all other industrial branches dealing with accelerated masses - lightweight design is a key issue for achieving this goal. Higher process stability, improved material exploitations, and general shortening of process chains are the most important aims of Fraunhofer IWU. The requirements of the future car achieve the lightweight construction concepts, in which materials, design and manufacturing process harmonize optimally. The usage of lightweight materials is only reasonable when their mechanical characteristics such as stability, stiffness, and temperature resistance are better than those of classic steel. The same is true for the material and production costs. Therefore, Fraunhofer IWU researches on forming and joining technologies in order to achieve the optimum usage of high-strength steels, aluminium, magnesium, and fiber composite materials. New forming technologies as press hardening or electromagnetic forming (EMF) bring positive effects by resource efficiency and energy savings. By developing new materials, it is important to design the whole process chain according to the specific material properties. Press hardening offers an effective method of forming high strength steels. EMF is a high-speed forming technology applicable for shaping, joining, and cutting electrically conductive sheet metal or hollow profile components. A target-oriented design helps to save weight by using optimally adapted structures.

Keywords: Electromagnetic forming, hydroforming, lightweight, press hardening

1. INNOVATIONS IN CAR BODY STRUCTURES

The growing demand for resources absolutely requires new efficient technologies. To be successful in global competition, energy and material efficiency need to be integrated as one of the main economically relevant dimensions for planning, operation, and optimization strategies. Material- and energy efficiency represent considerable potential for further cost reductions in the manufacturing industry. Fraunhofer IWU and research partners developed and validated holistic approaches towards significant improvements of resource efficiency in manufacturing. In a three step sequence, first material and energy use have to be assessed, processes and process chains need to be optimized, and efficiency potential on the manufacturing site and beyond its system boundaries will be raised.

In 2014 the global production of passenger cars main materials reached critical values (1662 million tons of steel, 53 million tons of aluminium, 19 million tons of copper, and 303 million tons of plastic) [1]. The ferrous metals achieved 62 % of all material used in automotive industry, whereat the non-ferrous material (aluminium, magnesium, copper) achieved only 9 %. Fraunhofer IWU sees a huge potential by using lightweight materials. The reduction of weight is one of the important tasks to reduce CO_2 emissions of car production.

Generally, following options are possible to achieve the aims of efficiency:

- application of lightweight materials
- high efficiency of forming technologies
- application of new forming technologies
- application of new structures

2. APPLICATION OF LIGHTWEIGHT MATERIALS

The use of lightweight metals (aluminium, magnesium) increases a remarkably in comparison to steel. The lower density of these materials allows significant weight saves up to 50 %. Beside the extrusion and cast parts, sheet metal parts find more solutions in the automotive industry [2]. Especially magnesium alloys have been being discussed in the construction of passenger cars for 10 years. When analyzing lightweight material engineering, referencing the characteristic strength values as Young´s modulus (E), yielding point $R_{p0.2}$, or tensile strength R_m to the density of the materials is even more important than the absolute parameters. Magnesium is the lightest useful metal with two-thirds the density of aluminium. In the TeMaK project (Technologieplattform Magnesium-Knetlegierungen) the fundamentals for the utilization of magnesium wrought alloys in a series production were outlined. During this project, a full-scale passenger car door was manufactured completely from magnesium wrought alloys AZ 31B and AZ 61 A to demonstrate the technical feasibility (**Figure 1**).

Figure 1 The inside component of a passenger car door with a joined frame

The door consists of outside component, inside component, frame with hinge reinforcement, and side reinforcement. The load-bearing structural frame consists of two extruded magnesium profile segments that are joined by welding. A complexly bent magnesium profile is used for the first segment while the second segment is a magnesium profile shaped by hydroforming at elevated temperature and simultaneously joined with the hinge reinforcements. The complete structural frame is integrated into the inside component of the door by welding. Finally, the skin (inside and outside component are rolled sheet metals) is joined with the subassembly by folding. The focus of the research was on the tempered forming (deep drawing) and joining of the structural frames by hydroforming. In two experimental series the hydroforming connection of the magnesium profile with the hinge reinforcement was studied. Therefore, the extent to which the magnesium profile can be formed in and around the hinge reinforcement by the hydroforming process was measured. The extensions in circumference achievable without component part failure by using adequate preforming operations such as forming a circular pipe to cuboid form dropped to 25 %. The reasons for this are seen in the impeded axial material feed due to the preforming geometry, the material distribution, and in the restricted material flow in the forming zone. Furthermore, scientists at the Fraunhofer IWU studied whether the form closure of the magnesium profile and hinge reinforcement can absorb sufficiently high forces without moving the hinge reinforcement on the magnesium profile. Therefore, forming experiments with various means of feeding, varying calibrating pressures, and variably inclined pressure build-up curves were analyzed. Magnesium profiles were heated in two stages for the forming process: they were inductively heated to 300 °C within 30 seconds followed by 30 seconds of maintaining this temperature at a lower performance level. The resulting component part geometry and the joining area were completely formed and correspondingly fully jointed.

Another solution of lightweight materials is the application of plastic. Different glass and carbon fibres can be economically used for mass production [3].

3. HIGH EFFICIENCY OF FORMING TECHNOLOGIES

One possibility of lightweight vehicle engineering is applying by high strength steel and ultra-high strength steel. In addition to sheet metal-based components, an increasing trend for implementing closed, weight and functionally optimized profiles for structural applications has been identified. Due to the complexity of components and the fact that the forming characteristics of metallic lightweight materials are frequently limited at room temperature, conventional forming processes such as hydroforming are reaching more and more feasibility limits. Unfortunately, liquid active media such as thermal oil cannot be used for forming because depending upon the material temperatures ranging from 800 ° to 1000 °C are needed for hardening.

Press hardening is an innovative technology by which advanced ultra-high strength steel is formed into complex shapes more efficiently compared to traditional cold stamping. The process involves the heating of the steel blanks until they are malleable, followed by formation and then rapid cooling in specially designed dies, creating a transformed and hardened material in the process. Because of this ability to efficiently combine strength and complexity, press hardened parts accomplish relatively light-weight pieces, while conventional manufacturing would typically require thicker, heavier parts welded together in more than one process under cold stamping. Press hardening can be used for forming of sheet metals, tubes, and profiles. The whole process is illustrated in **Figure 2**. There is a trend towards using more high strength materials and this is why the Fraunhofer Institute for Machine Tools and Forming Technology is studying materials with high level of strength and sufficiently high elongation at rupture for their applicability in press hardening processes based on active media [4].

In addition to 22MnB5 Fraunhofer IWU has been testing different high strength steels (LH800, 34MnB5, MW 1000L, 42SiCr). Conventional press hardening can be used to manufacture component parts that have approximately the same component part properties over their entire geometry. Unfortunately, the high level of hardness makes mechanical trimming and joining of single press-hardened parts into subassemblies much harder. Furthermore, there is a need for component parts with strength properties differing from one area to another to pass on loads and absorb impact energy. This is the reason why the Fraunhofer IWU is presently studying various technologies to achieve these tailored properties in the components. The range of feasible solutions spans from partial component part heating to various cooling rates per component part section. Tool and process design play a significant role in the control of the process chain.

Figure 2 Process chain press hardening

4. NEW FORMING TECHNOLOGIES

Based on the use of new materials it is necessary to find the available forming technology for specific material properties. Fraunhofer IWU has been developing new forming technologies for applications of sheet metal and tubes for many years. Beside conventional forming technologies, electromagnetic forming (EMF) allows shaping new geometries by a very small energetic power consumption.

EMF is a metal working process that uses electromagnetic forces to form highly electrically conductive metallic work-pieces at high speeds. In this process, a transient electric current flows through a coil due to the sudden discharge of a capacitor bank via high-speed switches. The coil current induces a magnetic field and a current in the nearby conductive work-piece (sheet metal, tube or hollow profile) which is directed opposed to the coil current. The magnetic field, together with the eddy current, induces Lorentz forces that drive the deformation of the work-piece. In an EMF process, the material can achieve velocities in the order of up to 100 m/s in less than 0.1 ms. EMF is expected to help overcoming some formability barriers that prevent more widespread use of materials such as aluminium in lightweight structural applications. Depending on the geometry and the arrangement of work-piece and tool coil, this forming principle can be used for compression and expansion of tubes or other hollow profiles as well as for forming of flat or 3-dimensionally preformed sheet metals [5].

The typical setup for sheet metal forming consists of a spirally wound tool coil, above which the work-piece and the die are positioned. Tubes or profile cross sections can be reduced by means of compression coils or widened by means of expansion coils. In any case the work-piece is formed in the direction away from the tool coil. Depending on the forming process, the coil is positioned inside or outside the tubular component. Thereby, the forming machine can be represented in a simplified model by an equivalent circuit consisting of a capacitor C, an inner inductance L, and an inner resistance R [4]. The main forming principles are illustrated in the **Figure 3**.

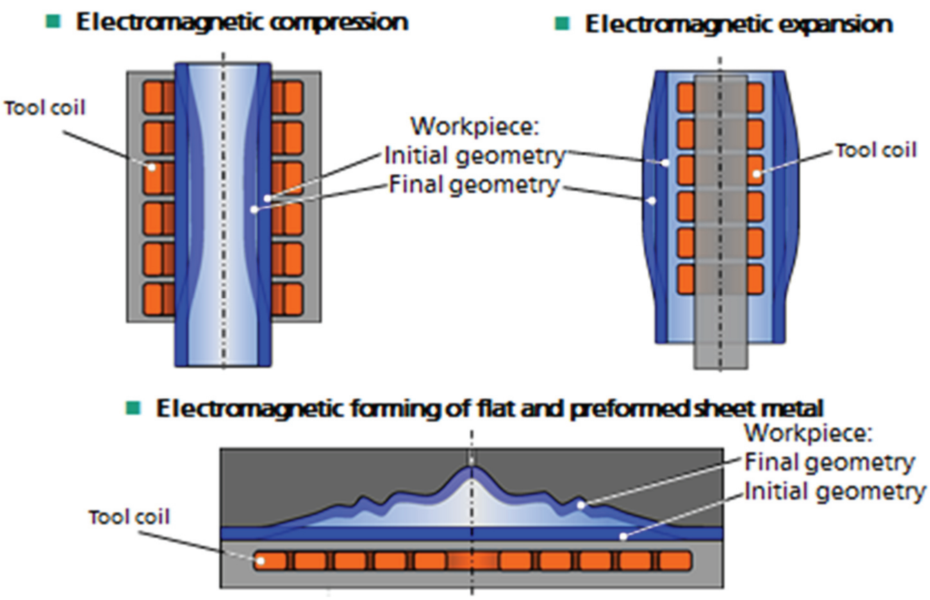

Figure 3 Technology variants of electromagnetic forming

EMF can be used for joining by forming similar and dissimilar material combinations. In fact joining profile shaped parts has been identified as the most promising process variant for industrial applications. Since only one joining partner needs to be electrically conductive, the potential material combinations include metal / metal as well as metal / non-metal hybrid structures (e.g. aluminium - fibre reinforced plastic-connections, copper-ceramic-connections, metal-glass-connections and others). The resulting joints can be based on interference-fit, form-fit, or - in case of metal / metal connection - even on metallic bonding realized by magnetic pulse welding.

Applications of field shapers enable focusing the forces to a smaller diameter and/or length compared to the tool coil. This allows using one and the same tool coil flexibly for different forming and joining tasks. Moreover, the application of a field shaper can contribute to improving the coil lifetime, because the force acting on the coil is smaller compared to a setup without field shaper. Accordingly, the use of a field shaper supports the joining of tubes with greater wall thickness, which typically requires high forces [6].

5. NEW STRUCTURES

Another way to reach weight saving is changing the component design. If the component geometry is optimally adapted to the load profile by implementing appropriate structures, a reduction in wall thickness is possible. At the same time the acoustic properties can frequently be improved.

The hexagonal combs (**Figure 4**) with different sizes (**Figure 5**) have been systematically analyzed. Forming via elastomer and electromagnetic forming (EMF) were applied for structuring. Structuring with an elastomer tool is a forming technology using an elastomer insert in the punch, which shapes the sheet metal workpiece. The die is usually designed as a conventional steel tool. The elastomer applies a pressure to the workpiece during closing of the tools which causes the sheet to align to the die according to the structuring geometry. In doing so, flat as well as slightly curved workpieces and workpiece sections can be structured. Thereby, the application of an elastomer punch offers several advantages compared to conventional deep drawing with a set of classical full steel tools. The most important ones are that the elastomer insert applies the forming forces very uniformly, thus decreasing the stress gradient in the workpiece and consequently reducing local sheet thinning. The resulting strain distribution is more uniform compared to conventional deep drawing and the maximum strain values are lower. Consequently, the forming area features more remaining formability, which is related to higher energy absorption potential. This is of interest especially for crash relevant components from the automotive and transport industry.

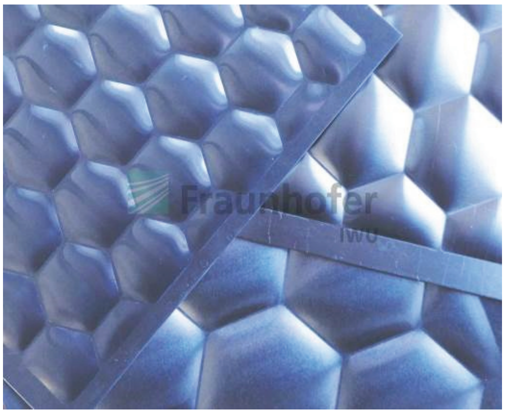

Figure 4 Hexagonal comb structure

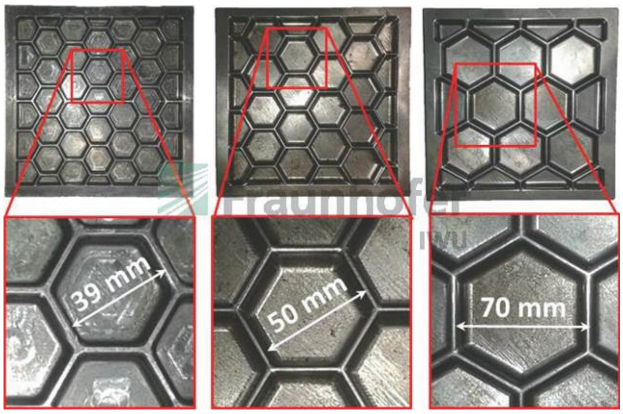

Figure 5 Variation of honey comb sizes

By structuring via EMF, a tool coil with rectangular winding geometry was applied with the same structuring die. In principle, the pressure distribution applied for structuring should be uniform, but in EMF only the areas of the workpiece close to the coil winding are pressurized, so that the coil considered here features an unpressurized area in the centre as it is known from spirally wound tool coils. To overcome this deficit, the structuring was performed in two forming sequences. After the first sequence, the work-piece was moved relative to the coil, so that the zone initially positioned in the non-pressurized centre area of the coil was shifted to the pressurized area in the second forming sequence.

The implementation of structures is not limited to regular geometries, but it is also possible to apply arbitrary designs including bionic ones that are inspired e.g. by cobwebs or the wings of a dragonfly. Based on the material choice, the sheet thickness, and the geometry and size of the structuring elements, the bending stiffness can reach three-times the value of a flat sheet. The high weight saving potential was exemplarily proved. Compared to the parts structured with an elastomer tool, specimens structured by EMF feature a relatively high spreading of the individual comb depths even within one and the same part. This is probably owed to the specific pressure distribution and to the sequential forming approach. The qualitative wall-thickness distribution of parts structured by EMF and such structured with an elastomer punch is similar, but in case of EMF localized thinning and cracking occurs at significantly higher depths.

CONCLUSIONS

Lightweight materials offer a good possibility to save the weight of vehicles by constant or better performance in comparison to the conventional steels. New technologies should be developed to shape or join the different materials. Fraunhofer has been demonstrating and optimizing in the research the possible forming techniques.

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