

# Continuous-Fiber-Reinforced Parts Safely in Sight

## *Integrated Production Monitoring Boosts the Reliability of KraussMaffei's FiberForm Process*

Lightweight parts with integrated functions can be produced efficiently by combining injection molding with the thermoforming of continuous-fiber-reinforced thermoplastic inserts. KraussMaffei has taken the production cell and adapted its layout with a view to achieving precision positioning of the organic sheet and the shortest-possible transfer time to the mold. Software integrated into the machine control system supplies all the quality-related process data necessary for seamless monitoring and evaluation.

To ensure that parts made by a combination of injection molding and thermoforming are of reproducible quality, the organic sheet must be heated evenly and gently. The process data of the heating stage have to be documented and monitored for the purposes of quality assurance. KraussMaffei Technologies GmbH, Munich, Germany, therefore set about developing its own control system for its infrared heating station and fully integrating it into the standard machine control system. As a result, the entire manufacturing process can be monitored inline. This enables the machine manufacturer to offer a manufacturing cell capable of mass-producing lightweight continuous-fiber-reinforced parts and featuring an integrated quality-monitoring system.

Successful mass-production of lightweight parts is contingent not only on an intelligent combination of design and computer simulation for achieving maximum weight reduction of parts, but also on extensive experience of the production and process technology used for producing large quantities reproducibly and reliably – especially since lightweight construction projects are often only implemented if weight reductions are accompanied by slashing manufacturing costs, which is generally achieved by integrating functions.

Injection molding is the preferred process for manufacturing thermoplas-



FiberForm process combined with multi-component technology: the central arm rest features a particularly soft and optically attractive surface thanks to the TPE component (© KraussMaffei)

tic parts because it has proved capable of delivering cycle times of less than one minute and facilitating a high degree of functional integration, e.g. of screw domes or reinforcing ribs. Combining injection molding with thermoforming of semi-finished textiles or semi-finished layups, such as unidirectional (UD) tapes, therefore affords an efficient way to produce lightweight thermoplastic parts reinforced with continuous fibers. This process combination can, in turn, be combined with many of the other available injection molding technologies,

such as multi-component technology and foaming.

### *Weight Reduction is Just one Concern among Several*

A current example of a multi-component lightweight part reinforced with continuous fibers is the center armrest (**Title figure**) unveiled at the international plastics trade fair NPE2018 in Orlando, FL/USA, in May 2018 [1]. The goal of this project was not just to make the part lighter than the original armrest, but also to improve me-

chanical deflection, without changing the haptic properties. The resulting arm-rest consists of three parts:

- A polypropylene support (PP),
- an organic sheet insert (PP/glassfiber, 1mm thick), and
- a cover layer of thermoplastic elastomer (TPE) to provide the desired haptic properties and appearance.

This design reduced the part weight by 20% and the deflection by a factor of 3 and led to a cycle time of approx. 60s. The associated manufacturing cell was built from standard components, such as a swivel-platen injection molding machine and two industrial robots. Comparable results for weight reduction and cycle time had already been achieved in an earlier project [2]. Efficient production of lightweight parts can therefore be considered state of the art.

Robust production of lightweight parts is contingent, however, not just on the manufacturing solution, but also on the actual process by which the parts are created. Consistent production is ensured by monitoring the appropriate process data. One process step that critically determines the bond between the organic sheet and the injection molding material and thus the properties of the finished part is the heating of the continuous-fiber-reinforced organic sheets [3]. This, together with the requirements to seamlessly document safety-relevant components, makes it necessary to monitor the entire production process.

### Transfer Time as Short and Reproducible as Possible

KraussMaffei therefore devised an integrated production solution (Fig. 1) in which all essential process steps such as heating and transfer time are monitored and analyzed centrally via the machine control system. As just described, heating the inserts is one of the key process steps because excessively low processing temperatures during the forming step lead to fiber breakage. This must be avoided at all costs, because broken fibers in the part have a substantial degrading effect on mechanical properties, and thus give rise to rejects.

So, it is important for the uniformly heated organic sheet to be transferred from the infrared heating station to the



**Fig. 1.** Thermoplastic lightweight engineering for mass-production: KraussMaffei FiberForm systems are equipped with an integrated quality control system (© KraussMaffei)

injection mold as quickly as possible. To this end, the heating station is located above the fixed mounting platen, with one robot inserting the heated organic sheet and another removing finished parts. This ensures a short transfer time for the organic sheet, during which period it cools by only a few degrees. The heating temperature can now be selected so that it is only slightly above the forming temperature. This prevents thermal degradation during heating.

The heating process is controlled and monitored by an infrared heating controller integrated into the standard machine control system; this enables the fabricator to use the current monitored value from the injection molding process. Tolerances for numerous process parameters, such as maximum melt pressure and heating time, can be specified for the current values, and this enables deviations exceeding these tolerances to be automatically detected. However, only individual values in the current values can be monitored; it is not possible to conduct a detailed analysis of process curves.

### From Molding Machine to Measuring Instrument

To resolve this, KraussMaffei developed what it calls the DataXplorer, a preconfigured data memory for the automatic acquisition of sensor and control data from

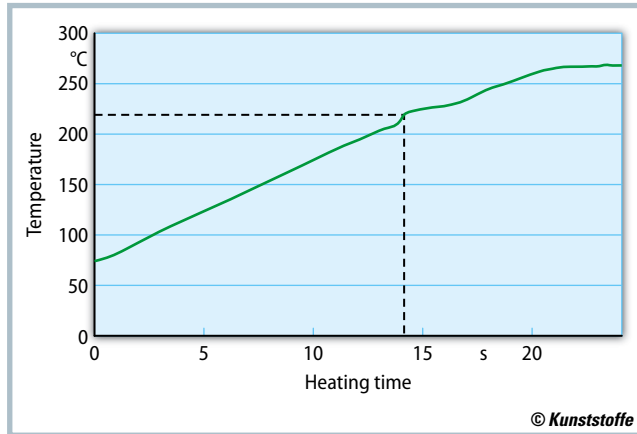


**Fig. 2.** Typical measurement of the contour of an organic sheet with a camera system reveals possible defects (shown in red) (© KraussMaffei)

the injection molding machine. The DataXplorer records up to 500 machine signals at a sampling rate of 200Hz and thus allows the entire process to be analyzed in detail. The injection molding machine has thus essentially been transformed into a precision measuring instrument.

Another necessary aspect of consistent product quality is the positioning of the organic sheet in the mold. To ensure that small tolerances are observed, a gripper keeps hold of the organic sheet from the centering station until the point of transfer to the injection mold. Mold designs that enable reproducible fixing in place of the organic sheets by means »

**Fig. 3.** Heating curve for a continuous-fiber-reinforced PA6-GF organic sheet. The dotted line indicates the melting temperature (source: KraussMaffei)



of clamping elements integrated in the tool are already known [4].

### *The Quality of the Organic Sheet Insert Is also Key*

Part quality is influenced not only by the process parameters but also by the quality of the continuous-fiber-reinforced organic sheet inserts. More especially, the

mechanical properties of the part depend on the number of reinforcement layers, the orientation of the layers and the dimensions of the insert. These parameters can be checked, if necessary. A thickness check, e.g., ensures that the correct number of layers is present and that the robot has actually picked up only one organic sheet. In addition, a camera can be used to visually check both the fiber angle on the surface of the insert and the contour of the insert.

An example of the deviation of an insert from the nominal contour is presented in **Figure 2**. The correct contour is marked in green and the expected contour of the outer edge of the insert is marked in red. The red marking was applied by the evaluation software in order to make the deviation visible immediately. Consequently, deviations in dimensions, fiber angle or thickness of the organic sheet inserts can be detected automatically. Any inserts that fail to meet the quality requirements and fall outside a specified tolerance can then be segregated.

For seamless documentation, the outcome of the camera inspection can then be saved along with the production parameters. In addition, the current position of the insert can be determined from the evaluation of its contour and transmitted to the insert robot, which can then readjust the position. There is thus no need for a centering station.

This stage is followed by transfer to the infrared heating station, where a pyrometer measures the temperature of the insert contactlessly during the heating process. The power of the infrared emitters is adjusted in line with the measured surface temperature. The outcome is a

characteristic heating curve, as shown in **Figure 3** for a continuous-glassfiber-reinforced polyamide 6. The target temperature for this organic sheet is 265°C and so is 5K above the upper forming temperature recommended by the manufacturer of the semi-finished product. The dotted line marks the temperature range over which the polyamide begins to melt. Melting manifests itself as a rise in temperature: when the melting point is reached, the flow of heat into the core of the insert decreases because the specific heat capacity changes. In addition, the residual stresses frozen into the organic sheet are released and the thickness increases as a result [5].

### *Process Monitoring with a Part-Specific Code Number*

The temperature at which the sudden temperature rise occurs can be automatically evaluated with the aid of the process data captured by the DataXplorer. Comparison of the temperature determined in this manner with the melting point for the semi-finished product stated in the manufacturer's data sheet furthermore

## The Authors

**Dipl.-Ing. Stefan Schierl** is a technology developer at KraussMaffei Technologies GmbH, Munich, Germany; [Stefan.Schierl@kraussmaffei.com](mailto:Stefan.Schierl@kraussmaffei.com)

**Dr. Mesut Cetin** is Group Leader of Product Management at KraussMaffei Automation GmbH, Schwaig, Germany; [Mesut.Cetin@kraussmaffei.com](mailto:Mesut.Cetin@kraussmaffei.com)

**Dipl.-Ing. (FH) Christian Herrmann** is a development engineer in the Lightweight Engineering department at KraussMaffei Automation GmbH, Schwaig; [Christian.Herrmann@kraussmaffei.com](mailto:Christian.Herrmann@kraussmaffei.com)

**Dipl.-Ing. Martin Würtele** is Head of Technology Development at KraussMaffei Technologies GmbH, München; [Martin.Wuertele@kraussmaffei.com](mailto:Martin.Wuertele@kraussmaffei.com)

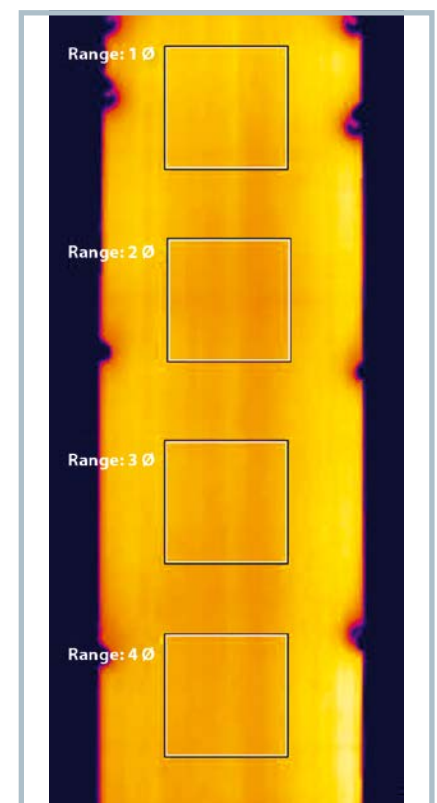
## Service

### References & Digital Version

- You can find the list of references and a PDF file of the article at [www.kunststoffe-international.com/7989719](http://www.kunststoffe-international.com/7989719)

### German Version

- Read the German version of the article in our magazine *Kunststoffe* or at [www.kunststoffe.de](http://www.kunststoffe.de)

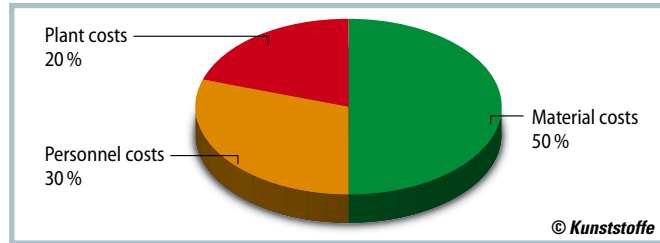


**Fig. 4.** An infrared camera checks for homogeneous temperature distribution on the organic sheet surface (© KraussMaffei)

facilitates rapid analysis of both the condition of the organic sheet and the temperature measurement in the infrared heating station. The value for the melting temperature, as determined from the illustrated temperature curve (Fig. 3), is 218 °C. As the manufacturer's data sheet states a value of 220 °C, the processor can be sure that the organic sheet has been processed as desired.

The recorded data can thus not only be used for process analysis; they also enable the fabricator to monitor the process in terms of an individual, part-specific key metric, which may also be derived from a number of quality-related process-data points. Such a key metric could, for example, also include an analysis of the time required to transfer the semi-finished product from the infrared heating station to the injection mold.

In addition, the KraussMaffei-defined heating quality index (Hq), which is used to evaluate the temperature distribution across the surface of the semi-finished product, can also be determined automatically [6]. The heating quality is determined by using thermography (Fig. 4) to measure the temperatures of part-specific fields [7]. The fabricator thus has at his disposal a range of tools for achieving reproducible part production. The advantages are two-fold. First, defective parts



**Fig. 5.** Typical breakdown of unit costs for Fiber-Form parts

(© KraussMaffei)

are automatically segregated and, second, the evaluation ensures consistent part quality.

This leads not only to shorter cycle times, because, e.g., lower target temperatures can be set for the heating process. Cost savings also accrue, because rejects are detected immediately by the continuous monitoring system – and not just when the tolerance limit is exceeded. When it is considered that 50% of the common unit costs associated with lightweight parts stem from material costs (Fig. 5), a low reject rate is key to driving them down. KraussMaffei has developed its own cost tool to enable customers to calculate their own unit costs.

### Conclusion

A reproducible heating process is indispensable for the production of continuous-fiber-reinforced parts. The shortest-

possible transfer time and precise positioning of the insert in the injection mold are key to part quality. However, the entire manufacturing process can only be captured if other parameters are captured in addition to the process parameters known from the injection molding. KraussMaffei achieves this with the DataXplorer, which enables detailed analyzes of the manufacturing process to be performed.

For example, it is possible to determine a key metric for the heating quality of the organic sheet. This allows the homogeneity of the temperature distribution across the organic sheet to be automatically evaluated and optimized. What is more, the continuous-fiber-reinforced inserts can optionally be subjected to an incoming-goods inspection. The user thus has at his disposal a wide range of options for ensuring reproducible parts production. ■

## Double Production Rates without Quality Losses

### Two Different Recipes at the Same Time

According to **ST Blowmoulding**, Monza, Italy, the ST Aspi 150.3 Duo doubles the production output of blow molded 3D products compared to a single machine without doubling capital and operating costs, while providing high flexibility of use. Like all models in the Aspi series, the Duo machine can also be used for 2D blow molding: each clamping unit is optionally prepared for installation of a blowing unit from the bottom, complete with nozzle and spreaders.

The machine construction is based on two adjacent clamping units. An accumulator extrusion head and associated extruder move on the upper platform to alternately fill the two molds ac-

ording to the cycle rate. This structure requires a relatively small machine footprint, because the locking units do not have to be moved back and forth, but are static. It offers good accessibility to the molds (the clamping units – “tiebarless” type – are accessible from both sides) and – because only one extrusion head is used – a uniform production quality.

The cycle parameters can be set separately for each of the two molds, such that the machine can handle two different recipes at the same time. If required by the production requirements, two different molds can be mounted to fully exploit the machine's potential.



**ST Aspi 150.3 Duo:** the machine can handle two different recipes at the same time (© ST Blowmoulding)

To the product presentation:  
[www.kunststoffe-international.com/7730860](http://www.kunststoffe-international.com/7730860)