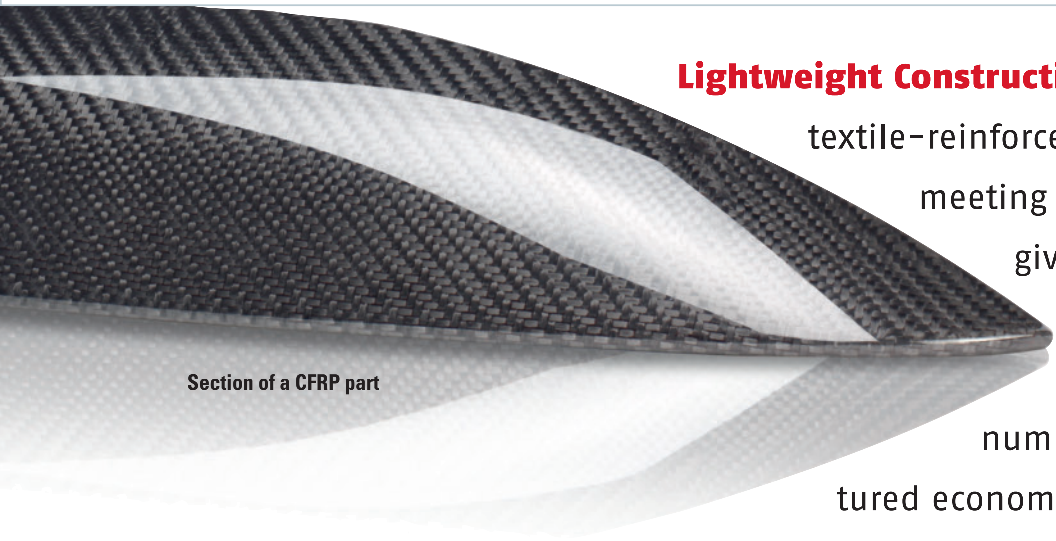

Section of a CFRP part

Lightweight Construction. Rising demand for textile-reinforced structural parts for meeting high requirements has given development a boost within the industry. In order that the necessary numbers may be manufactured economically and at acceptable cost, automating the production processes to facilitate mass production is unavoidable. One system manufacturer considers two processing methods for fiber-reinforced plastics to hold out huge potential for the future.

Economical Production of Highly Stressed Structural Parts

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Vehicle construction has always been a driving force and source of inspiration behind the use of innovative lightweight concepts for producing weight savings. Efforts to promote electric vehicles have seen high-strength structural parts increasingly take center-stage. These parts owe their requisite strength to suitable textile reinforcement systems, profiles, or unidirectional fiber systems. Zones exposed to particular stress can additionally be partially reinforced.

Many of the methods **(Fig. 1)** employed so far share a high degree of manual labor, whether before or after the manufacturing process or in the form of machining. The method to choose depends on many factors, because each one has its own merits. What counts is to weigh up the various conflicting demands against each other. Relevant aspects are

- the required numbers,
- the proposed application,
- the required mechanical properties,
- the cycle and process times,
- additional functional criteria, and of course
- the costs.

In this article, we present two representatives of these highly varied methods which possess the greatest potential for →

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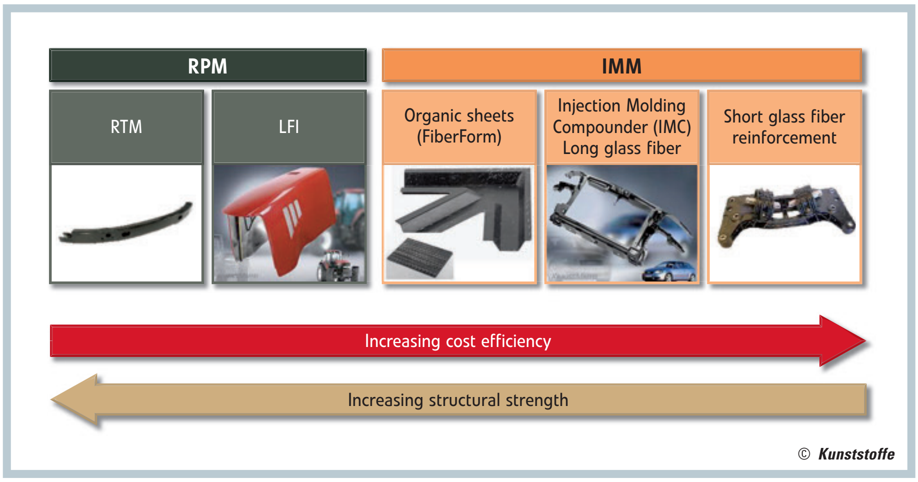

Fig. 1. The fiber-reinforcement methods presented here offer high development potential and are caught between mechanical properties on one hand and part costs on the other (photos: KraussMaffei)

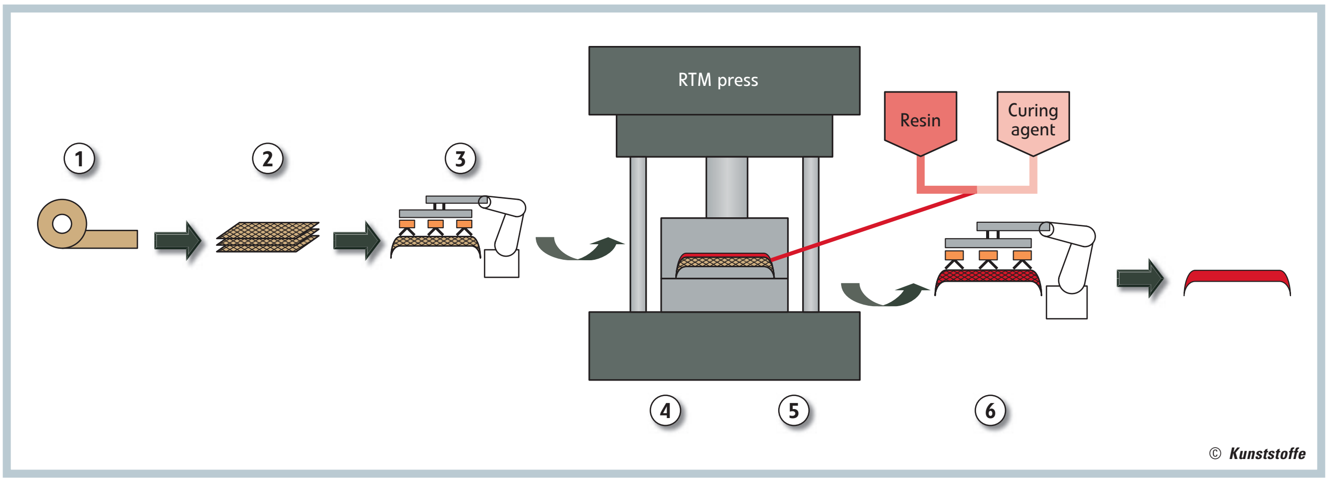

Fig. 2. Schematic representation of the HD-RTM process. 1: Unrolling of the carbon fiber mat, 2: Cropping and possibly forming, 3: Pick-up and insertion by robot, 4: Injection of the reaction mixture, 5: Curing, 6: Removal and further processing (e.g. trimming, bonding, etc.)

economic and mass production of highly stressed structural parts.

High-pressure RTM – Great Finish with a Hard Core

Resin transfer molding (RTM) was first used in motor racing and the aerospace industry for the production of large, very lightweight structures that possessed high strength. For automated mass production of such structural parts, KraussMaffei Technologies GmbH, Munich, along with Dieffenbacher GmbH & Co. KG, Epping, both Germany, is working on developing high-pressure resin transfer molding (RTM-HD), including the entire process chain with metering and forming **(Fig. 2)**.

In this automated process, the scrim or fabric is unwound from a roll and cut to size in a cutting device. The reinforcing materials can be glass, carbon, aramid or natural fibers, as well as combinations thereof. The individual layers of continuous fibers, oriented in different directions, are composed so as to match the stress profile of the final part. They are secured to each other by stitching or by means of a binder. Having been shaped into a preform, the reinforcing lay-up is then inserted by a handling device into the mold. Precision and accurate placement are important here; to prevent the individual layers from moving relative to each other, the fiber lay-up in the mold is held by fixing surfaces.

The mold closes, and the resin is injected via a docked, self-cleaning high-pressure mixing head. High-pressure injection is faster at wetting the fibers with the matrix than its low-pressure counterpart. Furthermore, the resultant faster filling of the mold makes it possible to process systems which cure at a mold temperature of up to 130 °C in less than two-and-a-half minutes, the precise time varying with part size and thickness, and which have a lower porosity combined with high surface quality. The short cycle times render the method attractive for mass production. The requirements imposed on the parts determine which of the various reactive matrix systems is processed **(Fig. 3)**.

To improve the flow of the low-viscosity reaction mixture of resin and hardener, and to avoid air pockets, the mold, which is clamped in a press and is designed correspondingly, is placed under vacuum and operated at cavity pressures of up to 100 bar. The metering device delivers quantities of resin ranging from 10 to 200 g/s, the exact figure depending on the resin system and part. The cycle time is determined by the accuracy of the temperature control in both mold halves in the further course of the process.

For easier demolding, an internal release agent can be metered automatically and repeatably directly at the mixing head via a metering module. This obviates the need for non-reproducible manual application of release agent or investment in automated application by robot.

Machining is the last step in the process chain and serves to give the part its final shape, along with any mounting holes and cutouts for fittings. Trimming takes place in a sound-insulated cabin that can be linked up to a suction and filter installation. If the milling dust is directly extracted at the spindle, there is usually no need to clean the parts separately after milling. The method is characterized by high speeds (up to 200 mm/s, depending

Fig. 3. The RimStar Thermo high-pressure mixing-and-metering unit processes the reactive resin matrix by the HD-RTM process

Fig. 4. The effective and production-ready machining of structural parts takes place in a milling cell

on material thickness) and the high quality of the cut edges (machining accuracy ± 0.2 mm). Even kiss cuts are easy to implement **(Fig. 4)**.

Given the right resin viscosity, fiber materials and pressure, HD-RTM can be used to make very large parts. In the case of carbon fiber-reinforced parts, for instance, the carbon fibers constitute up to 70 % of the total volume. These parts are up to 30 % lighter than comparable products made from conventional materials. The parts also exhibit excellent surface properties, and can be painted on both sides. A further important advantage of the method is its high reproducibility, which manifests itself in low dimensional and thickness fluctuations of the parts.

Injection Molding – a Multi-functional Processing Method

Molded parts possessing high mechanical properties have been produced from continuous strand pellets on injection molding machines since the mid-nineties. There are numerous, long-established productivity and profitability arguments in favor of injection molding. However, the mechanical properties can cause headaches if the parts in question are of the highly stressed structural type. The reason is that the requisite mechanical properties profile necessitates a high proportion of continuous fibers, preferably in a defined orientation and structure (fabric, roving, mat).

KraussMaffei offers a combination of injection molding with thermoforming to further raise the strength level of injection-molded parts. The resultant "FiberForm" method was unveiled for the first time at K 2010, where a so-called technical carrier element of organic sheet in the shape of a door impact beam was produced. The primary purpose of the structural part is to determine material characteristics and to further develop and validate the process technology for high-volume use.

Put simply, organic sheets are slab-like semi-finished products that are made from continuous fiber-reinforced fabric that has been impregnated with a polymer matrix. Thus, the processed organic sheet used for the impact protection consists of six 0.5 mm layers and a matrix of PA6.

The production cell designed for the project typically comprises an injection molding compounder (type: CX 300-1400 IMC) with 3,000 kN clamping force, combined with an LRX 150 linear robot, and an infrared oven **(Fig. 5)**. The fully automated process forms organic sheets in the mold and overmolds them with a glass fiber-reinforced polyamide in a single stage process. To this end, the robot, equipped with a butterfly hook (vacuum cup and needle gripper), removes the pre-assembled organic sheets from a magazine and passes them to a handling device, which places the semi-finished product on a shuttle that features integrated centering. The semi-finished product then moves into the infrared oven. The power-controlled furnace adjusts to a default surface temperature, heating the organic sheets under defined conditions. Should the process be interrupted, the oven therefore does not need to be switched off separately.

Compact Production Cell for Pre-finished Structural Parts

After the required temperature, as determined by a pyrometer in the heating field, has been reached, the robot passes the moldable organic sheet to the mold where it is fixed in position by integrated hydraulic needles. At the same time, the finished part on the opposite side is removed. The gripper, too, is equipped with a pyrometer to monitor the temperature of the organic sheet during the period from removal from the furnace to insertion into the mold. Should an interruption to the production process prevent the semi-finished product from being inserted immediately into the mold and should its tem- →

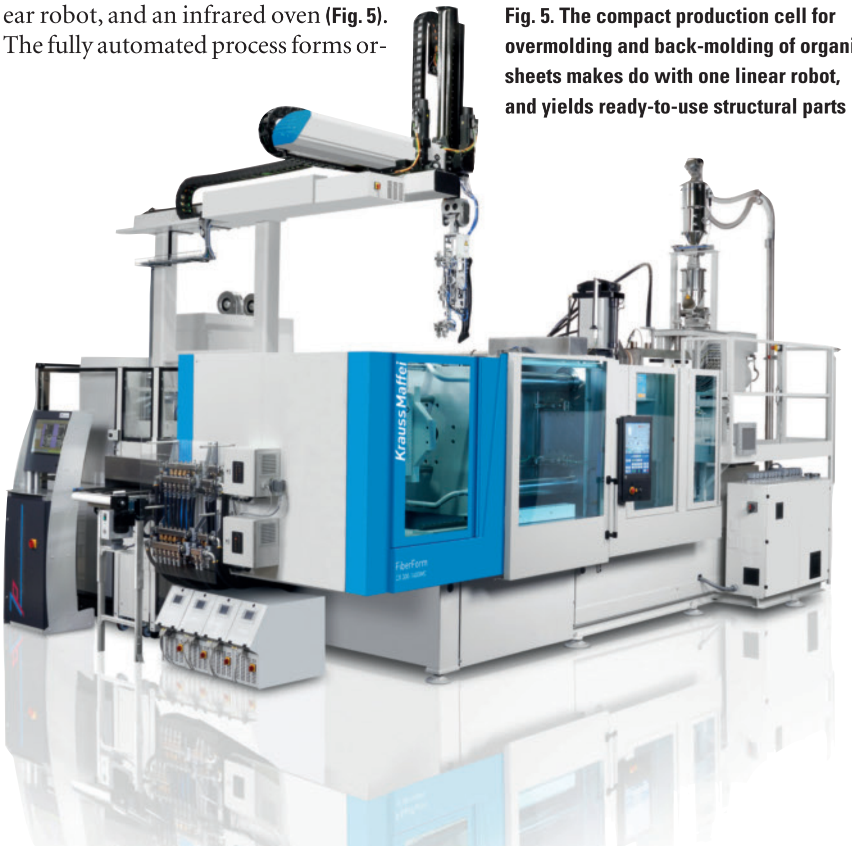

Fig. 5. The compact production cell for overmolding and back-molding of organic sheets makes do with one linear robot, and yields ready-to-use structural parts

Fig. 6. Insertion of a heated organic sheet into the injection mold and removal of a pre-finished molding on the opposite side occur synchronously

perature temporarily drop below a predetermined target value, it is segregated, because it cannot be reshaped thereafter.

In the mold, a hold-down fixes the organic sheet in a defined position, so that when the mold closes it glides fully and wrinkle-free into the cavity with the aid of a preleading pin [1]. There, the semi-finished product is back-injected with ribs and its entire edge region is fully overmolded. This seals the edges, protects the fibers and, as water, for example, cannot penetrate, suppresses any delamination **(Fig. 6)**.

The use of an IMC injection molding compounder extends the range of the production cell: the machine permits incorporation of continuous strand glass fibers with a fiber content of up to 60 %, with the fiber length in the part capable of being adjusted individually. Moreover, customized matrix formulations can be processed on the compounder, a fact which opens up greater scope for tailor-made part concepts. What is more, the special gas vent incorporated into the plasticization unit of the compounder eradicates the need for pre-drying polyamide. This eliminates a separate step, the material is not thermally affected unnecessarily and energy is saved.

Comprehensively Documented Quality Control

Fully automated, repeatable processes offer the best conditions for a comprehensive and documented quality control, as demanded by the automotive industry. For this reason, the entire process is monitored continuously. One goal of this is to demonstrate process consistency, which is why, for example, the mold is equipped with several pressure, temperature and force sensors [1]. Overall, in this development project, 25 signals are logged from 15 positions inside the mold. Crucial to reproducible parts quality is a consistently uniform process pressure at all points in the mold. A final inspection is carried out to ensure that the fabric is correctly laid in the parts.

Project Partners Involved in FiberForm and their Responsibilities		
Audi AG, Ingolstadt, Germany	www.audi.de	Part design
Bond-Laminates GmbH, Brilon, Germany	www.Bond-Laminates.de	Organic sheet
gwk Gesellschaft Wärme Kältetechnik gmbH, Kierspe, Germany	www.gwk.com	Mold temperature control
Jacob Composite GmbH, Wilhelmsdorf, Germany	www.jacob-composite.de	Part design
Georg Kaufmann Formenbau AG, Busslingen, Switzerland	www.gktool.ch	Mold
Kistler Instrumente AG, Winterthur, Switzerland	www.kistler.com/Plastics	Pressure, temperature and force sensors
KraussMaffei Technologies GmbH, Munich, Germany	www.kraussmaffei.com	Process technology, heating station, handling
Lanxess Deutschland GmbH, Leverkusen, Germany	www.lanxess.com	Raw material and simulation
Heraeus Noblelight GmbH, Hanau, Germany	www.heraeus-noblelight.com	Infrared emitter and pyrometer

Conclusion

The answer to the question as to which method is recommended for which application depends on many factors. Undoubtedly, production numbers, application profile, the necessary or desired materials, and economic reasons are crucial.

What makes the HD-RTM process stand out is its flexibility. Depending on the composition of the material (matrix and reinforcement material), custom-made parts with very high fiber contents can be made to specification. Sandwich constructions having core materials of polyurethane foam or other materials are also conceivable. Attention is drawn to the high mechanical properties, the heat resistance conferred by the thermoset matrix and the high surface quality.

With “FiberForm”, processors will in the future be able to avail of an economically and technically attractive process for the manufacture of fiber-reinforced structural parts. The combination of injection molding and thermoforming into a one-step process eliminates manufacturing steps and reduces cycle times significantly. A major advantage is that the parts are ready for installation as soon as they leave the machine. The method’s potential extends far beyond applications in the automotive sector. Basically, it is suitable for all high-volume, mechanically highly stressed constructions. ■

ACKNOWLEDGMENTS

Projects such as those described here can only be realized in close and trusting interdisciplinary cooperation by all parties involved. At this point, the authors would like to extend their thanks to the participating companies (see table), and all team members.

REFERENCES

1 See article entitled “Lightweight Parts with Thermoplastic Matrix,” on p. 65 of this edition

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