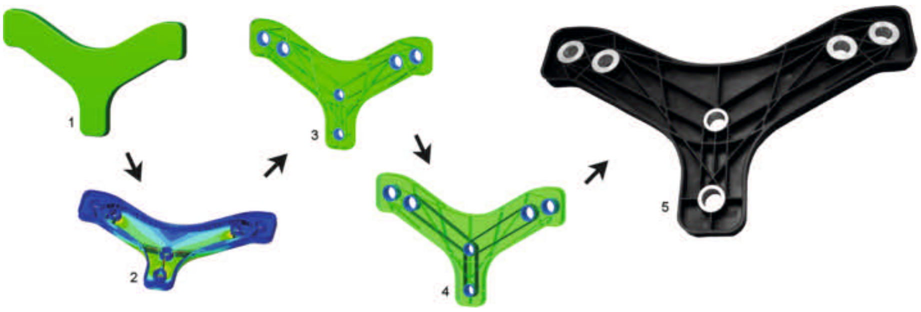

Iteration steps until the final product: area of application (1), FEM Analysis (2), optimized component (3), component with wound continuous fiber reinforcements (4), real molded part with reinforcing structures and metal force application points (5) (fig.: Fraunhofer ICT)

Multi-Material Design. While demands placed on lightweight constructions are growing, it is frequently not sufficient to merely replace materials. Holistic approaches and the targeted combination of different materials with their specific benefits are the key to efficient lightweight design.

Resource Efficient Lightweight Design for Mass Production

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TIMO HUBER ET AL.

The price of raw material is increasing, the demand for lightweight components is constantly on the rise, and the pressure on costs from competitors from the Far East is growing. This calls for novel types of lightweight design, in order to provide for economic large-scale production in integrated processes. To show just one example of the potential of hybrid lightweight design, this article will present an application of local reinforcement by continuous fibers, and will also provide information on a new tape laying process suitable for large series.

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Local Continuous Fiber Reinforcement – Tailored Injection Molding

Provided the engineer knows the type of load acting upon a component, as well as its exact application, it is possible to divide the part into sections according to the different types of load. On this basis, the designer can define force distribution lines representing a model of the course of force transmission. By placing continuous filament structures along these lines between the force application points, hybrid components are obtained with high load capacities and good mechanical properties related to the specific weight [1]. It is essential that the fibers within a component are oriented in the direction of load, and that exterior loads are applied directly into the reinforcing fibers, if possible. The fibers are placed within the component only where needed ("tailoring", which means customized component reinforcement in this context).

A simple tensile bar geometry is best suited to clarify the potential of local continuous filament reinforcement: in basic research carried out by the Fraunhofer Institute for Chemical Technology (ICT) in Pfinztal, Germany, unidirectional glass fiber inserts (UD strands) were produced

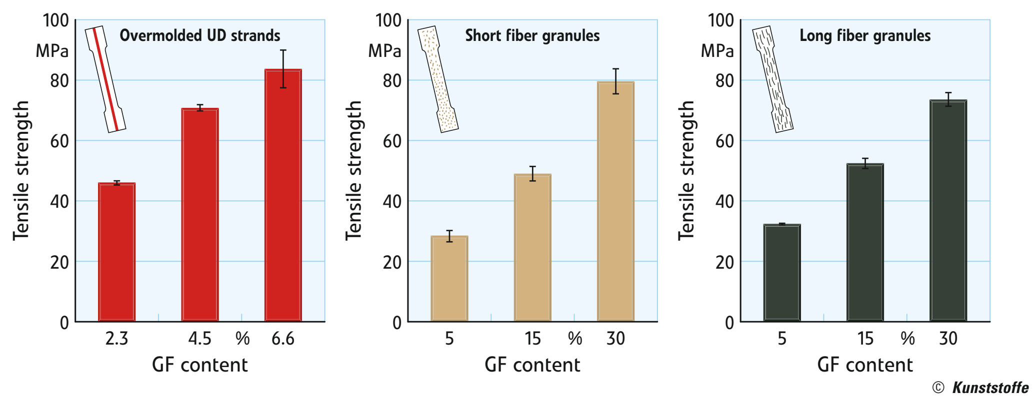


Fig. 1. Tensile strengths are higher for tensile test specimens (PP-GF) with UD-reinforcements and low fiber content, than in the case of short glass fiber reinforcement (SGF), or long- glass fiber reinforcement (LFT-G) (source: Fraunhofer ICT, [5])

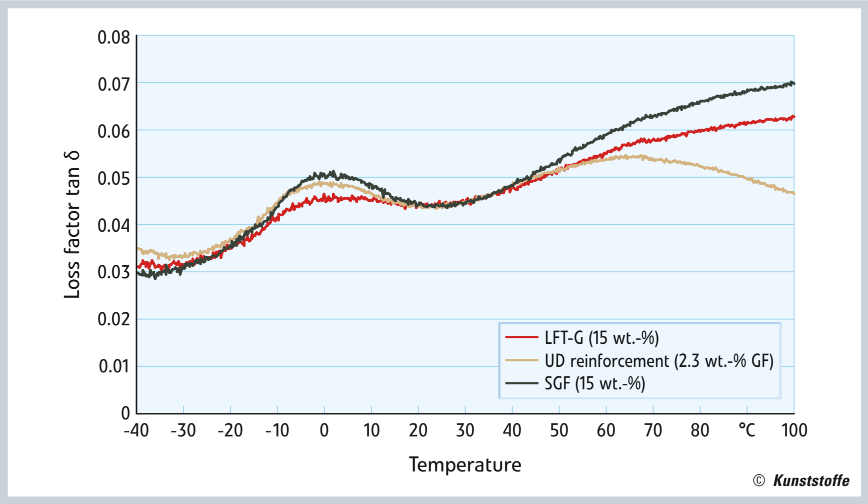


Fig. 2. Findings obtained from dynamic-mechanical analysis (DMA) of tensile test specimens (PP-GF): The UD reinforcement is superior to SGF and LFT-G, at temperatures above 60 °C, in particular (source: Fraunhofer ICT, [5])

from hybrid rovings (PP-GF60) in a pultrusion process, and then overmolded with non-reinforced polypropylene. In doing so, tensile test specimens were reinforced with one, two, or three UD tapes in axial direction, and compared to the same tensile bar geometry reinforced with short fibers (SGF) or long-fiber (LFT-G) granules, with different shares of glass fibers [2]. Employing oriented continuous fibers, a mere 6.6 wt.-% (three UD strands) is able to generate the same tensile strengths that require approx. 30 weight percent of SGF or LFT granules **(Fig. 1)**.

Using short fibers or long fiber granules, the fibers homogenously reinforce all zones of a component. Due to the fibers' higher density, if compared to the matrix, the component's total weight is increased, as all sectors of the component are reinforced with fibers, even including zones that have to withstand only little or no load at all.

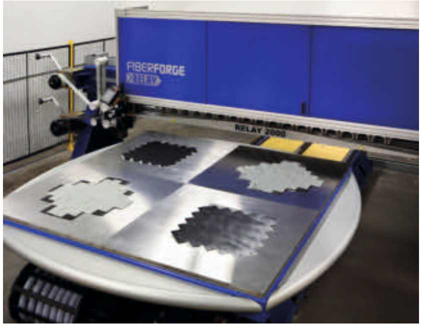


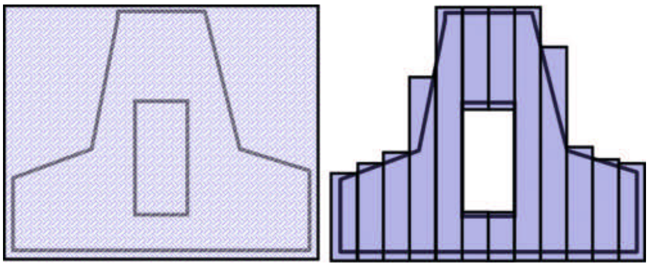
Fig. 3. Using the „Relay 2000" thermoplastic tape laying equipment, UD strands can be placed at any desired orientation and in a variable number of layers (photo: Fiberforge Corp.)

In comparison with plastics reinforced only with short or long fibers, the continuous fiber reinforcement features reduced tendency to creep, and increased heat resistance. This becomes obvious, for instance, when investigating the mechanical properties under dynamic load (dynamic-mechanical analysis, DMA). Considering the mechanical loss factor tan δ, which characterizes the ratio between loss and storage modulus under cyclic load, it becomes obvious that the benefits provided by UD reinforcement, in comparison with SGF and LFT granule reinforcement, are particularly striking from approx. 60 °C on **(Fig. 2)** [3–5].

Thermoplastic Tape Laying Using an Instrument Panel Cross-member as an Example

To locally reinforce thermoplastic structural parts, one option is tape laying of pre-impregnated UD tapes. For large-series application of this technique, two crucial prerequisites must be fulfilled in order to provide for efficiency: the laying process must be automated, and material throughput must be sufficiently →

Fig. 4. Strand layups (right) reduce waste to a minimum, compared to woven prepregs (left) (fig.: Fraunhofer ICT)



high. The Relay technique developed by Fiberforge Corp., Glenwood Springs, Colorado, USA, meets both these requirements.

Layers of pre-impregnated UD tapes are placed on a movable table to form a fabric. The orientation of the tapes (i.e. the fibers) can thus be adjusted almost infinitely to the respective case of load via the table rotation. To make sure the fabric can be handled in the following processing steps, the single layers are connected in some spots by ultrasonic welding. In the future, Fraunhofer ICT will be able to produce fabrics of up to 2 m × 2 m size on a machine of this type which is unique in the world **(Fig. 3)**. This technique provides benefits such as:

- Fast tape laying in accurate position with any desired orientation,
- option of varying wall thicknesses,
- minimizing waste from production and
- production of hybrid fabrics.

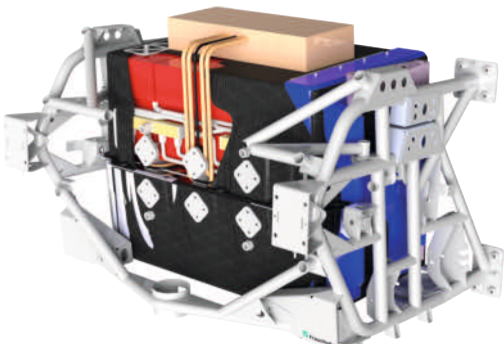


Fig. 6. For the battery casing due to be fixed to a vehicle rear frame, the LFT basic material was combined to two layers of fully consolidated woven PP-GF47 fabric (photo: Fraunhofer ICT)

Especially the minimization of waste is one of the major benefits compared to woven prepregs **(Fig. 4)**.

When processing pure fabric structures, the high fiber content of unidirectional tapes (approx. 40 to 60 vol.-%) means a restriction to formability and flowability. In the production of complex geometries (e.g. ribs), integrating functions (screw bosses, snap fits, etc.) and meeting the demands of the application call for combination with short- or long-fiber reinforced materials. For load-bearing elements, the techniques of overmolding in highly automated injection molding or compression molding processes are particularly suitable.

A cross-member of an instrument panel **(Fig. 5)** was produced and evaluated as part of a joint research project of Fraunhofer ICT and Peguform GmbH, Bötzingen, Germany, clarifying the options included in the Relay technique and combination with other methods. The reduction of waste is of particular benefit with such complex structures. Moreover, the fabric structures can be adapted to the respective type of load in all sectors (1 to 5). For highly loaded sections, carbon fibers are feasible, instead of glass fibers (2, 4) or the designer may stack several tapes (variable wall thicknesses; 1, 5). Areas with low loads, complex structures (3) or metal inserts (5) can be realized in an injection molding process.

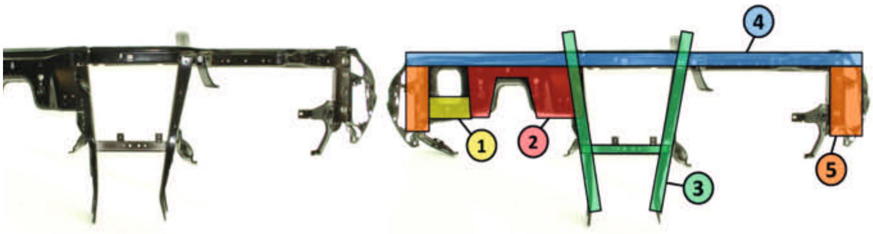


Fig. 5. Example of an application of local continuous fiber reinforcement, showing an instrument panel cross-member: The fabric layers can be adjusted to the respective loads in all zones (see text) (fig.: A2Mac1 / Peguform GmbH)

Battery Protective Casing in a Multi-material Design

In a joint research project named "Fraunhofer System Research for Electromobility (FSEM)" several research groups have worked on the issue of electric vehicles over the past two years. The Fraunhofer ICT has undertaken research aimed at the development of a battery protective casing from a multi-material based on D-LFT, customized local continuous fiber structures, and intrinsic metal inserts **(Fig. 6)**.

The long fiber-reinforced thermoplastics (LFT) employed here have been used as a semi-structural material in vehicle construction for many years. The material combination of polypropylene and glass fibers is state of the art in many areas of technology [6, 7]. In order to produce the battery protective casing (incl. supporting structure) as a hybrid component, lightweight materials were integrated into an existing large-scale production process (D-LFT in compression molding) [8, 9]. The frame of the structural group consists of thermoset CRP fixtures and an intrusion-protected LFT battery protective casing. To stiffen the casing, intrinsic metal reinforcements (tailored LFT) and light metal crossheads were employed. In a future step, the CRP fixtures can be further optimized by means of thermoplastic tape laying (e.g. Relay).

The li-ion battery built in the framework of the FSEM project includes 16 single modules with an overall weight of 350 kg. Its support consists of two mirrored halves of a battery protective casing **(Fig. 6)**. The concept was designed for 3 g acceleration in driving operation (gravitational acceleration 1 g = 9.81 m/s^2) and for a 10 g crash case. For the battery casing, the LFT basic material was combined to two layers of fully consolidated PP-GF47 woven fabric (type: Tepex; manufacturer: Bond-Laminates GmbH, Brilon, Germany). Loads are applied to the battery modules via light-metal crossheads from AIMgSi0.5 and internal steel inlays from H420LA [10] into the LFT/woven fabric structure of the side walls and the ground area. The intrinsic metal insert, for instance, doubles the transverse extraction force, and appears to suppress the tendency to creep.

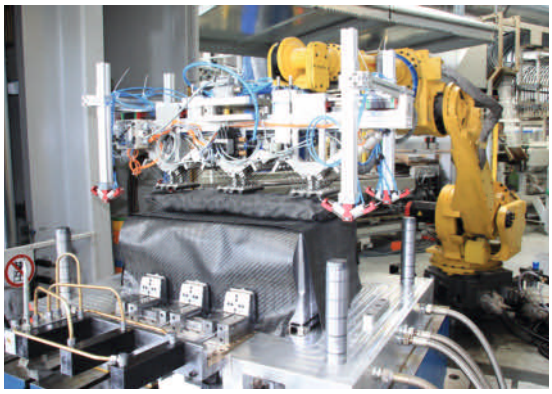


Fig. 7. A specially designed handling unit places the polymer LFT material and the prepreg into the cavity (photo: Fraunhofer ICT)

Component testing under the assumption of quasi-static load has confirmed the calculated simulation results of the Mises

Contact

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→ **www.ict.fraunhofer.de**

tensions in a crash case. Final evaluations of the investigations carried out on the creep behavior of the multi-material structure are currently being completed.

The entire process was established as a partially automated process for the production of the battery protective casing prototype at ICT **(Fig. 7)**. With wall thicknesses between 5 and 6 mm, cooling time amounts to 45 s; the overall cycle takes 65 s. The polymeric LFT material is compounded on a D-LFT plant (manufacturer: Dieffenbacher GmbH + Co. KG, Eppingen, Germany), and, together with the fully consolidated glass fiber fabric, is inserted into the compression mold by a needle gripper robot. The hybrid PP/GF fabric is heated to processing temperature in a paternoster circulating air oven (manufacturer: HK Präzisionstechnik GmbH, Oberndorf, Germany). In the same way, another infrared heating field prepares the second prepreg, which is then inserted manually, together with the intrinsic metal reinforcing structures, and compression molded in an SMC press with parallel motion control (type: Compress Plus DCP-G; clamping force: 36,000 kN), to eventually generate the component.

Conclusion

Multi-material solutions are a promising approach of using thermoplastic matrices for an increasing number of structural applications (metal substitution), or further reducing the component weight of existing thermoplastic solutions. Weight reduction is not the only consideration which can lead investors to accept the cost of new equipment or more demanding production processes. Another major driving force is the option of stepping up functional integration with new functionalities or improved material properties. Multi-material components are based on a mixture of materials, with the individual materials employed in the particular place where they offer the most benefit. Optimizing a component for a defined application always means specialization at the same time. If, for instance, components reinforced by continuous filaments, contrary to their original purpose, are submitted to load in perpendicular direction to the fiber orientation, their material behavior is extremely poor, and they mostly fail at very little load. Adequate methods for early lay-out (by simulation), as well as a strategy aimed at recyclability of multi-material components must be adapted and/or developed. ■

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You will find a free download of the list of references at www.kunststoffe-international.com/A038.

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