High Surface Quality, Half the Compression Force

Variothermal LFT Compression Molding for Improved Process and Component Characteristics

In the processing of long fiber-reinforced thermoplastic (LFT) components, the properties are significantly influenced by the mold temperature. Through variothermal process control, the optical and mechanical properties of LFT components are improved and the required compression force for component production is decreased. As a result, the investment in compression technology can be reduced.

The saving of energy and raw materials in the manufacturing and use of products is a key topic in the industry. At the same time, the performance of components has to be maintained or even increased. A major driver is the automotive industry, in which innovative lightweight construction concepts are particularly important. Weight advantages can be achieved with fiber-reinforced plastics (FRP), which are used more frequently in body panels, structural components in the chassis, and in safety-relevant interior components, such as seat structures. Cost advantages over traditional construction materials have to be proved to enable their widespread use.

An established and widespread manufacturing procedure for the economical production of lightweight components for large-scale production is the compression molding of long fiber-reinforced thermoplastics (LFT) [1]. Compression molding is particularly suited for the production of large and complex components, such as the instrument panel support (IPS), technical front-ends and underbody structures [1–3]. The LFT compounds are usually pre-impregnated glass mat-reinforced thermoplastics (GMT) or LFT/direct LFT compounds produced by extrusion. During the compression molding, the LFT compound is placed into a compression mold, pressed and cooled under high pressure [4]. A disadvantage, however, is that the components cannot be used in visual applications due to their inferior surface quality. Furthermore, the fiber weight content is limited by the flowability of the material. These component and process properties can be attributed to the low mold temperature during compression molding. The low mold temperature leads to a significant increase in material viscosity and the required compression force. Therefore, a cost-intensive compression technology is often used with compression forces of up to 50,000 kN. For thin-walled components, freezing effects and fiber imprints occur on the component's surface, which means that these components are not suitable for visual applications. Due to the necessary fluidity of the LFT compound in the mold, the fiber content and fiber length and thus the mechanical properties of the component are limited. As shown by the Institute of Plastics Processing (IKV) in Industry and the Skilled Crafts at RWTH Aachen University, a significant advantage in terms of component properties and process efficiency can be achieved by optimizing the temperature control of the compression mold. A comparison with the conventional compression molding is shown in **Figure 1**. Before inserting the molded compound, the mold temperature is increased and then lowered again after complete filling of the mold. »

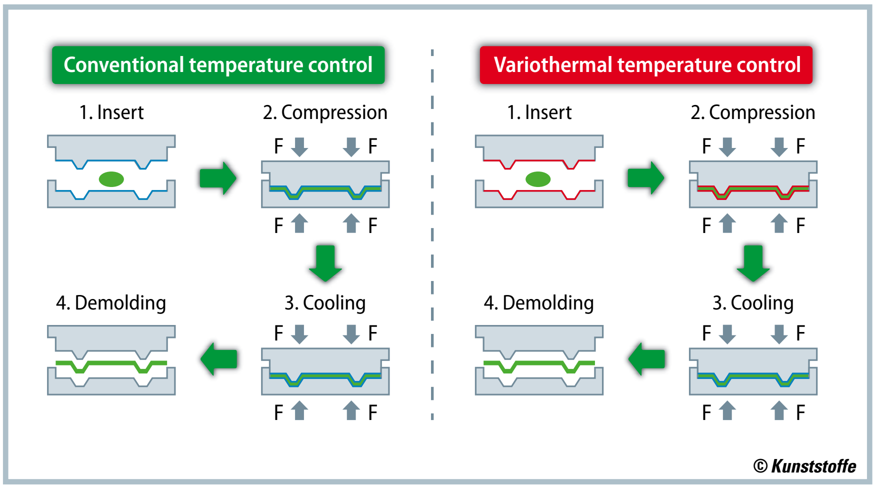

Fig. 1. Process sequence of LFT compression molding: conventional and variothermal (source: IKV)

Dynamic Temperature Changes for Near-Surface Temperature Control

A compression mold with a dynamic temperature control was developed by Werkzeugbau Siegfried Hofmann GmbH, Lichtenfels, Germany. This prototype compression mold (400 x 200 mm²) has five changeable cavity inserts, which can be used to produce flat and ribbed components. The cavity inserts are manufactured in a generative LaserCusing process, whereby a three-dimensional network of heating and cooling channels can be arranged directly under the cavity surface. It furthermore reduces the mass of cavity inserts, which need to be temperature-controlled. Depending on the inlet temperature of the used thermal oil, heating and cooling rates of up to 10 K/s can be achieved by this temperature control.

Figure 2 shows the design of the variothermal experimental mold as well as the profile of the mold surface temperature, measured at the opened mold.

The comparison of measurement points 1 and 2 shows examples of the surface temperature at the fastest point in the region of the inlet (1) and at the slowest point in the region of the outlet (2) of the thermal oil. The temperature profiles are characterized by a rapid increase in temperature at the beginning. The recrystallization temperature of the later processed molding compound is exceeded after 13 to 22 s. These times can be shortened by choosing a higher heating temperature (here, for example T = 190 °C). Upon cooling, the temperature drops below the recrystallization temperature after 3–7 s at a cooling-circuit temperature of T = 30 °C. The minimal cycle times for economical component manufacturing are analyzed during the subsequent course of the project.

Considering the flow behavior as a function of the mold temperature, a constant temperature of the mold surface is ensured during filling of the cavity by a long heating time of 8 min. The constant mold temperatures, depending on the chosen heating circuit temperature, are shown below in **Table 1**.

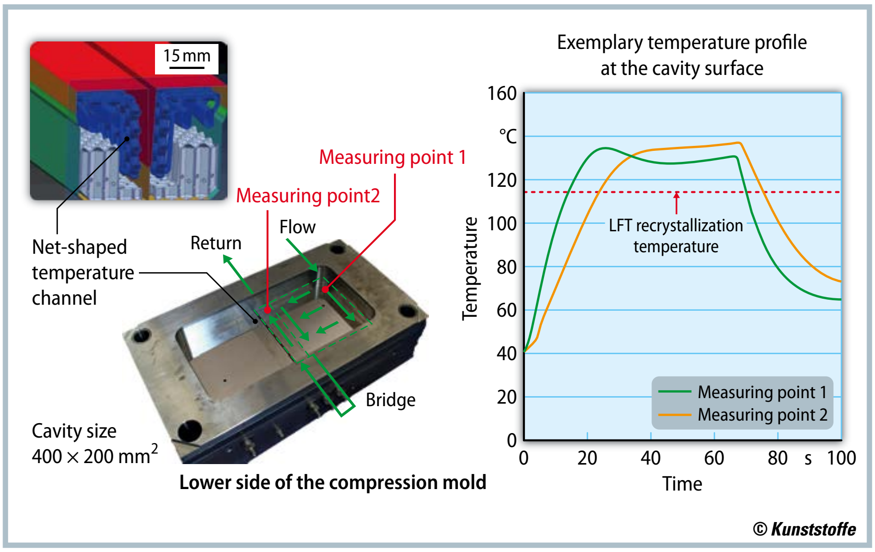

Fig. 2. Design of variothermal compression mold and exemplary temperature profile at mold surface (source: Hofmann tool manufacturing, IKV)

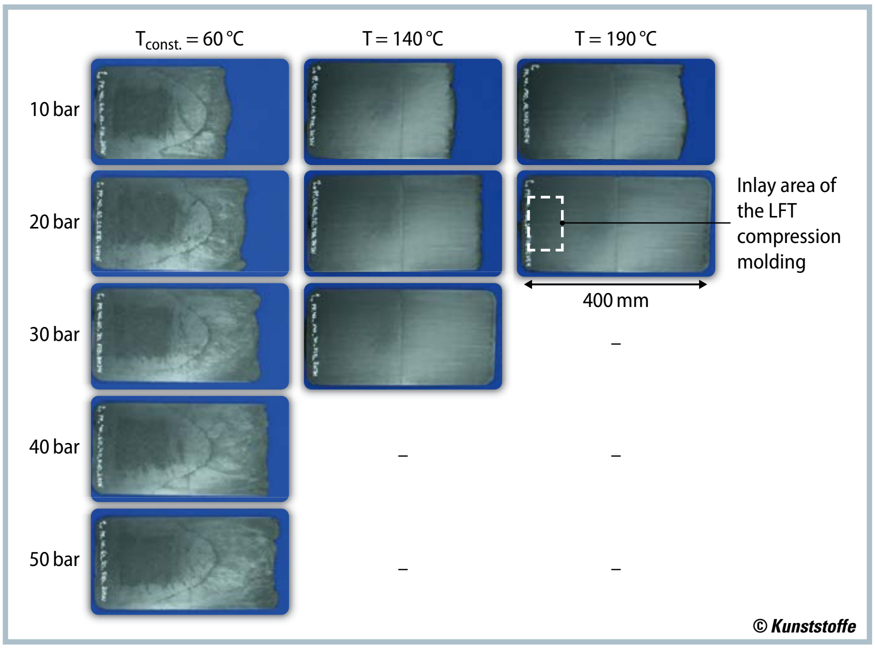

Fig. 3. Compression force depending on the heating circuit temperature (source: IKV)

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Acknowledgment

The research project (18078 N) of the Forschungsvereinigung Kunststoffverarbeitung has been sponsored as a part of the "Industrielle Gemeinschaftsforschung und -entwicklung (IGF)" by the German Bundesministerium für Wirtschaft und Energie (BMWi) due to an enactment of the German Bundestag through the AiF. We would like to extend our thanks to all organizations mentioned.

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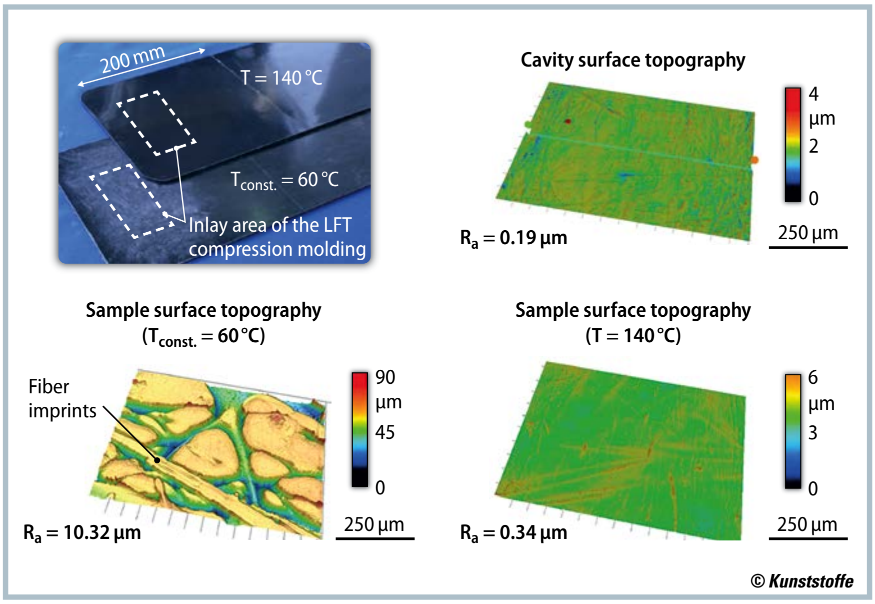

Fig. 4. Comparison of surface qualities of variothermal and conventional LFT compression mold components (source: IKV)

Halving the Compression Force

To determine the required compression force for the complete filling of the cavity, molding compounds at a temperature of 220 °C are inserted into the temperature-controlled mold. The experimental material is a long-fiber granulate (LFG) – Celstran PP-GF40 from Ticona GmbH, Sulzbach, Germany – with a fiber weight content of 40 wt. % and an initial fiber length of 10 mm. In the experiment, the melt for a flat component with a height of 3 mm and an area of 400 x 200 mm^2 is inserted into the mold. The closing of the mold and the flow of the molding compound is carried out until a defined compression force is reached. Maintaining the compression force to the solidification of the molding compound, the mold is then cooled with a cooling circuit temperature of T = 30 °C. **Figure 3** shows the filling behavior in the cavity as a function of the compression pressure, relative to the cavity surface, at various heating circuit temperatures as well as a conventional isothermal mold temperature of $T_{const.}$ = 60 °C.

The investigations show that the cavity is not filled completely during compression molding with a conventional mold temperature and a compression pressure of 50 bar. However, at a heating circuit temperature of T = 140 °C and compression pressure of only 30 bar, the cavity is filled completely. On increasing the temperature to T = 190 °C, the compression pressure required to fill the cavity is reduced to 20 bar. The results show that, with a heating circuit of T = 140 °C, the required compression pressure can almost be halved. By further increasing the heating circuit temperature to T = 190 °C, the required compression force can be reduced by another third. The compression force can be reduced to about 50 %, allowing the use of presses with significantly lower compression forces and saving investment costs.

Improving Surface Quality

In conventional LFT component production with low mold temperatures, the surface quality is reduced significantly by freezing effects and fiber imprints on the component surface. **Figure 4, top left,** shows a direct comparison between components produced with a mold with variothermal temperature control and components produced with conventional isothermal mold temperature. The differences in surface quality are obvious, particularly in the insertion area. Surface topographies of the cavity and the test specimens, recorded by a confocal laser scanning microscope, demonstrate the better surface properties as well. The images show the fiber imprints on the sample's surface for a constant mold temperature of $T_{const.}$ = 60 °C. The exemplified mean roughness of the cavity surface of R_a = 0.19 µm cannot be achieved by the test specimens produced at a heating circuit temperature of T = 140 °C (R_a = 0.34 µm). The mean roughness of test specimens produced at $T_{const.}$ = 60 °C is R_a = 10.32 µm. This shows that, by the use of a variothermal temperature control (here T = 140 °C), the characteristic freezing effects on the surface can be prevented and significantly improved surface qualities achieved.

Conclusion

By developing and examining compression molding by means of variothermal mold technology for the production of high-quality LFT components, it has been possible to avoid or limit the restrictive effects of conventional compression molding on the component properties (poor surface properties, high compression force). The investigations at the Institute of Plastics Processing (IKV) showed that components with constant high surface quality can be produced by using variothermal temperature control for LFT compression molding. By increasing the mold temperature, the compression force required for the production of 3 mm thick components can be halved. The reduction of the compression force allows the reduction of investment costs for the press technology. The downside is the slightly longer cycle time. Cycle times below one minute can be predicted on the basis of previous investigations. A further reduction of the cycle time is the subject of current investigations and the basis for the consideration of the economic efficiency of compression molding of LFT by variothermal mold technology. ■

Temperature of the thermal oil for the heating circuit	Constant mold temperature after 8 min heating time
140 °C	126 °C
190 °C	169 °C

Table 1. Mold surface temperature after 8 min heating time depending on the heating circuit temperature