Scalable, Single-stage Manufacturing of Hybrid Components

The new MultiForm process combines the deep-drawing of sheet metal with compression molding of long fiber-reinforced thermoplastics. The time- and cost-efficient hybrid technology, which was developed in a research project involving Weber Fibertech, opens up the way for thermoplastics toward automated mass production.

Two Process Steps in One

The goal in lightweight engineering is always fundamentally the same: to reduce component weight without compromising strength. It may even be possible to increase component strength while reducing the weight at the same time. And, in the best-case scenario, the development of a new material also goes hand-in-hand with the creation of a corresponding manufacturing process whose shortened production times and reduced costs help the material quickly become established.

E-LFT hybrid technology aims in this direction. It merges two process steps into one: the molding of a long fiber-reinforced thermoplastic and the forming of the metal substrate. An adhesion promoter applied to the metal connects the plastic and sheet metal through adhesive bonding.

The process is based on Long Fiber-reinforced Thermoplastic (LFT)-technology, which offers a high degree of freedom in the design engineering process. Endless fibers are embedded in this basic structure for structural reinforcement and increase the component's strength. The E-LFT hybrid technology is the result of the German MultiForm research project.

Three Steps to the MultiForm Process

A brief retrospective in advance will help illustrate the stages that resulted in the development of the MultiForm technology and emphasize the specific performance of the new process.

The process started with polypropylene- or polyamide-based thermoplastic components manufactured in a compression molding process. First, the plastic granules are melted. Then the glass fibers are added in the extruder. Because these are long fiber-reinforced thermoplastics, the term LFT is also used. Finally, the melt-like plastic cake, for example the extrudate, is made to flow by means of compression in a vertical press.

As a result of this process, fiber lengths of 10 to 15 mm are achieved in the component. That significantly increases its strength compared with an injection-molded component. The component can therefore be thinner and lighter for the same or better strength values.

To strengthen the thermoplastic component, Weber Fibertech incorporated endless glass or carbon fibers primarily as unidirectional profiles. That yields significantly higher stiffnesses. For cost reasons, the long fibers are not incorporated throughout the thermoplastic component in this process, but are only inserted where higher loads are expected to occur. One application for this process, called the E-LFT process, for which the company holds a patent, is in structural seat components, such as seat pans and backrests, which withstand the highest forces in the area where the belt is fastened, Figure 1.

The MultiForm project

The E-LFT hybrid technology is the result of the German research project MultiForm, conducted by the University of Siegen and a consortium of companies, headed by specialty chemicals company Evonik and thermoplastic specialist Weber Fibertech. Additional partners such as Volkswagen AG, voestalpine Automotive Components, Simpatec and Sprick Technologies supplied technical support for the project. Germany's Federal Ministry of Education and Research (BMBF) provided financial support for the project from August 2014 until February 2018 (BMBF: 02PN2081).

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FIGURE 1 Part of a car seat backrest using E-LFT technology. The black endless fiber profiles are positioned both vertically and horizontally according to the load cases (© Weber Fibertech)

In certain cases, however, components have to withstand even higher loads. Aluminum or steel are best suited to this because of their material properties. That was the idea underlying another research project named HyBriLight that was successfully completed by the Fraunhofer Institute for Laser Technology (ILT), Weber Fibertech and others during the project's duration from November 2014 to June 2018. The engineers used a laser to create a surface structure on the sheet metal. During the pressing process, the thermoplastic melt completely fills this structure and thus creates an outstanding bond between the two joining materials on curing (tensile strength approximately 12 MPa; shear strength approximately 48 MPa).

That was the starting point for, and backdrop to, the development by the project partners of the MultiForm process. In this, for the first time, the extrudate and sheet metal were successfully formed in a one-shot production step – that means: in a single press pass. E-LFT hybrid is the name of the fully automated process used by Weber Fibertech.

The company is currently working on behalf of a customer on the use of thermoplastics with endless fibers in the E-LFT hybrid process. One of the goals is to further increase the load capacity of car seat elements. However, series production is still estimated to be three years off.

Project Design and Demonstrator

The project focused on the development of the manufacturing process with the relevant parameters that had to be matched to the different material components, steel and LFT, and the development of corresponding die seal concepts. This enabled a cycle time of less than 60 s to be achieved with a 3600-t press. Depending on the size of the components, multiple parts can also be manufactured in one press pass. The seal concepts were implemented both for an open U-section (a lengthy structural member) and also for a pan-type component, such as the longitudinal control arm demonstrator component.

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For the conclusion of the project, the potential of the process was highlighted using a demonstrator component. For this, the engineers chose the transverse control arm of a car rear axle from a German vehicle manufacturer – a highly stressed safety-relevant component with good potential for weight reduction. The aims were to satisfactorily replace the steel component with the hybrid material and to make processing with the new method as cost-effective as possible.

The design, analysis and testing of the component were carried out by staff at the University of Siegen headed up by Prof. Xiangfan Fang. High-tensile sheet steel (DP800) was combined in the composite

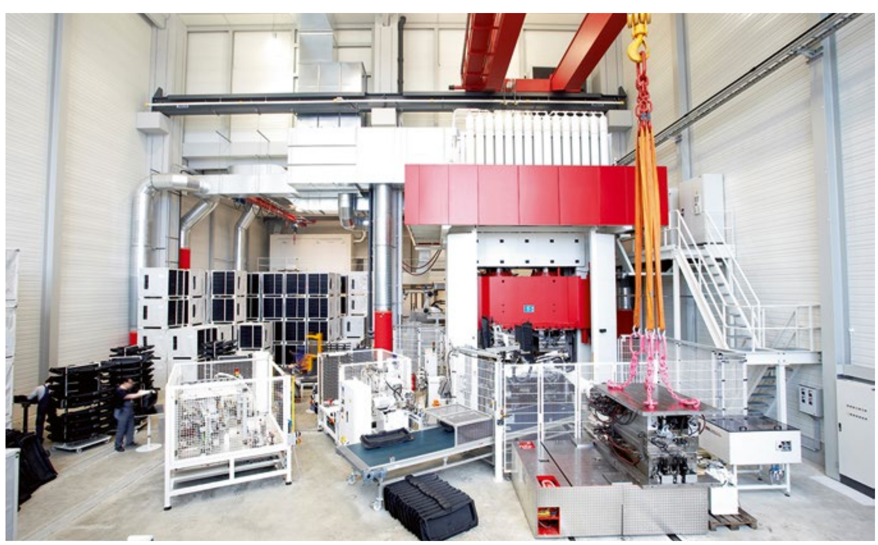


FIGURE 2 A fully automated production system in Markdorf: At the heart of the system are a 3600-t vertical press and a system developed by Weber Fibertech for preparing and applying the endless fibers (© Weber Fibertech)

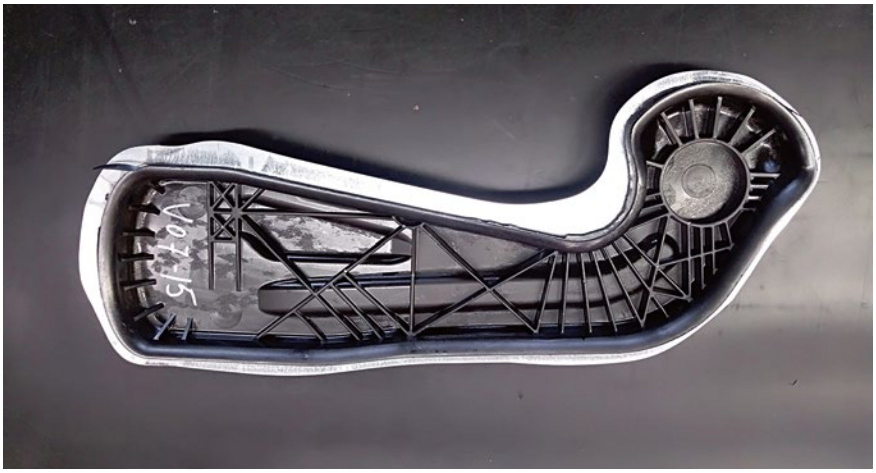


FIGURE 3 The transverse control arm as it leaves the press, untrimmed (© Weber Fibertech)

with polycaprolactam, also known as polyamide (PA) 6.

The thermoplastic was reinforced with 25-mm-long glass fibers manufactured by Weber Fibertech on a fully automated E-LFT production line. The company in turn produced the compound, comprising 60 % plastic and 40 % glass fibers by weight, in a direct compounding operation during the system cycle.

Direct compounding means that the company does not buy compound materials such as PA GF40 rod-shaped pellets, but compounds the PA GF 40 itself from pure polyamide, additives for color, flowability etc., and the added glass fibers. Every 60 s, the compounding process delivers fresh compound extrudate, Figure 2.

The outcome is a component whose weight had been successfully reduced by more than 20 %, although the transverse control arm is usually a textbook case for the use of metals because of its high load capacity and reliability against failure. For other applications (tailgates, roof elements, door structures), correspondingly higher weight savings of up to 50 % can be expected and have already been achieved in some cases.

The transverse control arm is therefore an excellent example for the rising number of automotive lightweight design applications using Multi-material Design (MMD). This approach requires the use of suitable material combinations in the component, but also the development of cost-effective manufacturing processes.

Process Forces: Metal Properties

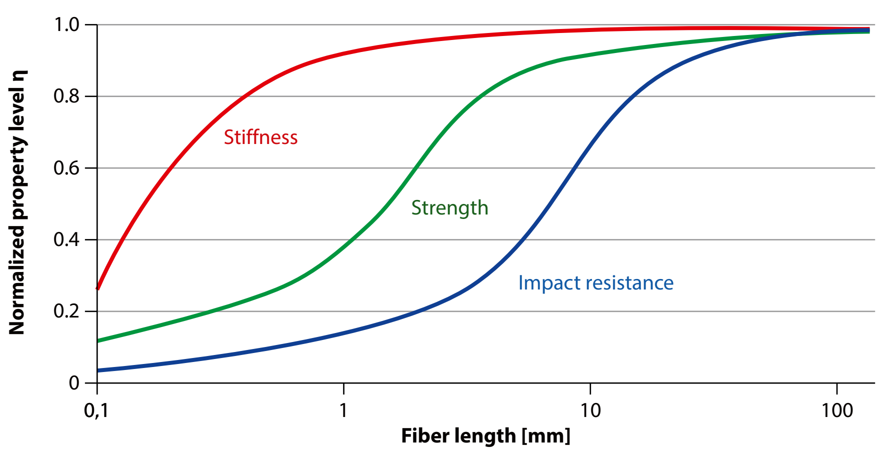
The MultiForm process combines deep-drawing of sheet metal with compression molding of long fiber-reinforced thermoplastics using an adhesion promoter. This enables hybrid components to be manufactured both time- and cost-efficiently. The thermoplastic, which is highly viscous in the plasticized state, acts like an active medium in hydro-mechanical forming processes, allowing the sheet metal to be formed, Figure 3.

The MultiForm project therefore set out to analyze the process-related influences of temperature and friction on the molding properties of steel and aluminum. The aim of that was, on the one hand, to simplify the choice of material and, on the other hand, enable reliable component design by means of simulation using the Finite Element Method (FEM simulation).

The first step, therefore, was to determine specific forming limit curves for steel and aluminum materials for the hybrid pressing process. The relevant FEM forming simulation was then adapted for the metals.

On the basis of previous experience during development of the process, it can be assumed that steel has a reduced formability. In the case of higher-tensile aluminum alloys, on the other hand, improved formability is expected because of the positive impact of temperature on the long fiber-reinforced thermoplastic in the plasticized state. However, this is currently still undergoing detailed investigation.

Aluminum is often a good choice in terms of optimal weight reduction, comparable thermal properties and sufficient load capacity. In the case of highly stressed, crash-relevant components, which call for ductile properties for energy absorption, the hybrid



Source: Influence of fibre length and concentration on the properties of glass fibre-reinforced polypropylene: 1. Tensile and flexural modulus, J.L. Thomason und M.A. Vlug, 1996

FIGURE 4 Effect of fiber length on the mechanical properties of the plastic component. High-strength thermoplastic components can be produced with the fiber length in the component which was achieved using the E-LFT process (© Weber Fibertech)

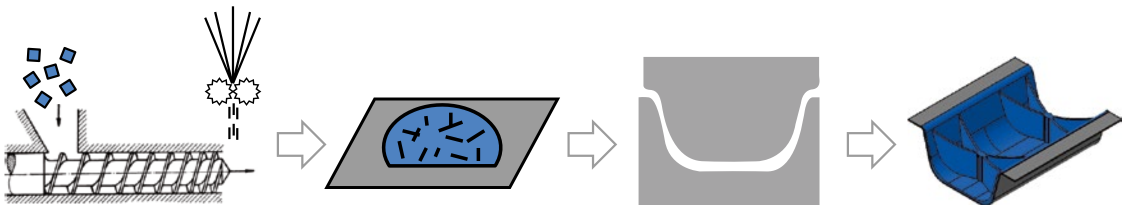


FIGURE 5 Schematic representation of the E-LFT hybrid method. The long fiber-reinforced extrudate is positioned fully automatically on the non-preformed metal plate and formed simultaneously into the hybrid component in a one-shot process (© Kloska/Universität Siegen)

combination of E-LFT with steel is a good solution for optimal weight reduction and the required strength. Similar thermal properties can be achieved by increasing the glass fiber content.

Compression Molding in the MultiForm Process

The MultiForm process combines deep-drawing of sheet metal with compression molding of LFT as a forming process. The main advantage of compression molding is that it achieves very long fiber lengths of up to 25 mm, whereas the lengths in injection molding are limited to a maximum of 2 mm because of the injectors.

The fiber length and the high fiber volumetric content associated with compression molding have a substantial impact on the component's mechanical properties. Whereas the stiffness of a fiber-reinforced plastic can be only moderately increased above a fiber length of 1 mm, the values for strength and impact resistance rise significantly, Figure 4.

Furthermore, when the material has long fibers, and a high fiber content as a result of only a minor tendency toward shrinkage and distortion, dwell time in the die can be reduced compared with the injection molding process. Precoating the sheet metal with an adhesion promoter creates a direct, adhesive bond between the sheet metal and the LFT during hybrid pressing, obviating the need for a subsequent joining process. The entire production process is illustrated in the following graphic (hybrid pressing process graphic), Figure 5.

After preparation, the LFT is processed directly in the fully automated system cycle. The sheet metal is coated with an adhesion promoter in advance. To activate the adhesion promoter, the sheet metal has to be preheated before the LFT is placed on it – depending on the die configuration (hat or normal configuration), it may also be necessary to place the LFT directly on the punch. In the third step, the sheet metal and LFT are formed simultaneously. Depending on the geometry, an all-round seal must be ensured by means of a hold-down device or additional seal elements, Figure 6.

FIGURE 6 The finished transverse control arm after subsequent trimming (© Weber Fibertech)

Potential Applications

The MultiForm process is recommended wherever lighter materials can further reduce the fuel consumption of conventionally powered vehicles on the one hand and extend the range of electric vehicles on the other.

Of particular relevance here are materials using multi-material design that allow the benefits of multiple materials to be combined in one component. For example, the high strengths of metals can be combined with plastics, which can be molded comparatively easily into complex forms and help to reduce component weight. The components are therefore ideal for the crash-relevant areas in vehicle bodies and chassis.

But the E-LFT hybrid process can even be used to manufacture a complete body. The body is being built for an electric vehicle as a customer commission, with the customer able to choose from E-LFT and E-LFT hybrids based on MultiForm technology, depending on the load case.

The MultiForm process is therefore paving the way for the use of thermoplastics in automotive mass production because, although thermoset materials are ultimately stronger, they are also more expensive, not least because of the longer cycle times by a factor of 3. By contrast, the lower strength of thermoplastics can be counteracted by combining LFT, E-LFT and metal.