New Technology for Lightweight Construction with Sandwich Structures

Developed for Series Production

Sandwich composites with continuous fiber-reinforced plastic face sheets offer optimum lightweight performance and associated material efficiency in the implementation of large-area structural components. The TS molding technology is based on a novel thermoforming process and was specifically developed for the fully automated production of continuous fiber-reinforced sandwich components with thermoplastic matrix in large series.

Sandwich structures are used for wind turbine rotor blades and other applications. © Pixabay

Sandwich structures made of highly rigid and strong face sheets and a lightweight core exhibit very high weight-specific bending and buckling stiffness. They are therefore mainly used for large-area lightweight structures which are prone to buckling, such as wind turbine rotor blades, boat hulls, truck trailers, aircraft wings, flaps and fuselages [1, 2].

The lightweight effect of sandwich structures is based on the principle of Steiner [3], according to which the area moment of inertia increases with the square of the distance between the two face sheets. The core essentially takes over the task of the spacer and is firmly connected to the two face sheets. The mechanical behavior of the structures is described by sandwich theory [1, 2]. For structures subjected mainly to bending loads, the sandwich design can demonstrate a weight saving potential of up to 70 % compared to monolithic structures.

For large-area structures in the above-mentioned applications with rather small quantities, sandwich constructions based on thermoset fiber-reinforced composites in the outer layers and corresponding foam or honeycomb cores have been used predominantly up to now. Due to the partly manual processing sub-steps and chemical curing reactions, the cycle time is often in the range of several hours.

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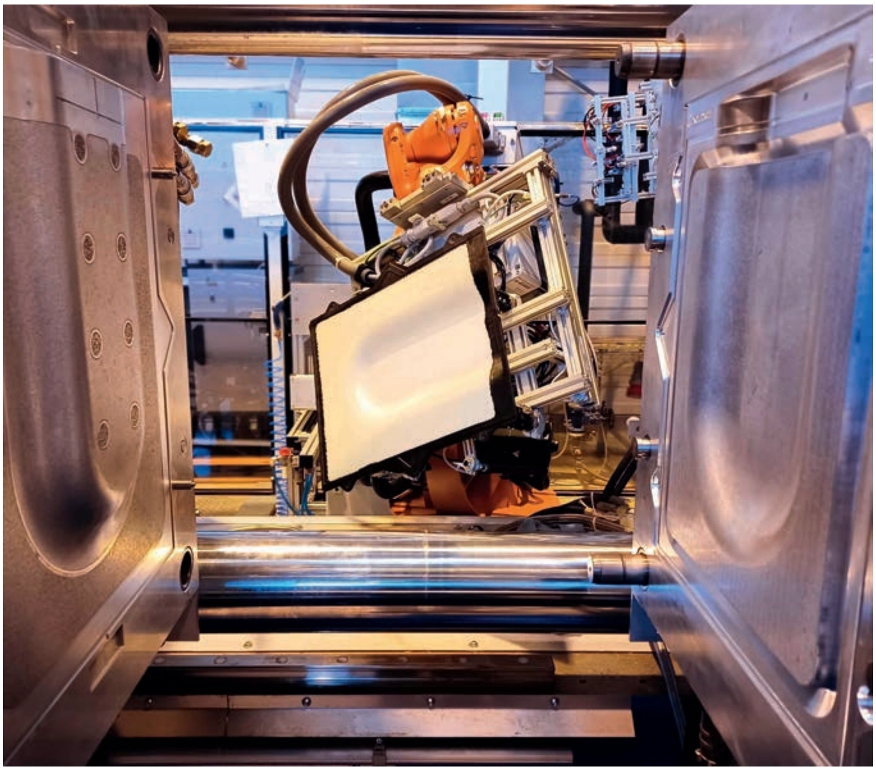

Fig. 1. Process engineering implementation of thermoplastic sandwich molding. © Fraunhofer IMWS

Lightweight Structures in Large-Scale Production

In order to make the enormous lightweight construction potential and the associated material and resource efficiency of fiber-reinforced composite sandwich construction usable also for components produced in large quantities, the use of thermoplastic fiber-reinforced composites and core materials for the realization of corresponding sandwich components has been researched for several years [4-6]. Various process routes for the production of molded sandwich components can be considered, which differ in the sequence of steps, molding and consolidation of the composite (bonding of core material and face sheets).

With the thermoplastic sandwich molding technology (TS molding), a process was developed at the Fraunhofer Institute for Microstructure of Materials and Systems IMWS, which enables the processing of pre-consolidated, thermoplastic sandwich semi-finished products. In this process, the shaping step takes place by thermoforming in a closed mold, which also enables additional functionalization by injection molding [7].

Thermoplastic sandwich semi-finished products consisting of a thermoplastic foam or honeycomb core and face sheets of fiber-reinforced thermoplastics, for example in the form of fabric-reinforced organosheets or laminates of UD tape single layers.

Transfer to Industrial Practice

In the research work of the Fraunhofer IMWS, the thermoplastic honeycomb core sandwich of ThermHex Waben GmbH was investigated. The honeycomb core made of polypropylene (PP) is produced in a continuous process and consolidated with glass fiber-reinforced (GF) face sheets to a flat sandwich semi-finished product. For the development of the TS molding technology, an injection molding machine equipped with IR oven and hot handling system (type: KM 200, manufacturer: Krauss Maffei) at the Fraunhofer Pilot Plant Center for Polymer Synthesis and Processing PAZ was used.

The implementation of appropriate mold and processing technology on a pilot scale enables the efficient transfer of research results into industrial practice. Based on preliminary investigations of the thermoforming behavior of thermoplastic honeycomb core »

Info

Text

Dr.-Ing. Ralf Schlimper has been working as a group leader at the Fraunhofer Institute for Microstructure of Materials and Systems IMWS in Halle (Saale), Germany, in the field of fiber composite structures since 2015; ralf.schlimper@imws.fraunhofer.de

Dr.-Ing. Matthias Zscheyge has been working as a group leader at the Fraunhofer Institute for Microstructure of Materials and Systems IMWS in Halle (Saale) and at the Pilot Plant Center PAZ in Schkopau, Germany, in the field of thermoplastic lightweight construction technologies since 2015.

Dr.-Ing. Thomas Glässer has been working as a research associate at the Fraunhofer Institute for Microstructure of Materials and Systems IMWS in Halle (Saale) and at the Pilot Plant Center PAZ in Schkopau in the field of thermoplastic lightweight construction technologies since 2015.

Prof. Dr.-Ing. Maik Feldmann has been Head of the Polymer Applications division at the Fraunhofer Institute for Microstructure of Materials and Systems IMWS in Halle (Saale) and Head of the Polymer Processing division at the Pilot Plant Center PAZ in Schkopau since 2022.

Company Profile

The **Fraunhofer Pilot Plant Center for Polymer Synthesis and Processing PAZ** is a joint initiative of the Fraunhofer Institutes for Applied Polymer Research IAP in Potsdam-Golm and for Microstructure of Materials and Systems IMWS in Halle (Saale), located at Value Park in Schkopau in the Central German chemical triangle.
www.polymer-pilotanlagen.de

Save the Date

The application of TS molding technology for automotive components is currently being investigated in ongoing R&D projects. The first results are to be presented at the Composite Sandwich Conference, which is scheduled for April 24 and 25, 2024, and will be organized by the Fraunhofer IMWS, among others.
www.faserverbund-sandwich.de

References

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sandwich semifinished products, a plant and mold concept was developed and implemented (**Fig. 1**).

The process (**Fig. 2**) includes the following steps:

1 Heating of the sandwich semi-finished product in an IR radiation furnace,
2 transfer to the temperature controlled forming tool,
3 thermoforming of the heated sandwich semi-finished product,
4 functionalization via injection molding and
5 removal of the ready-to-use component.

Based on tests with a sandwich semi-finished product with a total height of 10 mm, a PP honeycomb core and cross-ply laminate face sheets made of thermoplastic UD tape GF/PP individual layers, a cycle time of approx. 1 min. could be demonstrated. For this purpose, a sandwich component demonstrator with dimensions of 300 x 355 mm^2 was 3D thermoformed and additionally functionalized at the edge by means of injection molding (**Fig. 3**). In addition to forming a 3D contour, the thermoforming process step enables core melting and pressing of a circumferential edge with corresponding transition geometries, so that the sandwich component ultimately has a closed edge.

In the same mold, further functionalizations can then be realized in the area of the closed edge. The component demonstrator shows the possibility of an injection-molded, circumferential edge with locally inserted metallic thread inserts as potential fastening points.

Collapse at too High Temperatures

The greatest challenge in the development of the thermoforming process for thermoplastic honeycomb sandwich structures was the targeted setting of the temperature condition of the sandwich semi-finished product required for forming. On the one hand, the sandwich must be heated in such a way that 3D forming is made possible by shear deformation and single-layer sliding in the face sheet layers. On the other hand, the honeycomb core is in danger of collapsing if the temperature is too high.

To support process development, extensive process simulation models were developed which can describe both the temperature-dependent 3D deformation and the core melting and functionalization for the sandwich composite in the interaction of its various individual components (face sheets, core, interface layer, injection molding compound) (**Fig. 4**). Finally, systematic process studies enabled the targeted heating and stabilization of the sandwich in the mold to be developed into a robust process that can be implemented on common injection molding machines with appropriate IR heating technology and hot handling system. This makes the process comparable to the processing and overmolding of organosheets. However, instead of organosheet, a thermoplastic sandwich semi-finished product (organosandwich) is used, which enables a further significant increase in efficiency in terms of component weight and material usage.

Prediction of the Structural Behavior

During thermoforming of the heated sandwich semi-finished product, the face sheets slide on the honeycomb core. Due to the low elongation capacity of the continuously fiber-reinforced face sheets, material from the peripheral areas of the component must be subsequently drawn in order to achieve mod-

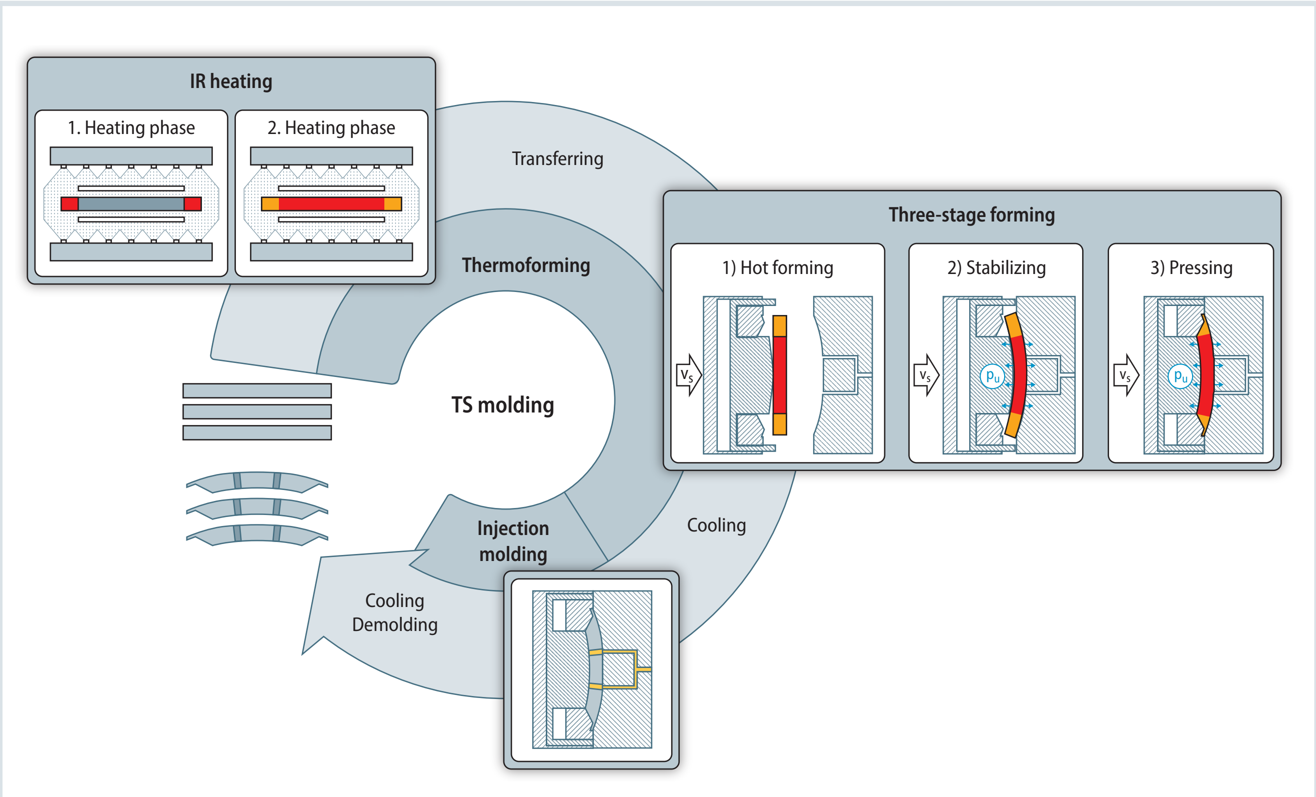

Fig. 2. Process diagram thermoplastic sandwich molding. Source: Fraunhofer IMWS; graphic: © Hanser

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Fig. 3. Component demonstrators : 3D molded sandwich structure with injection-molded component edge, sawed component (top) and variation of the face sheet material (black components).
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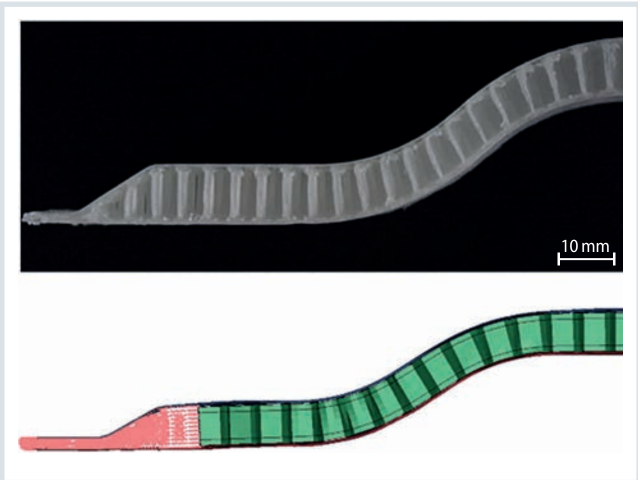

Fig. 4. Section through the 3D molded sandwich structure with honeycomb core (top); process simulation model of the sandwich structure (bottom).
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erate forming degrees. The honeycomb core remains almost completely intact during this process (**Fig. 4**): The cell walls of the honeycomb structure are also perpendicular to the face sheets in the formed areas of the sandwich, thus keeping them at a constant distance.

According to the sandwich theory, external bending loads are mainly carried by the face sheets. These are subjected to compressive and tensile normal stresses. The honeycomb core is mainly loaded in shear and transmits compressive loads in the thickness direction of the sandwich. The bending deformation of a loaded sandwich component is thus determined both by the stiffness of the face sheets and their distance from each other and by the shear stiffness of the core.

The behavior of honeycomb core sandwich structures was therefore characterized in corresponding flexural tests. It is shown that a PP honeycomb core sandwich with a core height of 6 mm and a GF/PP face layer with a thickness of 0.5 mm has the same flexural stiffness as a monolithic GF/PP laminate with a thickness of 4.5 mm. However, the sandwich structure weighs only slightly more than a quarter of the monolithic laminate. This means that the weight saving potential for the specific static bending load case is more than 70 %.

For real components, of course, further and typically combined load cases have to be considered. Even then, significant weight savings can still be demonstrated with sandwich structures. For the design of structures, numerical methods such as finite element analysis are used in addition to analytical design rules. In combination with adapted material models for the fiber-reinforced face sheets and the honeycomb core, they allow accurate prediction of the structural behavior of 3D-formed sandwich components.

Conclusion & Outlook

TS molding technology enables large-scale production of weight-optimized lightweight structures. With thermoforming and injection molding functionalization, the principle of sandwich construction can be efficiently transferred to 3D-molded lightweight components. In this way, weight savings in the double-digit percentage range can be achieved.

In numerous applications in the field of mobility as well as mechanical and plant engineering, significant contributions can thus be made to increasing resource efficiency and reducing material consumption. In current research projects, Fraunhofer IMWS is investigating the transfer of the developed technologies to concrete components in the area of vehicle interiors as well as structural vehicle applications. ■

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