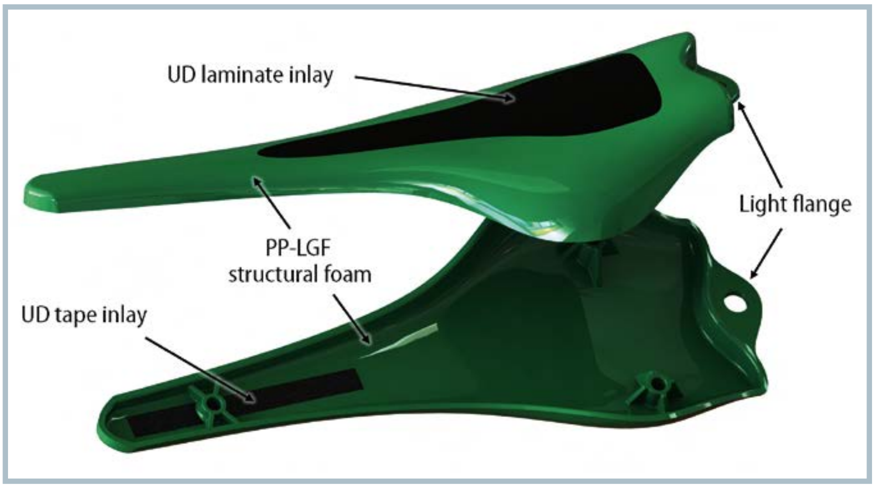
Industry 4.0 Saddles Up

Individualized Large-Scale Production of Thermoplastic Lightweight Components

Foamed injection molded parts with continuous fiber reinforcement satisfy high demands. The project of an industry consortium, led by IKV, shows how these parts are individually customized and produced using a fully automated manufacturing cell. The implementation of an Industry 4.0 cyber physical production system (CPPS) is a key technology to produce multi-variant products.



Foamed lightweight saddle with fiber reinforcement and functional elements (© IKV)

The combination of thermoplastic foaming injection molding and continuous fiber reinforcement offers high potential for cost-effective large-scale production without mechanically weakening the lightweight components. This combination can be used in every industrial sector. One example is the automotive industry. Here, the lightweight design enables cost-saving production as well as lower operating costs for the cars. The sports goods industry, too, focuses on lightweight concepts, with special equipment and clothing to enable humans to achieve maximum performance.

Manufacturers and suppliers have to take the individual customers' wishes into account and need to reduce the production and development costs by using platform strategies. Both the resulting variant diversity and the required lightweight design are encouraging the development of integrative production concepts. The integration of continuous fiber-reinforced thermoplastics into an automated and reproducible injection molding process allows the production of parts with high weight-specific mechanical properties. In accordance with the Industry 4.0 aspect, it is also possible to adapt the continuous fiber reinforcement to the individual customer demands.

Multi-Variant Combination of Foam Injection Molding and Continuous Fiber Reinforcement

At the K2016 fair, the Institute of Plastics Processing (IKV) in Aachen, Germany, will demonstrate this technology synthesis using the example of a bicycle saddle. This new approach from IKV is supported by an industry consortium (**Table 1**) and combines two process elements:

- The physical foam injection molding of long-glass fiber-reinforced thermoplastics (LGF), and
- the insertion of local continuous fiber reinforcements by using unidirectional (UD) laminates and UD tapes with a thermoplastic matrix.

The thermoplastic-based integration into a back-foaming process leads to a direct joining of the reinforcement in the direction of the load path and the foamed structure. This enables a specific reinforcement and the lightweight construction potential is used optimally.

The bicycle saddle is built of several components (**Title figure**): There is the polypropylene foam with long-glass fiber reinforcement (PP-LGF) and there is a 1 mm thick UD laminate on the top and a 0.5 mm thick UD tape on the bottom to improve the bending properties of the part. The local use of continuous fiber-reinforced high-performance materials (laminate and tape) reduces the material costs as a result of lower material consumption. Additional screw domes are an example to demonstrate the potential integration of functional elements via injection molding.

The integration of the laminates and tapes, which are adapted individually, improves the economic and technical aspects of the production processes. By using Industry 4.0 molds, it is possible to connect various machines to one production unit. The connection enables the control of every machine to produce individual single parts as a large-scale production depending on the incoming orders. The manufacturer is able to document the production process for every

Company	Project participation	Internet address
Arburg GmbH + Co KG, Lossburg, Germany	Injection molding machine and linear handling	www.arburg.com
ASS Maschinenbau GmbH, Overath, Germany	Manipulator system and linear handling	www.ass-automation.com
Georg Kaufmann Formenbau AG, Busslingen, Switzerland	Injection mold	www.gktool.ch
gwk Gesellschaft Wärme Kältetechnik mbH, Meinerzhagen, Germany	Temperature control	www.gwk.com
Hasco Hasenclever GmbH + Co KG, Lüdenscheid, Germany	Standard components	www.hasco.com
HRSflow/INglass S.p.A., San Polo di Piave, Italy	Hot runner system	www.hrsflow.com
IKV, Institute of Plastics Processing, Aachen, Germany	Process technology and project managment	www.ikv-aachen.de
IOS Gesellschaft für innovative Optimiersoftware mbH, Würselen, Germany	Data mangement and manufacturing control	www.ios-ibos.de
Kistler Instrumente AG, Winterthur, Switzerland	Data mangement and quality control	www.kistler.com
Krelus AG, Oberentfelden, Switzerland	Infrared heating oven	www.krelus.ch
Motan-Colortronic GmbH, Isny, Germany	Conveying and drying technology	www.motan-colortronic.com
Sabic AG, Riyadh, Saudi Arabia	Materials	www.sabic.com
SensoPart Industriesensorik GmbH, Wieden, Germany	Data mangement and quality control	www.sensopart.com
Stäubli Tec-Systems GmbH, Bayreuth, Germany	Coupling technology	www.staeubli.de

Table 1. A strong industry consortium of the IKV network enables the realization of an innovative production unit (source: IKV)

single part. This is also helpful for analysis purposes.

Laminates and Tapes for Thermoplastic Fiber Reinforcement

The laminates and tapes are added to the production unit as fiber-matrix semi-finished products (manufacturer: Sabic). They consist of a PP matrix with a unidirectional continuous glass fiber reinforcement. The planar layer structure is cut into shape. The tapes and laminates are positioned in the mold using a specialized gripper (manufacturer: ASS Maschinenbau) in combination with a linear handling system (manufacturer: Arburg). The tapes and laminates are formed inside the mold during the process.

Before the laminate is positioned in the mold, it is heated to 200 °C using an infrared oven (manufacturer: Krelus) to improve the bond between the foamed structure and the fiber layup. The heating process also simplifies the forming process in the mold. The thinner tape is positioned in the mold at ambient temperature. The laminate and tape are back-foamed by the ProFoam-technology.

ProFoam Technology Ensures Gentle Processing of the Fibers

This foaming injection molding process was invented by IKV and Arburg. It was further developed for LFT materials in co-operation with Sabic and turned out to be especially suitable for processing of long-glass fiber-reinforced thermoplastics. The blowing agent is added to the process through an airlock system at the inlet of the plasticizing unit (**Fig. 1**). The blowing agent dissolves in the ther- »

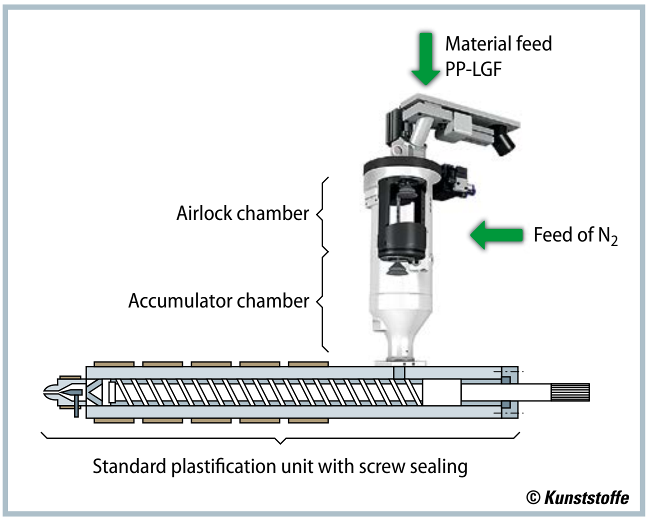


Fig. 1. ProFoam lock for physical foam injection molding. Because there is no need for shear and mixing elements, fiber damage is reduced (source: IKV)

Individual Bicycle Saddle

IKV will demonstrate this innovative technology consisting of foam injection molding and the use of continuous-fiber reinforcements at K:
→ **Hall 14, booth C16**

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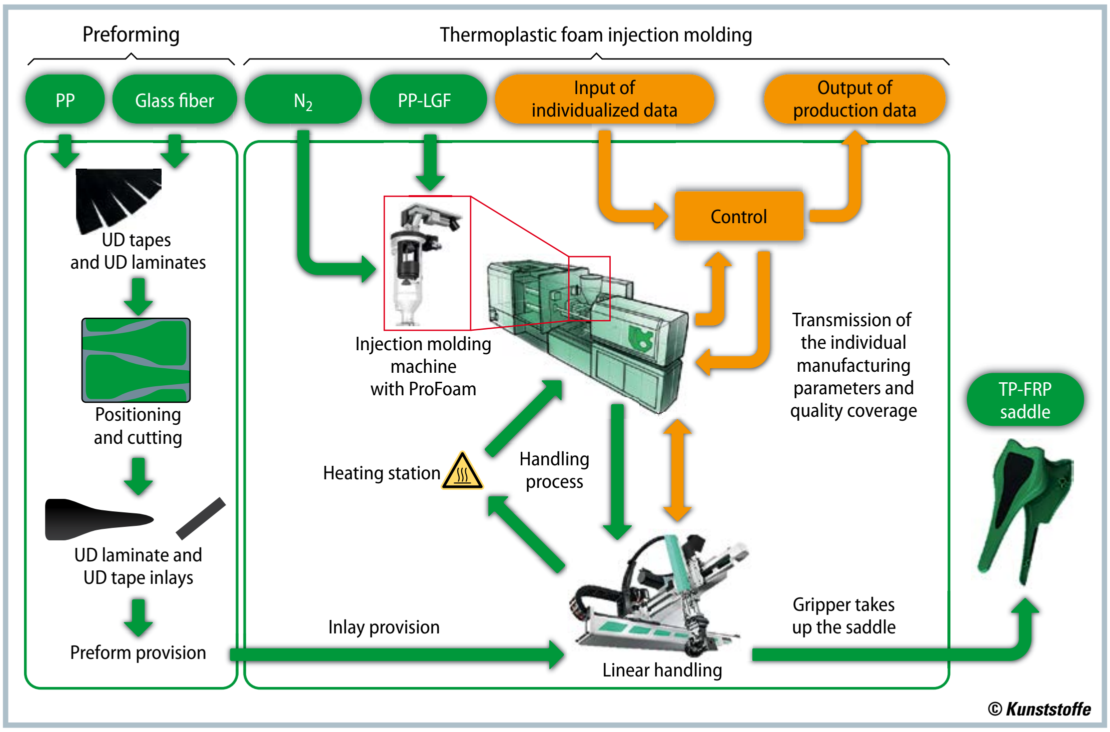

Fig. 2. Fully automated flow of substances and data: The injection molding machine interacts with different up- and downstream production stages (source: Arburg, IKV)

moplastic material under a pressure of 50 bar due to a large material surface inside the plasticizing unit. The dissolved blowing agent reduces also the viscosity and causes the melting to occur at an earlier stage. Due to this aspect there is no need for shear and mixing elements. Additionally, a flat pressure profile from the hopper to the nozzle leads to reduced shear values over the screw length.

The absence of shear and mixing elements as well as the flat pressure profile from the hopper to the nozzle reduce the resulting fiber damage. The fiber length in the final part increases by approximately 25 %, which leads to better mechanical properties. Due to the lower viscosity, the injection pressures and clamping forces can be reduced. The foam injection moulding process enables also a low shrinkage and warpage of the part.

Individualized Production with Large-Scale Production Costs

The K show exhibit illustrates not only the innovative combination of thermoplastic foam injection molding and fiber structures, but also the interaction of injection molding and different up- and downstream production stages (**Fig. 2**). Visitors to the fair can compile their individual saddles, which are added to the production plan. The focus is not on one-off manufacture ("batch size one") but on the economical, order-orientated production of different component variants. The mechanical and constructional component requirements are adapted to the customer needs.

The foamed component thickness and the continuous fiber reinforcement are adjusted to produce the adapted components. The application thus uses only the component flexibility; there is no need to adapt the manufacturing cell (**Fig. 3**). The flexible alignment of movable mold elements enables the production of different component geometries in successive cycles.

The interaction between heterogeneous and self-sufficient subsystems and the customer interface (manufacturer: IOS) results in an intelligent overall system. The relevant process parameters of every production cycle are measured. The quality characteristics are tested optically with a camera system (manufacturer: SensoPart). The process parameters and the quality characteristics of the produced part are available on a website. The website enables a continuous documentation and traceability from the order to the component output.

To monitor the molding process, two temperature-pressure sensors (manufacturer: Kistler) are combined with the con-

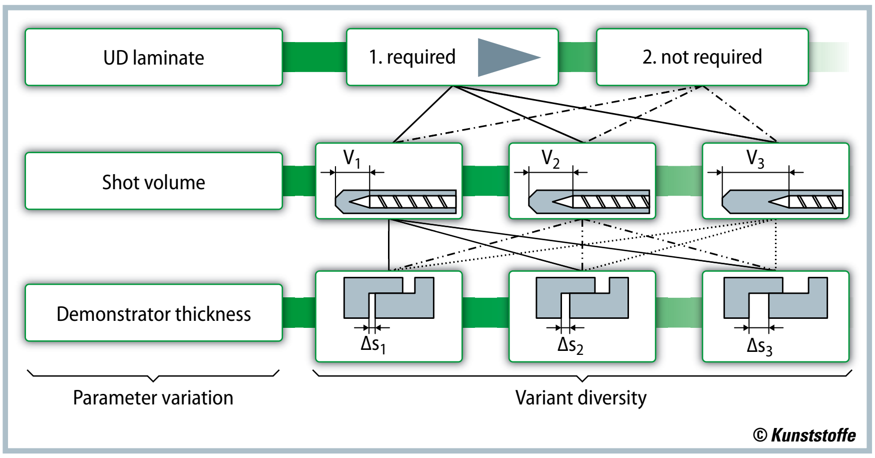

Fig. 3. Online variation of the process enables large variant diversity: The flexible alignment of mold elements allows the production of different component designs (source: IKV)

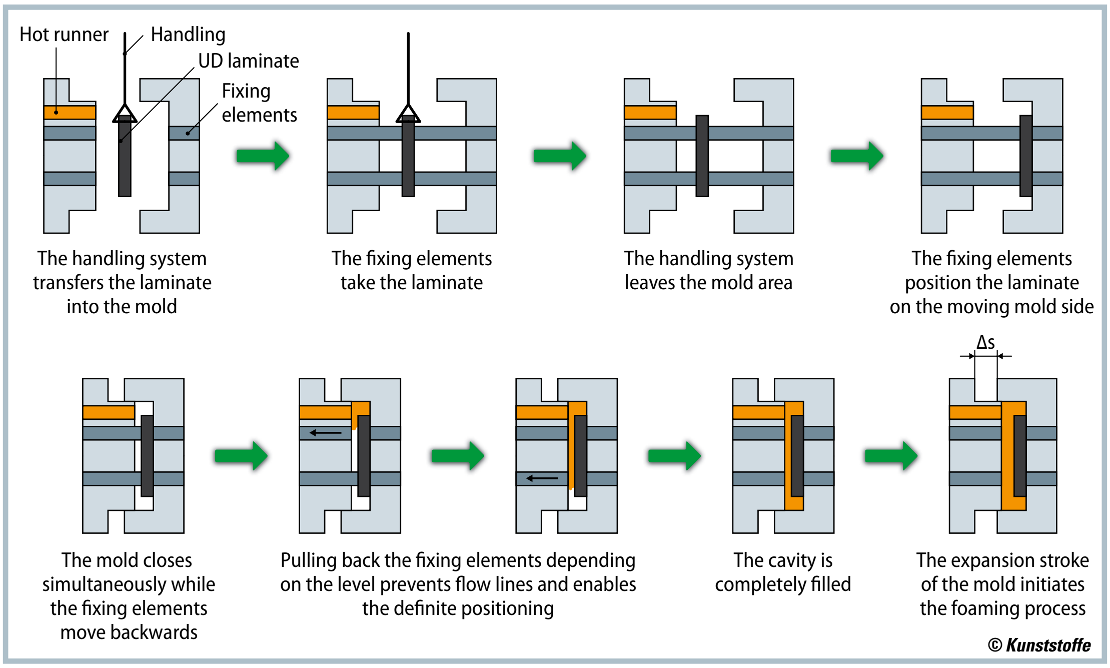

Fig. 4. Kinematic fixing elements inside the mold with dipping edges hold the laminates and tapes in position during the back molding process. Flow lines can be prevented (source: IKV)

trol system. The K exhibit demonstrates different Industry 4.0 aspects which are groundbreaking for many industries when individualization and traceability are required.

Dipping Edge Tool and Kinematic Fixing Elements

A dipping edge tool (manufacturer: Georg Kaufmann Formenbau) is used to flexibly vary the component thickness. During the injection phase, the laminate and tape are held in position by several kinematic fixing elements. The fixing elements can be controlled segmentally depending on the flow path (**Fig. 4**). Due to this fact, the cavity is filled homogeneously without weld lines. The fixing elements fulfil an essential task especially with unidirectional components. Only through solid fixing is it possible to achieve defined mechanical part properties with a homogenous laminate on the visible area of the part.

With the help of the dipping edge, the component thickness can be adjusted freely. To attain a high surface finish, the cavity is filled completely under holding pressure. After a short time delay the mold stroke causes an increase in the cavity volume. Due to the foaming pressure of the thermoplastic material, the cavity is filled up directly.

The mold (**Fig. 5**) has a valve gate system, with which the speed of the needle stroke and the position of the needle can be controlled precisely with a servo-driven electric needle valve hot runner system (manufacturer: HRSflow). The injection speed and pressure can be controlled without influencing the system dynamics. The melt can flow directly around the laminate and tape, and the positioning accuracy increases. The partial pressure of the polymer melt can be controlled and the melt front velocity can be held constant. Both factors play a role in the good surface finish of the foaming injection molding process.

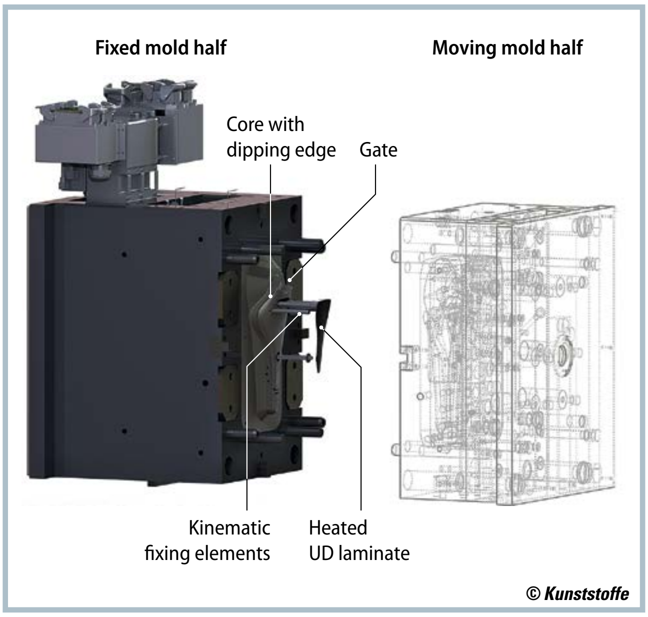

Fig. 5. The injection mold with dipping edges and kinematic fixing elements includes a servo-electrical needle valve hot runner system (source: IKV)

Conclusion

The combination of optimized foam injection molding cycle, continuous fiber reinforcement and the use of Industry 4.0 strategies enables the automated production of individualized component variants. To attain the flexibility of the manufacturing cell and prevent changeover times, there must be optimum interaction between polymer-based and informational processes. Only in this way can malfunctions be prevented and the economic advantage of a fully automated production unit be fully exploited. ■