The Networked Car Body

Function-Integrated Lightweight Construction with Hybrid Yarn Textile Thermoplastic Composites

Hybrid yarn textile thermoplastic composites offer enormous potentials for highly integrated structural components with additional functions, as represented e.g. by an integrated sensor network. The necessary manufacturing processes were developed by scientists in Dresden, Germany, and demonstrated on the "FiF" concept vehicle.

The demonstrator vehicle shows the extraordinary lightweight construction potentials of function-integrated textile-reinforced thermoplastic composite components (© ILK, TU Dresden)

Textile thermoplastic composites are outstanding materials for large-scale lightweight constructions, e.g. in the automotive industry, because they have excellent specific mechanical properties, and can be applied with high productivity in manufacturing processes [1]. In particular, composites based on hybrid yarn open up many possibilities for designers to adapt the material properties flexibly to the stresses acting in the component. This will be exemplified by means of composite materials made of glass fiber (GF) and polypropylene (PP), whereby the described results are also applicable for other material combinations. Moreover, the application range can be expanded considerably with additional functions, for example by integrating sensor networks in the composite structure [2].

The joint aim of the collaborative research center SFB 639 at the Institute of Lightweight Engineering and Polymer Technology, University University Dresden, Germany, was to investigate this still young group of materials in detail. Due to the complex interrelations this requires a consistent and overall view, from the filament up to the complex final component. The process chain starts with the online spinning process, in which hybrid yarns are created and thereby functionalized by means of special sizing finishes filled with carbon nanotubes (CNT). Thanks to the electrically conducting layers formed in this way, damage in the finished composite component can be detected via a change of the electric resistance. Subsequently, these hybrid yarns are used in highly productive textile processing methods to produce near-net shape preforms.

Textiles made of hybrid yarn permit the use of new processing methods and tooling technologies. In order to manufacture sandwich structures with resolved cross sections (spacer structures) a series-compatible compression method

Fig. 1. Highly integrated structural components in the driver's cabin: (a) complex-shaped front shell made of GF/PP multi-layer knitted fabric, (b) vehicle column made of near-net shape knitted preform, (c) textile composite spacer structures, and (d) bonded joint (© ILK, TU Dresden)

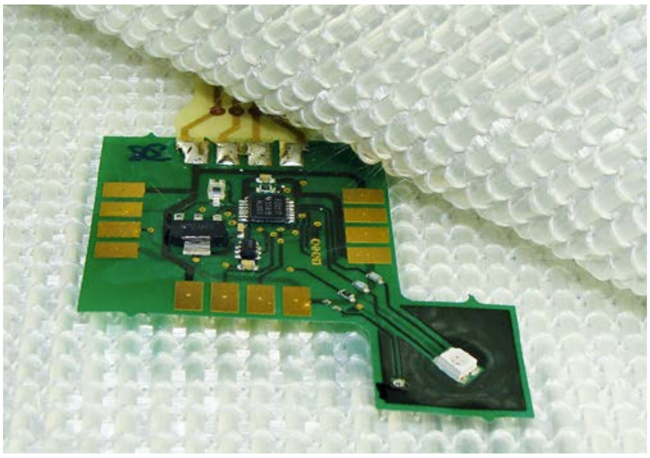

Fig. 2. The electronic components of the sensor network are inserted between two layers of hybrid yarn-based GF/PP multi-layer knitted fabric (© ILK, TU Dresden)

with process-active tooling systems was developed and successfully tested. The final component contour and function-related cutouts were formed precisely by means of a specially developed remote laser-cutting procedure. Furthermore, new bonding and form-fitting methods were created for joining the textile composites.

Parallel to these technical developments, the research project followed a mulit-scale design strategy, which makes use of adapted material models and simulation tools. Due to the consistent approach, the scientists were able to derive construction methods that are compatible with textile composites, and to implement novel processes for the integration of multiple functions along the entire process chain. The results found their way into the "FiF" (function-integrated vehicle system platform) demonstrator vehicle, and underline the extraordinary lightweight construction potential of this group of materials.

FiF Demonstrator Vehicle

The FiF demonstrator (**Title figure**) is a light commercial vehicle with a modern design. Thanks to its robust construction and the emission-free electric drive, it is predestined for urban or in-house transport. The vehicle's supporting structure consists of only two systems: the driver's cabin and the supporting structure. This permits a high proportion of lightweight components, and simultaneously reduces the manufacturing costs.

Moreover, the use of hybrid yarn textile thermoplastic (HYTT) composites permits a lightweight construction method with a high level of functional integration, so that the vehicle's entire supporting structure consists of only 14 components. Another special feature of the vehicle is the integration of structural, electrical, and adaptive functions into the components.

The entire demonstrator vehicle was dimensioned with the calculation methods developed within the SFB 639, and manufactured with the technologies of the HYTT process chain. For example, HYTT multi-layer knitted fabric made of glass fibers and polypropylene was used for the large shell structures (e.g. for the two-part vehicle front). As the fabrics have excellent draping properties, highly integrated and complex component structures can be built (**Fig. 1a**). Opposed to this, near-net shape knitted preforms were used in the supporting profiled cabin columns, in which the fiber orientation was already defined in the textile manufacturing process according to the force flow (**Fig. 1b**). Novel spacer structures were selected for the foot and tread areas, which are subjected mainly to bending forces (**Fig. 1c**) [3]. Cylindrical HYTT crash absorbers in the front provide additional safety for the driver's cabin in case of a collision. Here, selective use was made of the high specific energy absorption properties and the 'benign' failure characteristics of the textile thermoplastic composites (**Fig. 1d**).

Composite-Integrated Sensor Networks

Monitoring of the highly stressed lightweight construction elements in the FiF is carried out by composite-integrated sensor networks, which consist of the basic elements sensor, communication leads, and electronic processing unit. These elements are installed in the HYTT composite during the manufacturing process (**Fig. 2**). The integration of electronic components permits the measurement signals to be processed close to the sensors, which greatly reduces their vulnerability to failure, and leads to shorter connecting lengths. However, the electronic components and the process conditions during component production must be precisely matched to each other in advance [4]. Such sensor networks are suitable for detecting the actual operating status, for documenting load spectra and overload events, as well as the early detection of damage in the composite structure that is not visible externally. Such information are useful e.g. for planning and carrying out maintenance intervals [5].

The sensor networks contained in the individual components of the demonstrator vehicle are interconnected during the assembly stages. For this, the scientists developed combined joints that »

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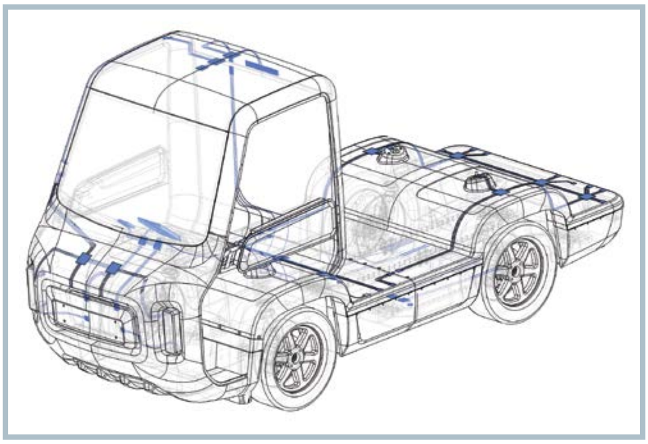

Fig. 3. Overview of the trans-component, composite-integrated sensor network of the demonstrator vehicle (© ILK, TU Dresden)

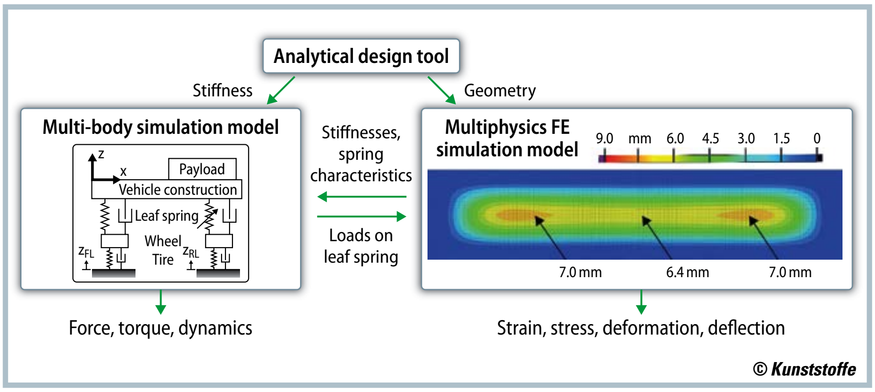

Fig. 4. Static and dynamic behavior of leaf spring and vehicle were simulated with the help of various calculating tools (source: ILK, TU Dresden)

permit the simultaneous transmission of mechanical forces and electric signals [6]. In the final result, a composite-integrated sensor network is spread out across the entire demonstrator vehicle (**Fig. 3**). The network handles most of the data communication within the vehicle, and thanks to its decentralized layout and numerous electronic processing units, it reduces the amount of wiring. For example, vehicle functions can be operated via this sensor network, and the data acquired in the individual components can be transmitted to the installed user interfaces. Here, the information is displayed for the user via the composite-integrated LED displays or a tablet. Moreover, the sensor data can also serve as input signals for control processes, e.g. for the precise adaptation of component characteristics.

Adaptive Leaf Spring

The potentials of function-integrated HYTT composite structures are demonstrated by the example of the adaptive leaf spring in the FiF, which is able to

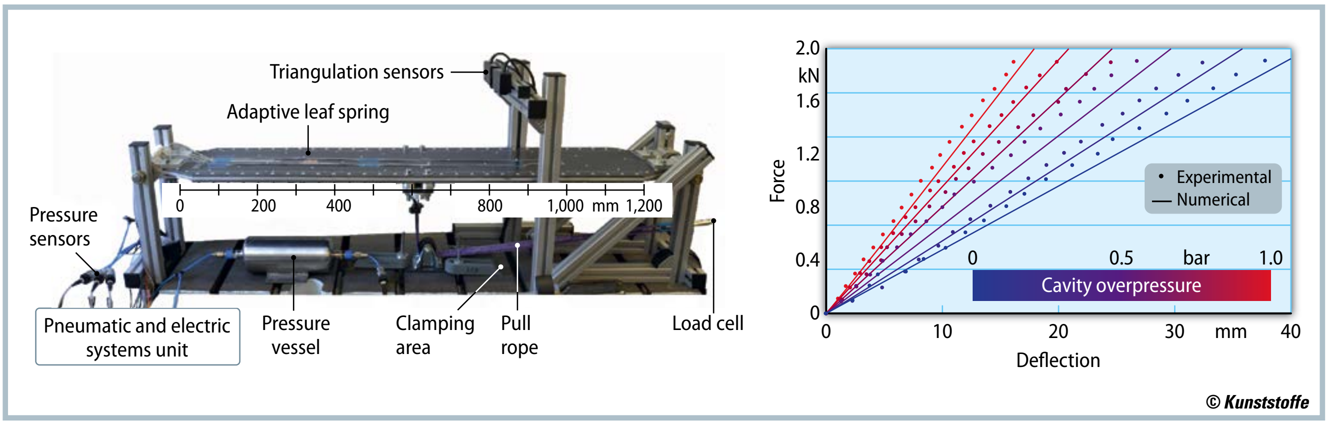

Fig. 5. Experimental test setup with installed leaf spring (left), whereby spring characteristics were determined experimentally and by means of a calibrated finite element model (right) (source: ILK, TU Dresden)

modify the spring's stiffness during operation, depending on the actual load. In this way it makes a significant contribution towards improved driving comfort and safety, as well as reducing component wear.

Sensors integrated in the material measure the strain fields and the applied loads as input data for the control unit. In order to regulate stiffness, the spring's cross-section and thereby its moment of inertia are adapted. In the developed spring concept, this is achieved by means of air-filled cavities in the leaf spring, which consists of a sandwich structure with two covering layers of GF/PP multi-layer knitted fabric and an aluminum frame. The geometry of the spring's supporting cross-section can be modified precisely via the overpressure in the cavities.

A consistent development procedure with four individual stages permitted a detailed description of the adaptive leaf spring to be made. The process includes both the calculatory and experimental determination of the static and dynamic behavior of leaf spring and demonstrator vehicle. In an earlier development phase, various calculation tools were used to adapt the leaf spring optimally to the requirements (**Fig. 4**). Based on the selected sandwich concept, a pre-design for the leaf spring was created with the analytical "fast design tool". Subsequently, the pre-dimensioned leaf spring was built up as a finite element model, so that the mechanical loads as well as the adjustable spring characteristics could be calculated. The resulting spring stiffness values then served as input data for a multi-body simulation that encompassed the entire FiF system. Finally, the geometry of the leaf spring as well as the structure of the HYTT covering layers are adapted in an iterative process.

Experimental investigations on prototypes showed that the selected component concept permits a significant stiffness adaptation to be implemented (**Fig. 5**). By raising the overpressure in the cavities from 0 to 1 bar, the stiffness of the examined leaf spring was increased by 130 %. Consequently, the experiments confirmed the pioneering concept of inflatable structures that are compatible with textile composites to obtain an adaptive spring stiffness.

Summary

The FiF demonstrator vehicle illustrates the great potential offered by the use of HYTT composites and the application of adapted lightweight construction methods in automotive engineering and also in other application areas such as aerospace, rail vehicles, or mechanical engineering in general. The solutions developed by the SFB 639 for demand-specific designs, the integration of functions, as well as the available efficient processes permitted the implementation of resource-conserving and economic lightweight structures. ■