The longitudinal control arm of a rear suspension system made from a hybrid comprising long fiber-reinforced PA6 and steel sheet is formed and bonded in one step. The two materials combine lightweight design with fail-safe crash behavior (© Evonik)

Plastic Forms Metal

One-Step Hybrid Forming Process for the Production of Hybrid Structures for Vehicle Bodies and Chassis

In large-scale automotive production, all-metal components are still mainly used instead of high-performance plastic/metal hybrids for reasons of cost. With a newly developed production process combining metal sheet forming and compression molding, hybrid components can now be manufactured more quickly and economically.

The demands made on structural components for vehicle bodies and chassis have continually increased in recent years. E-mobility is intensifying these demands, as vehicles are becoming heavier due to high battery weight. In the event of crashes, vehicle bodies must dissipate high energies and require high-performance structural components for energy absorption to ensure a high passive safety standard. Loads on the chassis, particularly on the rear axle, are increasing due to additional batteries, so weight reduction of chassis components is also becoming increasingly important. One possible option for saving weight and at the same time integrating functions in components is offered by long glass fiber-reinforced thermoplastics (LFT). So far, 100 % LFT components have not been used in safety-relevant car structures, such as suspension arms, because of their low ductility and the risk of abrupt failure. LFT can, however, be used with steel in a hybrid component, so combining the low density and high specific strength of LFT with the good fail-safe properties of a steel component.

Plastic/metal hybrid structural components are conventionally produced in at least two tools. In one tool, the metal sheet is formed, if necessary coated with an adhesion promoter, and then in a second tool overmolded with plastic (in-mold assembly). Alternatively, plastic and metal components are produced in two separate tools and then bonded together to form a hybrid component (post-molding assembly). In both cases, a number of process steps, relatively long cycle times, and high process costs prevent economic manufacture of a hybrid component as compared with an all-steel component.

Efficient Production of Hybrid Components

For this reason, a new combined process for simultaneous metal sheet forming and plastic molding ("hybrid forming") was developed by the Institute of Automotive Lightweight Design (FLB) at the University of Siegen, Germany, as part of the Federal Ministry of Education and Research (BMBF) "MultiForm" research project. In this process, a molten long-fiber-reinforced plastic (LFT) is placed in a compression mold with a metal sheet. On closure of the mold, the metal sheet is shaped by the punch and the pressure of the polymer melt. Here, the polymer melt serves as an active medium such as is known from hydromechanical metal sheet forming processes. The individual process operations are shown schematically in **Figure 1** in a section through a hybrid compression mold and described as follows.

Firstly, an LFT extrudate is produced and placed in the molten state in a heated mold (operation 1). Then, a metal blank coated with an adhesion promoter is positioned in the blankholder (operation 2). First of all, the blankholder closes so as to form a sealing edge (operation 3). Then the press closes the mold so that the metal sheet is shaped by the punch and the pressure of the polymer melt. Thanks to the adhesion promoter, a continuous material bond is formed between the plastic and metal (operation 4). After cooling to mold temperature, the hybrid component is demolded (step 5).

The aim of the newly developed production process is economic manufacture of load-oriented hybrid components that weigh less but are just as reliable and functional as a conventional metal component. Thinner metal sheets can be used, which reduces the overall weight of the component. The resulting lower stiffness and strength can be compensated for by lighter, load-oriented plastic ribs.

Tool Technology and Sealing Concept

A major challenge in one-step production of hybrid components by hybrid forming is sealing the tool during the entire compression molding operation. To solve this problem, FLB in collaboration with the project partners developed various tool sealing concepts for open (**Figures 2a and b**) and circumferentially closed profiles (**Fig. 2c**) and implemented them in demonstrator components.

A robust, wear-optimized tool seal to prevent polymer melt from leaking in the case of closed profiles (**Fig. 2c**) can be achieved by providing a rigid, peripheral sealing edge in the blankholder. Here, the sheet holding force is controlled via a hydraulic drawing cushion, which is a standard way of regulating metal flow in deep-drawing of metal blanks.

In hybrid forming of components with open ends, e.g. for body side or cross members, tool sealing is more complex. Two different concepts were developed and tested for this by FLB: in sealing concept (a), the faces of a three-part punch are mounted on advancing gas pressure springs to create a polymer-free sealing edge on the open profiles. The metal sheet-holding force here is also adjusted by gas pressure springs. In sealing concept (b), a step is provided at the ends of the rigid, one-part punch and a drawing gap at the head is adjusted so as to exactly correspond to the thickness of the metal sheet to be formed. In this way, a collar is formed at the profile ends, which prevents escape of polymer melt (**Fig. 2**).

A compound developed in-house by Weber Fibertech GmbH, Markdorf, Germany, was used as an active medium for metal sheet forming and for local load-oriented reinforcement of the metal profiles. This compound was based on polyamide 6 (PA6) from Lanxess AG, Cologne, Germany, and glass fiber rovings added to the polymer melt in the form of chopped glass fibers. Compounding was carried out in the D-LFT machine for direct processing of long fiber-reinforced thermoplastics.

With the sealing concepts shown in **Figures 2a and b** for profiles with open ends, sheet thicknesses of between 0.8 mm and 1.2 mm could be fully formed by the pressure of the polymer melt. In these tests, forming was first carried out with the readily formable, low-strength deep-drawing steels DX54 and DC04 for outer skin applications and then with the medium-strength, cold-rolled microalloyed steels HC220Y and HC340 for vehicle body structures.

With the sealing concept shown in **Figure 2c** for circumferentially closed »

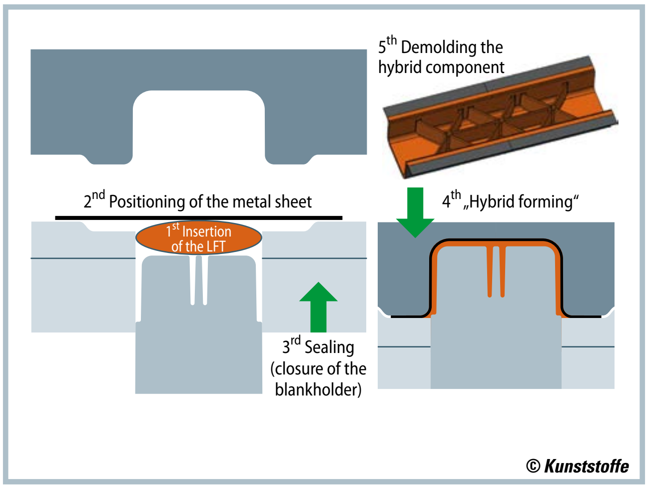

Fig. 1. The subsequent process operations shown schematically in a section through a hybrid compression mold (source: FLB Uni Siegen)

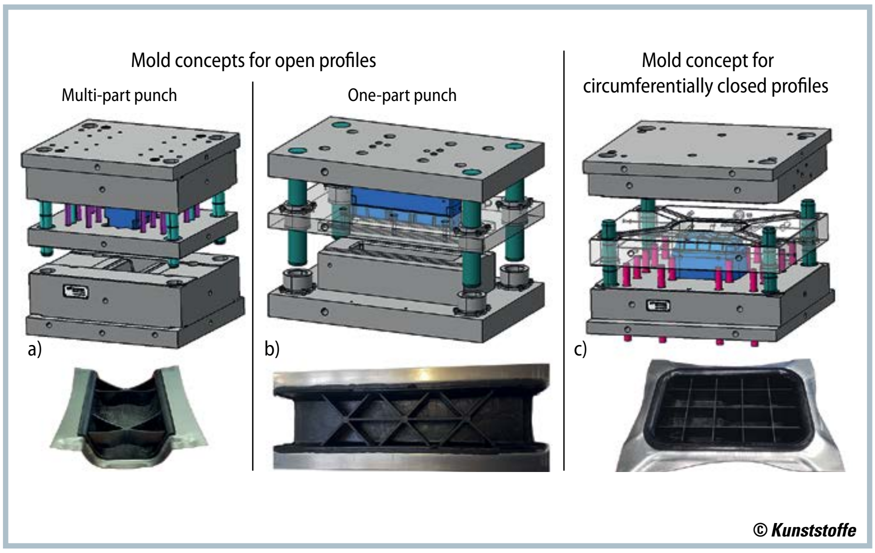

Fig. 2. To prevent escape of thermoplastic melt in hybrid compression molding, various sealing concepts were developed for the mold. Sealing profiles with open ends (a, b), such as for side or cross members, posed a particular challenge (source: FLB Uni Siegen)

profiles, steel sheets up to 2 mm thick could be fully formed using technically challenging drawing depths of up to 45 mm.

Design of Hybrid Components

The design methodology for steel/plastic hybrid structures used in the project breaks down into three stages: first of all came material selection based on pure material dogbone specimens and hybrid test specimens (head and tensile shear test specimens). The technical evaluation criteria for using hybrid structures in the chassis were primarily high strength, heat resistance, and suitability for cathodic dip coating. The LFT compound chosen was PA6 with 40 % long glass fiber reinforcement. The LFT compound PA6-LGF40 has good manufacturing properties and, because of its long fiber reinforcement, also high specific strength, even at elevated temperatures. In view of the tendency of PA6 to absorb moisture when used in the chassis, higher-performance polymers such as PA610 and PA12 from Evonik AG, Essen, Germany, were successfully tested in the project for possible use as the LFT matrix. To ensure sufficient bond strength between steel and PA6, the copolyamide adhesion promoter Vestamelt Hylink from Evonik was selected. The suitability of the adhesion promoter was also proven under thermally challenging conditions in application ranges between -10 and +65 °C in different cyclic climate tests.

In the second stage, a steel/LFT structure based on cross member geometry was produced by hybrid forming. The mechanical properties of this component were determined in three-point bending

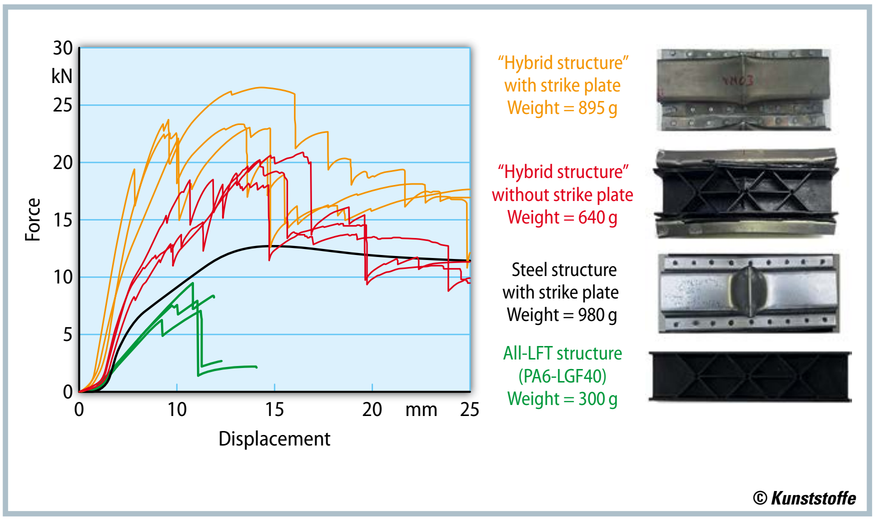

Fig. 3. Comparison and results of different component variants based on cross-member geometry in the three-point bending test. Weighing 10 % less than conventional steel strike plate structures (black), the steel/LFT (orange) structure can withstand twice the load (source: FLB Uni Siegen)

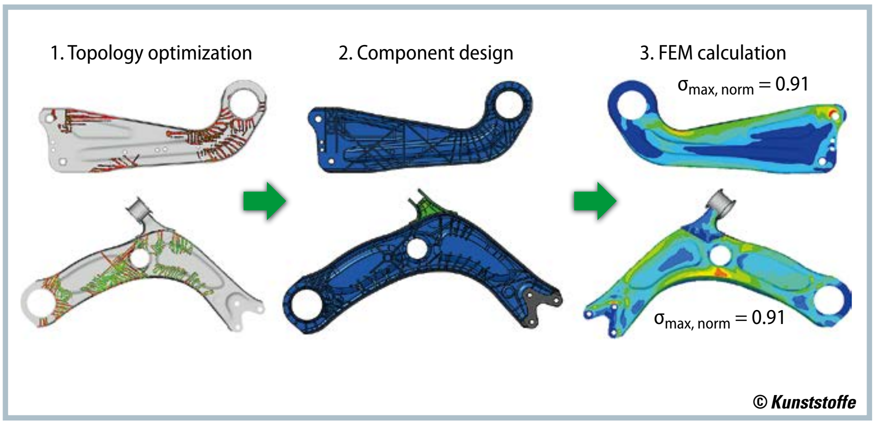

Fig. 4. Thanks to the component-optimized design of the suspension link, a thinner metal sheet could be used in combination with the plastic, so achieving an overall weight saving of around 20 % compared with the steel reference component (source: FLB Uni Siegen)

The Authors

Univ. Prof. Dr.-Ing. Xiangfan Fang is Director of the Institute of Automotive Lightweight Design (FLB) at the University of Siegen, Germany.
Daniel Heidrich is a scientific researcher at FLB University of Siegen.
Tobias Kloska is a scientific researcher at FLB University of Siegen.
Björn Sonnenstädt works in the Research & Development Department at Weber Fibertech GmbH, Markdorf, Germany.
Norbert Stötzner is Development Manager at Weber Fibertech GmbH, Markdorf.
Andreas Sprick is CEO of Sprick Technologies GmbH & Co. KG, Paderborn, Germany.
Rüdiger Heinritz is Project Manager Technology Development at voestalpine Automotive Components Schwäbisch Gmünd GmbH & Co. KG, Schwäbisch Gmünd, Germany.
Maximilian Gruhn is Manager CAE/CAD Application Technology & Technical Service at Evonik AG, Essen, Germany.

Acknowledgment

This research work was carried out as part of the research project "MultiForm". The authors would like to thank the German Federal Ministry of Education and Research (BMBF) for its financial support within the framework of the competition "High-performance processes for the products of tomorrow – technological innovations for smart production".

Service

Digital Version

- A PDF file of the article can be found at ***www.kunststoffe-international.com/7735480***

German Version

- Read the German version of the article in our magazine ***Kunststoffe*** or at ***www.kunststoffe.de***

Fig. 5. View of the D-LFT machine that precedes hybrid forming and view into the hybrid mold at Weber Fibertech. One-step production of the steel/LFT longitudinal control arm follows in a hydraulic upper ram press (© Weber Fibertech)

Fig. 6. The finished hybrid control arm components before (transverse control arm) and after (longitudinal control arm) the trimming operation (© FLB Uni Siegen)

and static and dynamic torsion tests. In the three-point bending test, the hybrid steel/LFT component weighing 10 % less than a conventional steel strike plate structure withstood twice the load (**Fig. 3**). In addition, the hybrid steel/LFT structure showed positive fail safe behavior, since it did not exhibit brittle failure when maximum load was reached but, due to the ductility of the steel, sustained a high force level until the end of the test.

In the third stage, building on the positive results of the tests described, the possibility of producing the longitudinal control arm of a multi-link rear axle and a front axle transverse control arm by hybrid forming was investigated and lightweight design potential assessed.

The design of the two suspension arms (**Fig. 4**) was based on topology optimization, which takes into account the various design-relevant static load cases. After analysis of the optimization result, the LFT reinforcement was designed specifically for the plastic and calculated with the aid of the material models calibrated and validated in the tests. Despite the reduction in metal sheet thickness, the stresses in the steel sheet of the hybrid component were lower than in the 100 % high-strength steel reference component thanks to load-oriented rib reinforcement. At the same time, a weight saving of 20 % was achieved. In this way, the steel sheet thickness in the longitudinal control arm was reduced from 3.5 mm to 2.0 mm and in the lateral control arm from 3.8 mm to 2.4 mm (**Fig. 5**).

Production of the Longitudinal and Transverse Control Arms

Following metal sheet-forming simulations carried out by voestalpine Automotive Components Schwäbisch Gmünd GmbH & Co. KG, Schwäbisch Gmünd, Germany, the drawing devices for the two control arm components for hybrid forming were designed. Both components were designed as circumferentially closed profiles, as successfully used for the exemplary geometries (**Fig. 2**) produced by the FLB at the University of Siegen, Germany. The mold for the longitudinal control arm was manufactured by Sprick Technologies GmbH & Co. KG, Paderborn, Germany.

One-step production of the steel/LFT longitudinal control arm by hybrid forming was carried out by Weber Fibertech in a hydraulic upper ram press (manufacturer: Dieffenbacher GmbH, Eppingen, Germany) using the attached D-LFT machine (**Fig. 5, left**). Press speed, press force, temperature control, control of drawing cushion force, and the interaction between these factors are key to ensuring good mold sealing and crack- and wrinkle-free sheet forming. Both low-strength (DC04) and high-strength (DP800) steel grades were successfully formed (**Fig. 5, right**).

Production of the hybrid transverse control arm was carried out by voestalpine Automotive Components at its press facility in Schwäbisch Gmünd in a standard metal press with drawing cushion function. The mold was manufactured by voestalpine Automotive Components. As in the production of the exemplary geometries (**Fig. 2**), a semi-finished product-based manufacturing process was used, in which the LFT compound from Weber Fibertech was heated by IR radiation. 2.4 mm thick low-strength (DC04) and high-strength (22MnB5, cold formed) steel sheets were formed crack-free. **Figure 6** shows the hybrid control arm components before (lateral control arm) and after (longitudinal control arm) the trimming operation, which can be carried out as part of serial production processes with standard punching tools.

Outlook

By hybrid forming of steel and LFT, the weight of chassis structural components could be reduced by about 20 %. Evaluation of the properties of the hybrid control arm components is the subject of ongoing studies at FLB University of Siegen. In addition, the process is currently being extended to semi-warm forming of 5000 and 6000 series aluminum alloys with the aim of achieving significant weight savings in vehicle body components. ■