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Plastic and Metal – an Inseparable Team

Innovative Injection Molding Technologies for Hybrid Lightweight Applications

The imminent paradigm shift in mobility makes it essential that the German automotive industry prepares itself to undergo a transformation, both now and in the future, the like of which has not been seen before. Resource-efficient lightweight system engineering in a multi-material design is a key differentiating feature here. In this connection, novel materials, highly automated, digitized manufacturing processes as well as functional integration for intelligent component structures and vehicle systems will form the basis for creating springboard innovations that will dominate the competition.

When it comes to enabling and establishing cost-effective electric vehicles, initiatives such as the Forel platform (Research and Technology Center for Resource-Efficient Lightweight Structures in Electric Mobility) are helping to boost the competitiveness of internationally active companies, to accelerate the development of new business fields in small and medium-size enterprises and to promote the training of new skilled workers. Meanwhile, the targeted development of novel process technologies coupled with further developments in plant and mold engineering are constantly increasing production flexibility.

For the components in automotive engineering, this translates to greater design freedom and scope to tap additional potential in functional integration. A number of technology projects that run under the Forel platform, namely Leika, Q-Pro, Thixom and FuPro, are studying ways of combining metals and polymers in a number of different integrated, highly automated variants of injection molding. All these approaches are focused on producing a high-quality bond between plastic and metal in the manufacturing process itself.

Combinations of fiber-reinforced polymers (FRPs) with conventional design materials such as metals can significantly expand the range of applications because they deliberately exploit the specific advantages of each material. Production efficiency and reproducibility of parts can be greatly enhanced by integrating the assembly steps into the manufacturing processes.

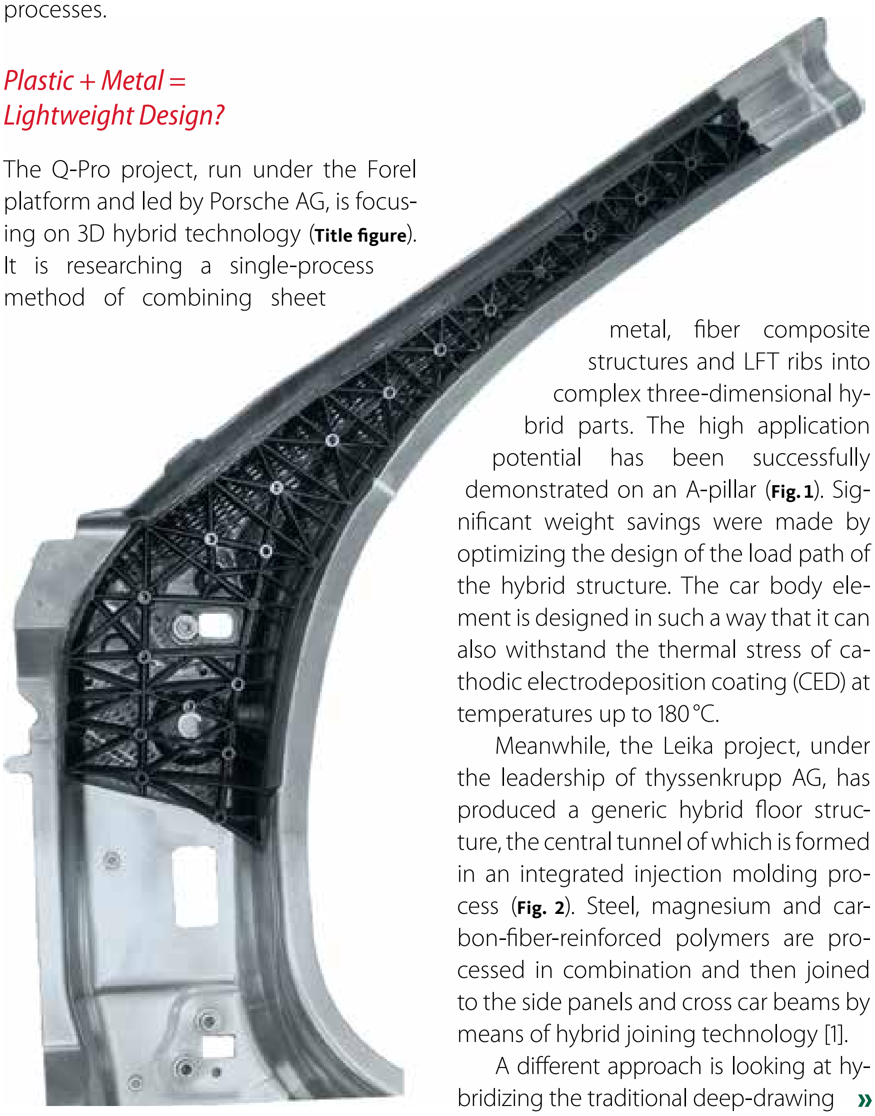
Plastic + Metal = Lightweight Design?

The Q-Pro project, run under the Forel platform and led by Porsche AG, is focusing on 3D hybrid technology (**Title figure**). It is researching a single-process method of combining sheet metal, fiber composite structures and LFT ribs into complex three-dimensional hybrid parts. The high application potential has been successfully demonstrated on an A-pillar (**Fig. 1**). Significant weight savings were made by optimizing the design of the load path of the hybrid structure. The car body element is designed in such a way that it can also withstand the thermal stress of cathodic electrodeposition coating (CED) at temperatures up to 180 °C.

Meanwhile, the Leika project, under the leadership of thyssenkrupp AG, has produced a generic hybrid floor structure, the central tunnel of which is formed in an integrated injection molding process (**Fig. 2**). Steel, magnesium and carbon-fiber-reinforced polymers are processed in combination and then joined to the side panels and cross car beams by means of hybrid joining technology [1].

A different approach is looking at hybridizing the traditional deep-drawing »

3D hybrid A-pillar demonstrator structure from the Forel project Q-Pro (© Porsche, ILK)



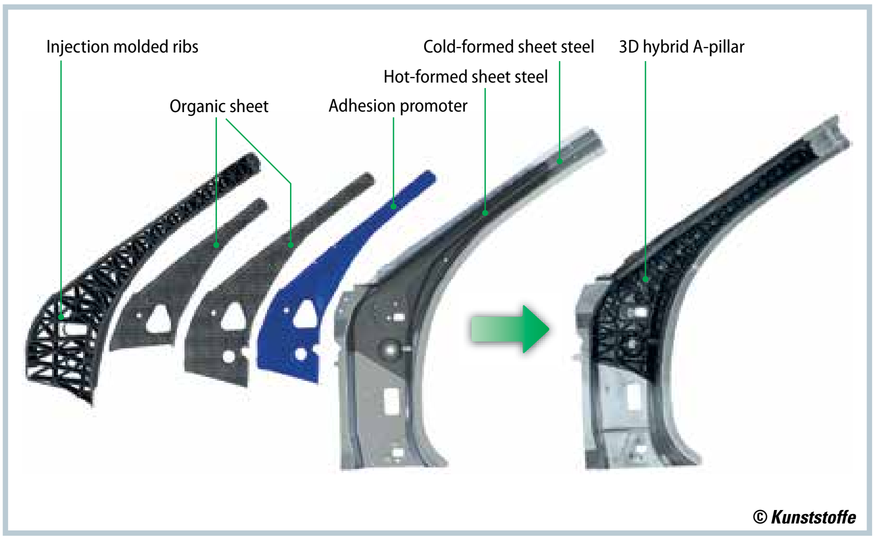


Fig. 1. Sheet metal, fiber composite structures and LFT ribs are combined in a single process to yield complex three-dimensional hybrid parts (source: Porsche, ILK)

process employed in metal processing. Here, the Institute for Forming Technology and Lightweight Engineering (IUL) at the Technical University of Dortmund, Germany, and its partners are investigating how metal sheets along with textile reinforcement layers can be processed together in a combined deep-drawing and infiltration process to yield a near net shape. The idea is to use the low viscosity during the in situ polymerization of cast polyamide 6 to facilitate strong forming operations before and during the consolidation phase. The production challenge here lies in coordinating the injection process with the process for forming the metal-textile laminate.

Thixom is a novel technology that offers a way to produce hybrid lightweight structures from particle-reinforced magnesium. Certain properties of magnesium, such as rigidity, heat stability and wear resistance, can be enhanced by modifications. The provision of additional functionalization through combination with thermoplastic materials makes it possible to further boost the degree of lightweight engineering and to increase the design freedom.

Fig. 2. System complex incl. bolt-on unit from KraussMaffei for manufacturing the battery tunnel of the Leika floorpan (source: ILK)

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Hybrid Structures Require Special Plant Technology

Before hybrid lightweight structures can enter into series production, the industry needs to be able to count on the availability of process chains that have short cycle times and are highly automated. This is the only way that the requisite part volumes can be served and manufacturing costs kept low.

A major driver of the costs of parts made from fiber-reinforced thermoplastic structures is often the costs of the semi-finished products. Novel plant technologies for fiber direct compounding (FDC) such as those developed by Arburg GmbH + Co KG offer solutions here. This enables the worker to adjust the fiber rovings feed at the injection molding machine itself and thus to vary the material composition as required. The process treats the fibers gently and so improves the material properties, ultimately enabling custom control to be exerted over the part properties (**Fig. 3**).

It takes complex plant technology and comprehensive process know-how to incorporate particle or fiber reinforcement into magnesium. The greatest challenges consist in completely wetting the fibers with the magnesium matrix and in finding a compromise between optimized processability and the best possible mechanical properties of the parts that will enable the fiber lengths to be adapted and used to specification. The new plant technology developed in the Thixom project is laying the foundations for tapping a new field for the near-industrial application of high-performance materials and ultimately, through the combination of magnesium and polymers, further potential applications in lightweight engineering.

The production of innovative hybrid structures is often difficult to implement on conventional production lines and requires substantial new investment in plant technology and infrastructure.

In the Leika project, KraussMaffei Technologies GmbH has developed a new design for a bolt-on injection molding unit which can be easily integrated into an existing compression complex due to its low overall height. This gives companies hitherto exclusively engaged in sheet metal processing the chance to expand their production complex to include the production of thermoplastic-metal hybrid structures, without the need for major investment in, e.g. a press pit.

Fig. 3. Section of the FDC unit with fiber cutting and feed at the front part of the injection unit (© Arburg)

Smart Mold and Automation Solutions

Lightweight load-bearing designs capable of withstanding stresses and strains require not only flat elements but also hollow structures that can transmit flexural and torsional loads. ElringKlinger AG achieves this with a technology which utilizes a combination mold to merge the hydroforming of metal pipes and polymer injection molding into a single process step. Users can choose the desired combination from different materials, for both the pipes (steel or aluminum) and the polymers (e.g. PA, PP, PPA, PC-ABS).

A process for functionalizing thermoplastic FRP hollow sections has been developed in a number of research projects at the Institute for Lightweight Engineering and Polymer Technology (ILK) in Dresden, Germany. This supports the production of hollow structures of complex cross-section and adapted fiber orientation which are subsequently functionalized by injection molding in the second step. The ILK project group, in cooperation with Porsche AG, has already provided an impressive demonstration in the example of a battery carrier [2].

This technology approach is now being developed for series production in the FuPro project. In this regard, a consortium has implemented a completely »

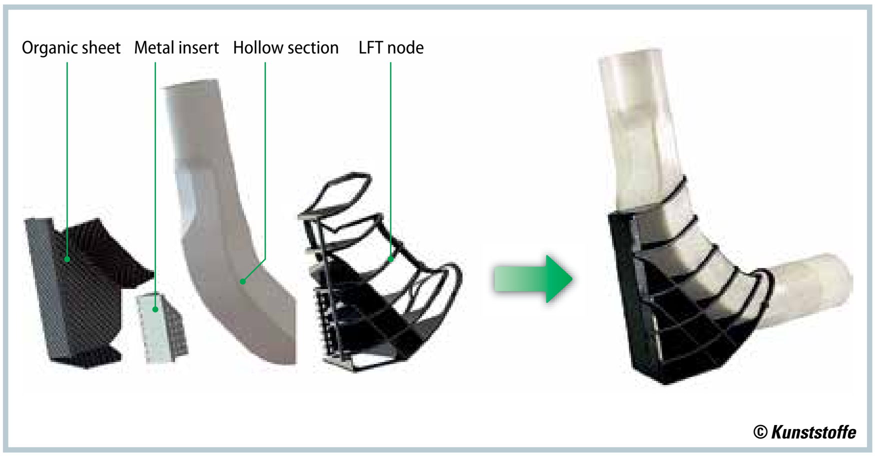

Fig. 4. The individual components in CAD (left) and the finished FuPro component (source: ILK)

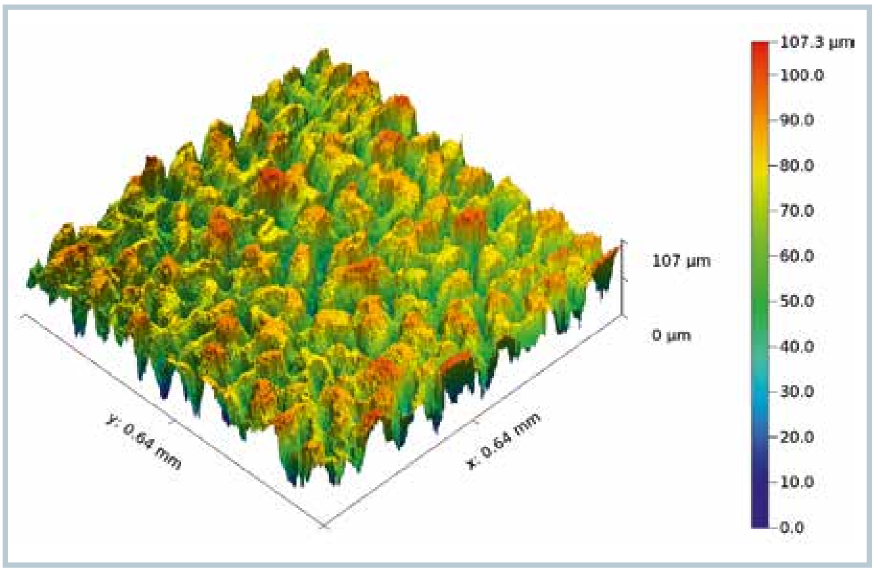

Fig. 5. Microtexture on the metal surface (shown in false colors) to improve the adhesion of a metal-fiber composite (© Bayerisches Laserzentrum)

modular system comprising flat components, hollow sections that withstand torsion and bending, as well as complex node-rib structures [3]. Under the leadership of Brose Fahrzeugteile GmbH, the project partners are working on developing new solutions for automated preforming, consolidation and functionalization. Thus, continuously produced sleeving from hybrid yarns is consolidated energy-efficiently (with heat recovery) into hollow sections in a variotherm mold and then combined in an injection mold with metal inserts, textile organic sheet reinforcements and long fiber-reinforced thermoplastic molding compounds. The demonstrator produced by the partners was a remarkable example of the enormous potential which this technology offers in the production of load-bearing structures of complex component geometry (**Fig. 4**).

In addition to series-capable plant and tooling concepts, the production of these hybrid structures requires customized automation concepts. Aumo GmbH and J. Schmalz GmbH are developing new gripper and transfer systems that support automated assembly. These will enable flexible braided sleeve from hybrid yarn to be cut to length from the roll, and multi-ply preforms to be constructed and formed into complex 3D shapes. Also under development are handling solutions for automated transfer of the textile preform into the consolidation mold [4].

Bonding Polymer and Metal Properly

The goal of supporting the intrinsic hybridization of metals and semi-finished fiber-thermoplastic products by injection molding and ensuring a high-strength connection between the components

Forel Platform

Forel is a nationwide, open platform for the development of high-tech lightweight solutions in multi-material design for the electric vehicles of the future. With this in mind, renowned German development and research centers have joined forces with industry to work on the following technology projects and others:

- Development of designs and processes for functionalized multi-component structures having complex hollow sections
  - www.plattform-forel.de/fupro
- Quality assured process chain linking for the production of ultra-strong intrinsic metal-FRP composites in 3D hybrid design
  - www.plattform-forel.de/q-pro
- Development of a process and design of a thixomolding method for the production of large-area reinforced magnesium/thermoplastic mounting structures
  - www.plattform-forel.de/thixom
- Resource-efficient hybrid designs methods for lightweight vehicle bodies
  - www.plattform-forel.de/leika

Fig. 6. Application of a plasma polymer layer to sheet metal by the "Plasma-SealTight" nozzle (© Plasmatreat)

can be pursued by a number of different approaches. The Q-Pro project is examining and comparing two such approaches. The first employs special adhesion promoters and process-compatible adhesive systems. Before the process parameters can be matched to the curing behavior of the adhesion promoter and to ensure a strong connection, it is essential to know the kinetics underlying the reaction. The high contact temperatures generated during compression and injection initiate the curing reaction by the adhesion promoter. The ultimate joint strength and thus the final crosslinking of the thermosetting component are achieved by availing of the high temperatures involved in cathodic electrodeposition coating [5].

The second approach to intrinsically connecting metals and plastics during injection molding uses lasers to generate microtexture on the metal surface (**Fig. 5**). Part of the Q-Pro project conducted by Bayerisches Laserzentrum GmbH consists in investigating how suitable structures for high connection properties can be created as a function of pulse duration, energy quantity and laser scanning strategy. Advantageously, full bond strength is achieved immediately after injection molding: no additional components or auxiliary materials are required and the process can be transferred comparatively well to other combinations of materials. A drawback, however, is the long process times entailed in pretreating large connecting surfaces. For this reason, the project partners are looking at combining both methods so that the respective disadvantages can be compensated for with the help of hybrid joining technology.

A further alternative is provided by the plasma techniques unveiled by Plasmatreat GmbH at last year's K fair. The metal surface is cleaned and then an adhesion-promoting layer is applied to the metal by a specially developed plasma nozzle (**Fig. 6**). The crux here is to match the polymeric layer of plasma to the two adherends such that subsequent injection molding will yield a material bond which also has a sealing function.

Instead of a universal joining technology that meets all requirements, it is necessary to select one which matches the materials and the expected type of load. Comparisons of the quality of complex hybrid connections require the use of uniform test methods and the determination of characteristic values under different load scenarios. The Laboratory for Materials and Joining Technology (LWF) at the University of Paderborn, Germany, has devised test concepts for evaluating hybrid joining processes for hybrid connections under different types of load [6]. The ILK hybrid test specimen also enables various manufacturing processes such as compression molding, injection molding and thermoforming and the associated influences of the process parameters to be taken into account (**Fig. 7**).

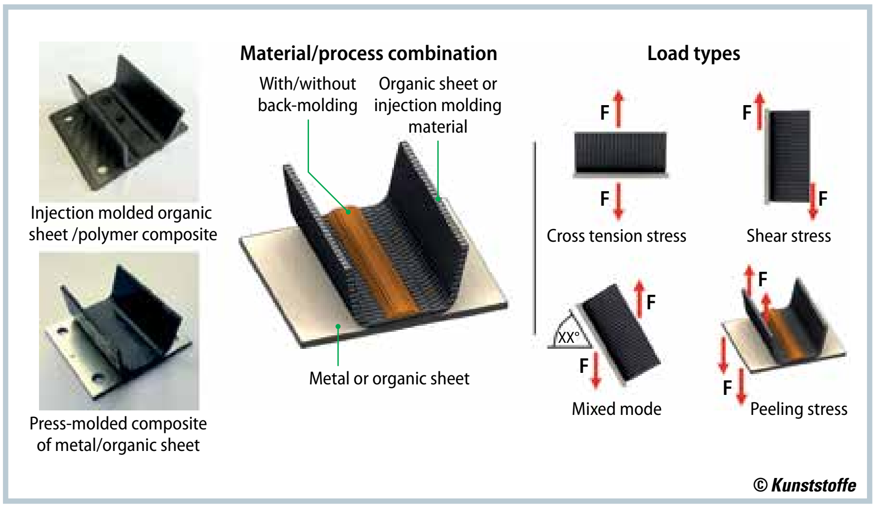

Fig. 7. ILK hybrid test specimens for analyzing the strength of the connections between different materials for different types of load (source: ILK)

Outlook

These examples are only a small selection from a large number of research projects on these topics in Germany. Aside from their focus on technology, the projects are also concentrating on the development of integrated simulation chains. New interfaces between process and structure simulation are raising the level of understanding the influence exerted by manufacturing parameters on structural properties and their integration into process and parts design.

These approaches for novel combinations of materials, plant technologies, molds and their interaction in automated process chains are opening up new prospects in the application of hybrid lightweight engineering technologies. The diversity of the solutions confirms that the efficient combination of metals and polymers can be expected to find greater use in industry, for example in new fields of application such as electric vehicles. ■