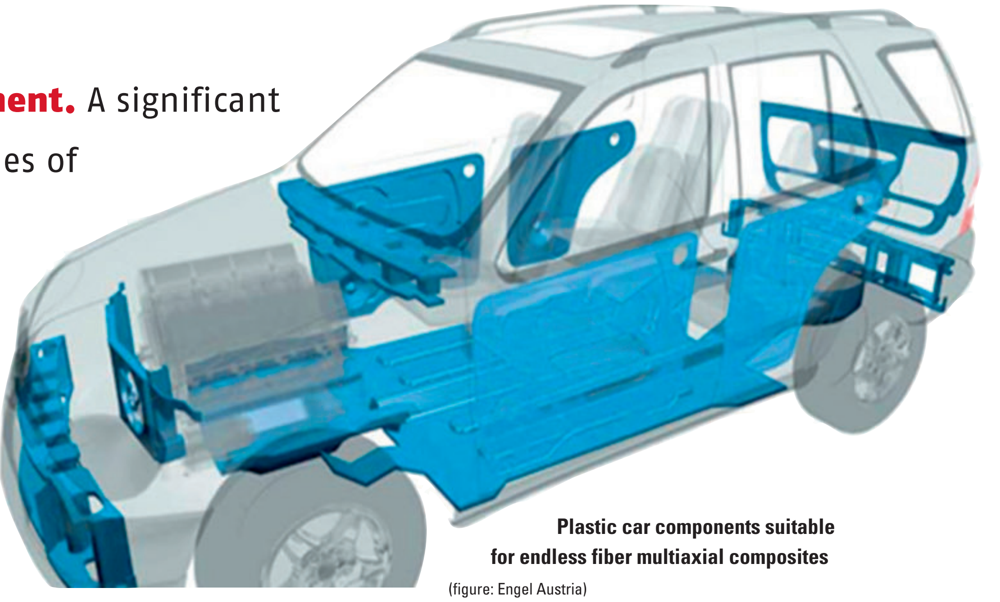
Flexible Textile Reinforcement. A significant improvement in the properties of plastic components can be achieved by introducing reinforcing textile grids. Moreover, parts reinforced in this way have a high potential for integrating additional functions.



Plastic car components suitable for endless fiber multiaxial composites (figure: Engel Austria)

Multiaxial Textile Grids

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In recent years, there has been a large increase in the range of applications of fiber composites with thermoplastic matrices. The main reasons for this fact lie in the potential savings in part weight. Moreover, fiber-reinforced thermoplastic parts can be manufactured inexpensively using high-productivity processes, such as injection molding, compression molding or long-fiber injection molding (LFI). To meet higher requirements on the load bearing strength of such thermoplastic parts, besides conventional short-fibers, there is a focus on the application of long-fiber and continuous fiber reinforcement. Along with glass mat reinforced thermoplastics, closed textile products or preconsolidated organic sheet, a new, highly promising reinforcement alternative is offered by thermoplastic endless fiber-reinforced multiaxial grids ("Temag"). This flexible textile reinforcement can selectively improve both local and global part properties. On the other hand, additional functions, such as variably positionable filaments with electrical and optical properties, or temperature and strain sensors, can be integrated into the composites. The technology for manufacturing and using the Temag reinforcing structures in plastics technology is the result of a multi-year research project at the Institute of Textile Machinery and High Performance Material Technology (ITM) and the Institute of Lightweight Engineering and Polymer Technology (ILK) at the Technische Universität of Dresden, Germany.

Textile Reinforcing Grids

This reinforcing concept is based on the layerwise bonding of biaxially to multiaxially oriented, completely stretched filaments of high-performance fibers, e.g. glass or carbon, and thermoplastic components, using modified warp knitting techniques. Such grids can be produced with openings adapted to the secondary processing technique and may be asymmetrical or symmetrical in form **(Fig. 1)** The reinforcing grids are produced on Malimo right/left stitch bonding machines with integrated infrared radiator units for preconsolidation. The preconsolidation of the grids by fusing the thermoplastic components is necessary to allow secondary processing in the composite forming process. **Figure 2** shows a non-preconsolidated grid structure of glass filament yarns after injection molding,

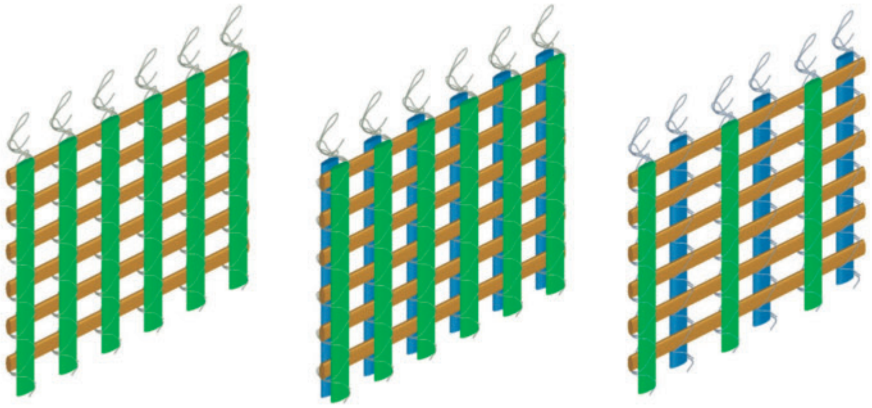

Fig. 1. Asymmetrical and symmetrical 0°/90° grid structures (figure: ITM)

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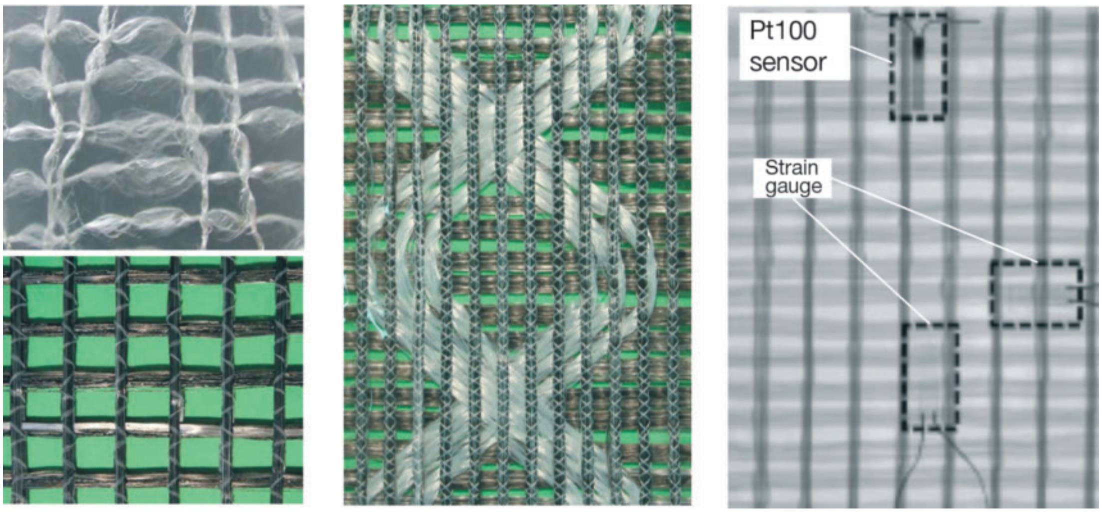

Fig. 2. **Temag structures: Need for preconsolidation (left), load-path-directed fiber orientation via warp manipulation (center), X-ray image of integrated strain gauges and temperature sensors (right)** (figure: ITM, ILK)

and a preconsolidated grid of hybrid yarns (glass/polypropylene (PP) black), which illustrates the dimensional stabilization problem.

Preconsolidated grids are very easy to handle. They are particularly suitable for use in injection molding, since the grid geometry does not change during production. The processing of online-spun parallel hybrid glass and polypropylene (PP) filament yarns as a reinforcing or matrix component has proved to be very promising. Textile studies show that the grid properties can be adjusted to the application within a wide range. From these parameter studies, asymmetrical and symmetrical preconsolidated biaxial grids of the parallel hybrid yarn Twintex (fineness 1,870 tex, 60 % glass, 40 % PP) are available. In the preferred variants they have weights per unit area of 260 to 780 g/m^2 and different grid sizes, and filament components in the reinforcing direction as the preferred variant.

Symmetrical grid variants are preferred for part production to avoid initial deformations after manufacturing. This can be achieved by laminating asymmetrical grids. A more efficient solution is already possible via the textile production process. At the ITM, a method of generating symmetrical layer arrangements with a shiftable needle bar [1] was used to produce the symmetrical grid **(Fig. 1)**.

To design multifunctional reinforcements oriented to the force flow, further technical process developments were performed at the ITM, which permit the production of textile grid structures with warp profiles following the load path and integrated functional elements. One possible way of realizing such reinforcement filament profiles is by "filament manipulation". Additional filaments are arranged at the particularly heavily loaded points. The principle of warp thread manipulation developed for this allows threads to be positioned precisely where they are required for additional functions [2], e.g. for additional reinforcement of load application points **(Fig. 2)**.

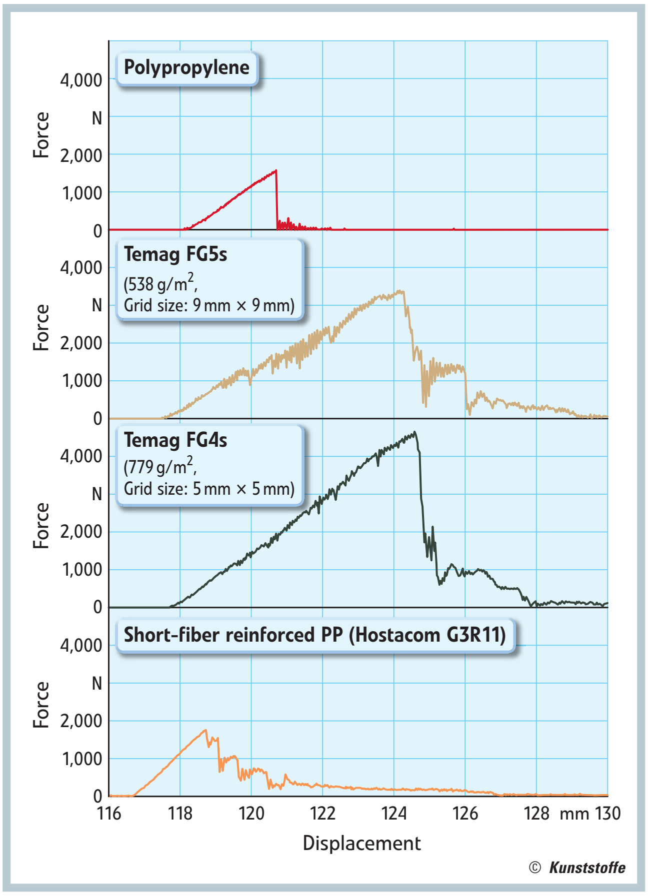

Fig. 3. **Comparison of force-deformation curves for impact testing** (source: ILK)

Production and Characterization of Grid-reinforced Composites

The Temag structures can be processed using various composite production methods. Tested processes were injection molding, the LFI process and compression molding combined with the extrusion of long-fiber-reinforced thermoplastics (LFT).

The production of Temag composites by injection molding was performed at the ILK on a horizontal injection molding machine with 500 kN clamping force. Selected technical questions that were solved included the positioning of the grid structures in the mold, the filling behavior and bonding of the preconsolidated grids to the PP-based matrix material. The interface surface properties can be considerably improved if injection is per-

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formed at an elevated mold temperature. In a specific case, optimum bonding could be achieved at a mold temperature of 115 °C. A fast and reproducible grid positioning can be realized by suitable preforming. The local heating and subsequent forming and cooling of the grid structure permit targeted positioning both in the thickness direction and in the reinforcement plane. At present, the visible impression of the grid on the surface is unavoidable, so Temag composites produced by injection molding cannot be used for appearance parts. Improved surface quality of the Temag composites while retaining all the advantages, is achieved by foaming in the LFI process. This was accomplished using the LFI system from KraussMaffei Technologies GmbH, Munich, Germany, which is available at the ILK. The central positioning of the Temag structure in the part is ensured by an upper and a lower LFI layer. With the multifunction high-speed press from Dieffenbacher GmbH & Co. KG, Eppingen, Germany, together with a single-screw LFT extruder, it was also demonstrated that Temag reinforcement can be processed by the LFT process. This allows composite structures to be realized, in which the Temag reinforcement is located at a defined position on one side of the part. A high surface quality can thus be ensured at one side.

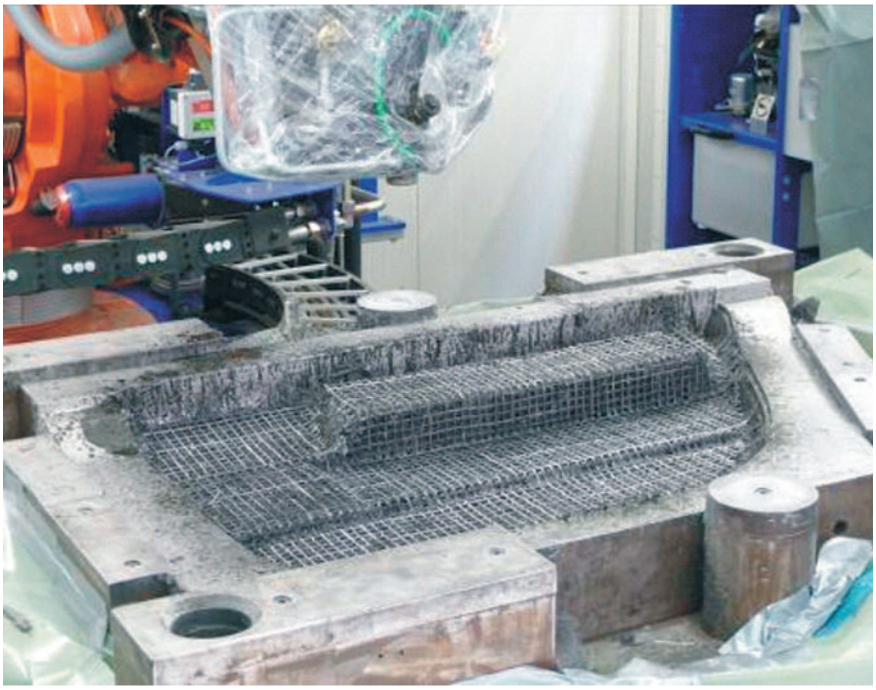

Fig. 4. Production of grid-reinforced door lining by the LFI process (photo: ILK)

The material behavior of the Temag composites was experimentally studied in an extensive test program [3]. The most prominent advantage of comparable materials is shown by Temag composites in crash tests. For example, in impact tests, it could be demonstrated that the energy absorption capacity during impact can be increased by up to 1,000 % compared to short fiber-reinforced PP, though the fiber volume content, at 6 to 10 %, was clearly below the

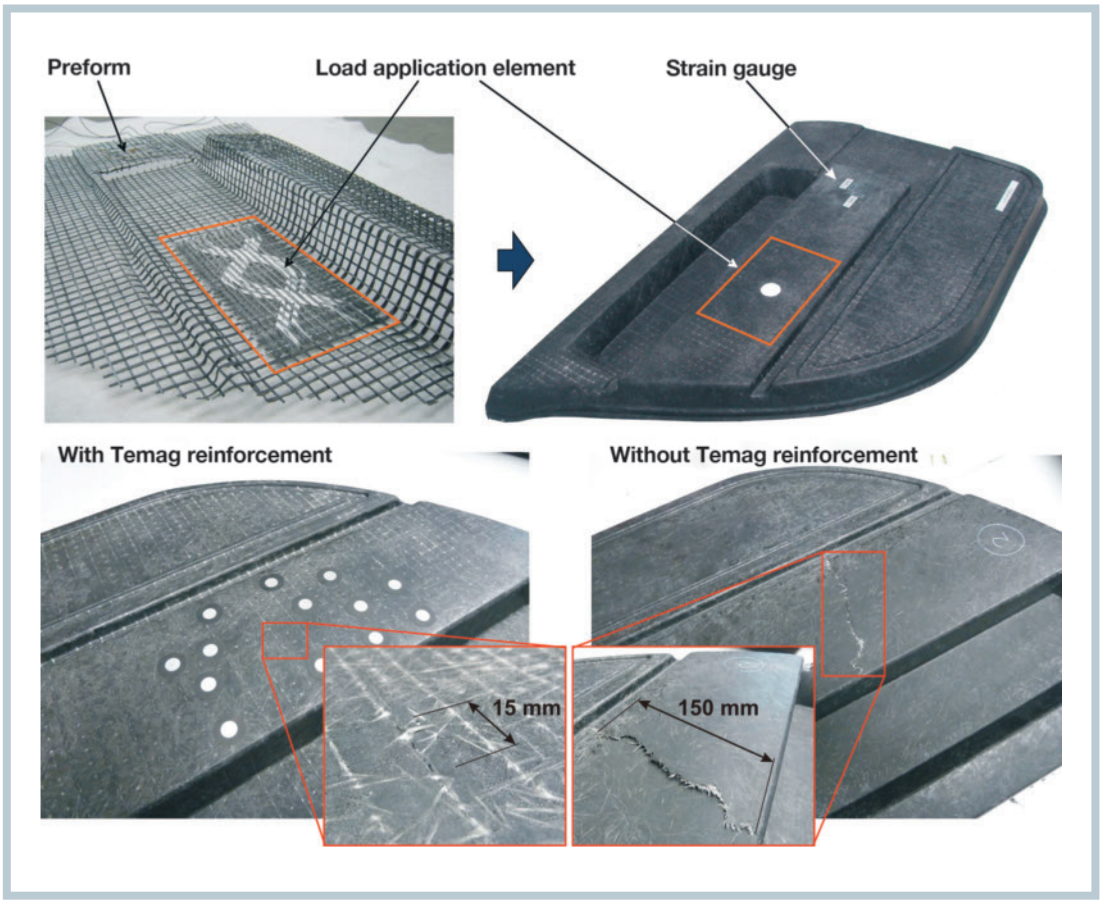

Fig. 5. Door lining with Temag reinforcement Preform (upper left), part with textile load application zone and integrated strain gauge (upper right) after drop tower tests (lower left) compared to the LFI-reinforced version (lower right) (figure: ILK)

reference (13 % Hostacom G3R11) (**Fig. 3.**: the absorbed energy corresponds to the area beneath the force/displacement curve). Temag composites are thus ideally suited for crash-loaded parts. It is conceivable to use, e.g., measures for splinter protection or for protection against stone impact.

Functional Integration

The introduction of additional functions into Temag composites permits an effective extension of the properties of such molds. This can be realized by using multifunctional Temag reinforcements combined with the use of sensors. Besides warp manipulation for producing force application zones, the following additional functions are possible in principle:

- Integration of optical waveguides into the textile by filament manipulation, e.g. for integrated measurement of temperature and strain;
- integration of carbon fibers or metal wires into the textile by filament manipulation, e.g. to provide heating functions or selective electrical conduction (e.g. antenna functions and signal transmission), and
- integration of strain and temperature sensors or sensor networks during the composite consolidation process **(Fig. 2).** The correct functioning of the sensors after injection molding was demonstrated. Furthermore, it is also ensured that the position of the sensors is not negatively affected by the injection molding process.

Practical Realization

Automotive parts for which Temag reinforcement can be used are shown in the **Title photo.** To illustrate the advantages of Temag structures, a door lining produced by LFI was chosen as demo **(Fig. 4).** The manufacturing process of the grid-reinforced door lining, in which both a textile load-application element and two strain gauges were integrated, is performed in four steps: After spraying the LFI inner layer (polyurethane with 100 mm chopped glass fiber), the prepared Temag structure is laid in the mold and the LFI outer layer sprayed on. The part is then consolidated by pressing.

These door linings with Temag reinforcement were tested for impact energy absorption in drop tower experiments at the ILK. The grid reinforcement significantly increases both the energy absorption capacity and the impact resistance of the parts. The Temag reinforcement can effectively prevent part failure **(Fig. 5).** On impact of a 2 kg steel sphere with a velocity of 20 km/h, considerably less damage results in the Temag-reinforced door lining compared to a purely LFI-reinforced part.

Summary and Outlook

The development of Temag structures and their further processing into fiber composites form the basis for providing tailored parts with a large number of additional integrated functions. Temag composites allow new product groups for promising lightweight structures to be opened up in future. ■

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