Reducing Load in Air Transportation

Fiber-Reinforced Thermoplastic Modules Can Be Used to Reinforce Airplane Cargo Compartments

The use of thermoplastic fiber composites enables outstanding specific stiffness and flame retardant properties to be combined with reaction-free and integrative joining technologies. This has been demonstrated by using an economical, industrial-scale process to manufacture a hybrid reinforcing component, which can be applied for example in the cargo compartments of airplanes.

Thermoplastic fiber composites enable the manufacturing of integral hybrid structures in large-scale processes. These structures combine lightweight construction and functional integration. While such approaches are already being used in series applications in the automotive sector [1], in the aviation sector thermoplastic applications are mainly monolithic [2]. However, the significant potential of thermoplastic structures with integrated functions can be exploited in this sector, too. Such integrated production approaches are increasingly relevant, especially in view of increasing quantities at high cost pressure. In aviation, specific material systems are needed which not only meet the mechanical requirements but also function at high operating temperatures and have very good flame retardant properties.

Together with its partners Airbus Operation GmbH, Laser Zentrum Hannover e.V. and TenCate Advanced Composites B.V., the Fraunhofer Institute for Chemical Technology ICT has developed a hybrid reinforcing component – based on the high-performance thermoplastic polyetherimide (PEI) – for the aviation sector. This component combines the advantages of the material, process and design. These advantages are fully exploited in a demonstrator developed for potential application in the cargo compartment of airplanes (**Title figure**).

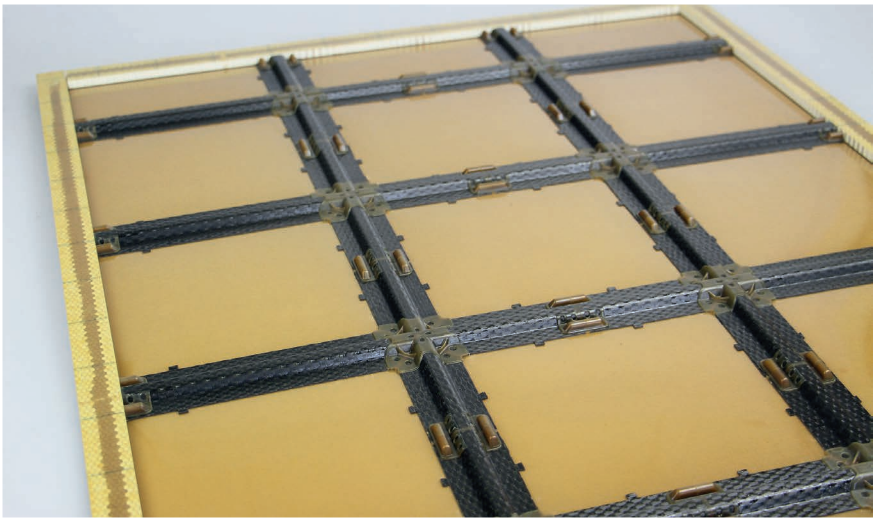
Flexibility through Connected Modules

A novel construction was developed for the reinforcing panel. The main component of the modular system is a hybrid reinforcement structure (**Fig. 1**) which consists of stamp-formed carbon-fiber-reinforced PEI composite laminates and injection molded node and joining elements made of short-glass-fiber-reinforced PEI. The subdivision into smaller, recurrent units reduces the complexity and enables larger batch sizes and lower investment costs for production machinery and molds. The individual reinforcement structures can be connected so that the size of the panel can be individually adjusted to the respective application.

Each substructure consists of four omega profiles with an identical cross-section made of composite laminate (two-layered 80/20 carbon fiber fabric, 0.84 mm thick), a torsionally-stiff node element, and four joining elements. The material and profile shape were selected to ensure that the structure is as rigid as possible for the given installation space, and after the subsequent laser welding to the facing. The four connection elements and the node element were designed to obtain the best possible load transmission and dimensional stability.

Laser transmission welding was used to join the assembled grid structure to the face sheet (lining) to obtain the finished panel (**Fig. 2**). This process makes use of the optical partial transparency of the glass-fiber-reinforced PEI to near-infrared radiation, which enables melting of the thermoplastic only in the joining areas of the reinforcing grid profiles.

The laser transmission welding of non-fiber-reinforced or short-fiber-reinforced materials is an established industrial process, and over the past years it »



Hybrid reinforcing panel for potential application in the cargo compartment of airplanes

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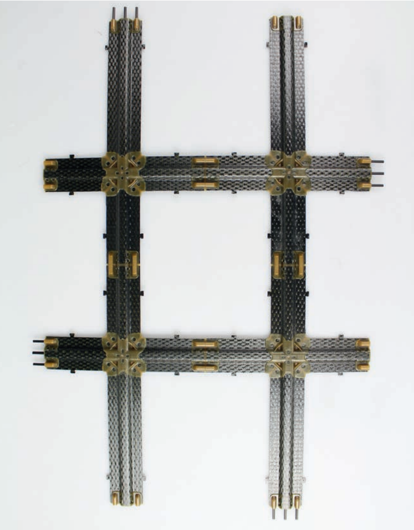

Fig. 1. Reinforcing grid assembled from four substructures (© Fraunhofer ICT)

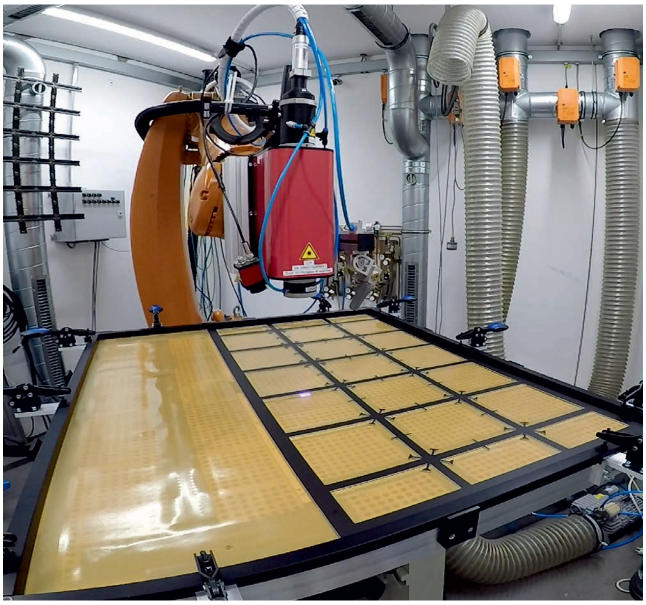

Fig. 2. The grid structures and the face sheet were joined using transmission laser welding at the Laser Zentrum Hannover (© LZH)

has been further developed for the processing of continuous-fiber-reinforced structures [3]. To join the components in this welding process, the project partners developed a clamping device with a modular construction, which applies pressure selectively and thus ensures a continuous joining pressure along all weld seams. A robot guides a specifically formed laser beam with a velocity of up to 5 m/min across the reinforcing panel. This makes it possible to switch quickly and flexibly between different component and material variants. The subsequent installation of the welded panels onto the secondary structure is carried out using the frame of the panel.

Advantages of the Two-Step Hybrid Molding Process

The substructures are manufactured in a two-step hybrid molding process. The stamp-forming of the composite laminates is carried out separately from the joining and the integration of functions via injection molding. Firstly, the omega profiles are manufactured in an industrial forming process. Secondly, these profiles are used as inserts in an automated injection molding process. Within this process step, four individual inserts are transferred to the mold and are firmly joined together by the injection molding compound (node element). Simultaneously, the four joining elements are injected to the open ends of the omega profiles. Compared to so-called 'one shot' processes, in which the forming and the integration of functions are carried out in one step, this two-step process has specific advantages in terms of process control and component design. On the one hand, as in the case of rigid (e.g. metal) inserts, common automated processes can be used to safely integrate the precisely shaped profiles into the injection molding process. On the other hand, the high stability of the inserts ensures that they can be positioned in the process with a very high degree of reproducibility. This results in an increased dimensional accuracy of the final component.

Forming with Handling System

The composite laminates were formed using an adjusted gripper system which permits a controlled tracking of the semi-finished materials on the parting plane (**Fig. 3**). This prevents the composite laminates from touching the forming die too early, which is especially important because the semi-finished composite laminates are thin (<1 mm). Subsequently, the stamp-formed parts can be precisely inserted into the injection molding cavity (**Fig. 4**). An undesired local over-injection in the subsequent injection molding process can therefore be avoided.

Adhesive Joining via Injection Molding

By selecting this processing chain, the complexity and precision of the preform can be increased, especially in the node area of the component. The injection molding can be reduced to a necessary minimum: it is used only for joining and functionalization, without the need for additional injection material for tolerance compensation. The mechanical properties can be better exploited in material compounds, and can help to achieve weight savings. The selectively placed injection molding compound also reduces

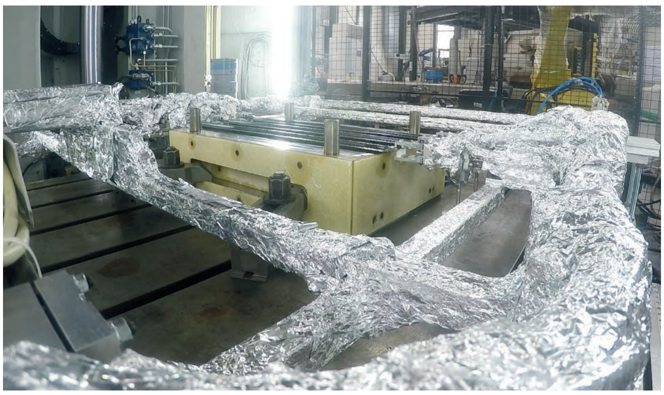

Fig. 3. The gripper-assisted forming process prevents the composite laminate from touching the forming dies too early (© Fraunhofer ICT)

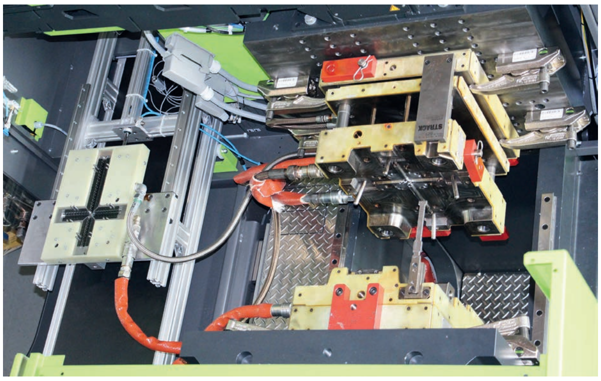

Fig. 4. Manufacturing of the substructure in the injection molding process (© Fraunhofer ICT)

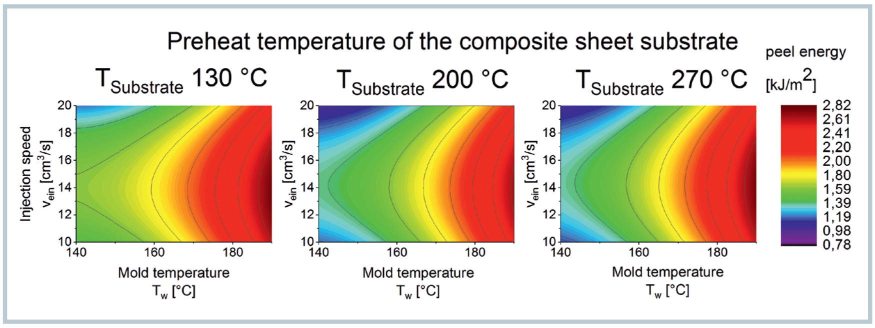

Fig. 5. The results of a statistical model for the peeling of a hybrid composite consisting of PEI composite laminate and PEI injection molding compound show the joining strength as a function of the process parameters (© Fraunhofer ICT)

the component distortion. In order to ensure dimensional stability, the preforms are symmetrically over molded. In addition, concepts for the local fixation of the inserts within the mold have been integrated, and the precise positioning during mold filling has been adjusted in advance using simulative methods.

The prerequisite for an appropriate and integral joint in the hybridization of composite laminates by injection molding is a sufficient joining temperature that is above the melting or glass transition temperature. This temperature is achieved in the selected process through the heat input of the injected melt (approx. 380 °C), although the inserts are below the glass transition temperature. Using integrated mold sensor systems to measure the real welding temperatures, and specifically developed testing methods [5], it was shown that this condition is primarily achieved through the correct mold temperature, and not by pre-heating the inserts [4]. **Figure 5** shows the results of a statistical model for the peeling of a hybrid composite consisting of carbon-fiber-reinforced PEI composite laminate and glass-fiber-reinforced PEI injection molding compound. The preheating temperature of the composite laminate, the mold temperature and the injection speed were varied. It is clearly visible that the mold temperature has the greatest influence on the final joint strength, and that the highest bond strengths are achieved at high mold temperatures. This is because the temperature of the thin composite laminate insert quickly adjusts to the temperature of the mold once they come into contact. The preheating of the composite laminate substrate does not improve the bond strength. Changes to the surface of the semi-finished product during melting can even lead to a slightly lower joining strength.

Conclusion

The newly developed modular component, combined with the large-scale processing approach, could enable the economically feasible use of thermoplastic hybrid structures in future aviation applications. This would enable further weight reduction, while at the same time ensuring reaction-free processing and recyclable components. The design of the reinforcing panel was based on requirements for a potential application in the cargo compartment of airplanes. Fraunhofer ICT and Laser Zentrum Hannover contributed the relevant production technology and know-how concerning the processing of high-temperature thermoplastics which was essential to the successful implementation of the project. ■

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Video Proof

The modular reinforcement structure was displayed at the trade fair "Fakuma 2017". In a video interview for Kunststoffe.TV, the author of this paper Tobias Joppich, who works at Fraunhofer ICT, explains the advantages of the examined materials, structures and manufacturing processes (in German language). Watch the video here:
- www.kunststoffe.de/4569268

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References & Digital Version

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