NEW PROCESSES FOR MASS PRODUCTION OF THERMOPLASTIC COMPOSITE LIGHTWEIGHT COMPONENTS

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Abstract

In conventional manufacturing processes, lightweight hybrid composite structures are formed in multistage, and therefore costly, process chains, and joined in additional process steps (e.g. gluing or welding). From a process engineering point of view, the biggest savings in mass production can be achieved by minimizing cycle time. Jacob Plastics has developed new processes which combine forming, molding and joining processes in one single process step. This method combines the benefits of the individual processes, thus achieving a particularly high level of functional integration.

1 Introduction

In conventional manufacturing processes, lightweight hybrid composite structures are formed in multistage, and therefore costly, process chains, and joined in additional process steps (e.g. gluing or welding). From a process engineering point of view, the biggest savings in mass production can be achieved by minimizing cycle time. Over the last 3 years, with a series of pioneering projects, Jacob Plastics has developed a new production method which combines forming, molding and joining processes in one single process step. This method combines the benefits of the individual processes, thus achieving a particularly high level of functional integration.

Current lightweight composite structure solutions demonstrate their technological feasibility by using a process that thermoforms continuous fibre-reinforced preforms. However, these materials cause processes and are therefore limited in the design freedom of these structures, which hinders wider market penetration by this class of material. The constraints of the processes and materials used are illustrated in Figure 1.

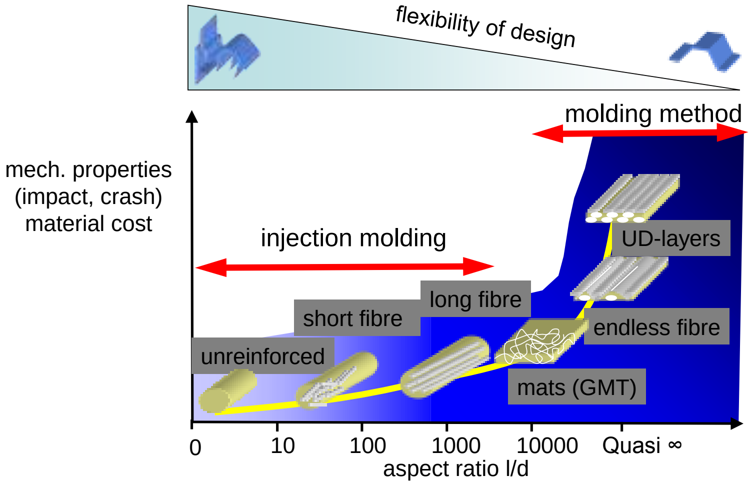

Figure 1. General conditions for composite processes [Prof. M. Schemme, FH Rosenheim]

The combination of the forming process for fiber-reinforced preforms with molding processes, such as injection molding, which offer greater design freedom but can have a more limited range of mechanical properties, should eliminate this conflict of aims. The advantages of continuous fibre reinforcement from a lightweight construction point of view are combined with the design freedom benefit of the injection molding process, making it possible to manufacture complex lightweight parts in a one-shot process (see Figure 2).

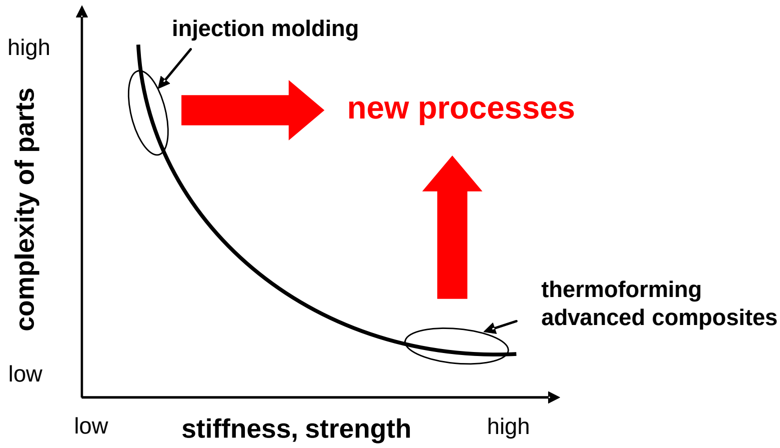

Figure 2. Component complexity over achievable performance for molded and thermoformed components as well as for the new processes under discussion here.

These innovations increase the composite materials' lightweight construction potential because of the potential of the lightweight structure. The lightweight structure is obtained by creating closed or ribbed profiles. To meet complex product requirements, the new processes also facilitate the combination of different component properties which are not achievable using conventional manufacturing processes or can only be realized in several separate process steps. The excellent formability of thermoplastic composite materials combined with tried-and-tested injection molding technology result in a high degree of design freedom. This, in turn, permits the integration of a host of functions within a limited space.

2 Experimentation / Results

2.1 Closed Structures / FIT-Hybrid

The FIT Hybrid process allows the manufacture of lightweight hybrid composite tubes with integrated functional elements. This involves combining the assembly injection molding process with fluid injection technology in the injection molding process. Preheated textile preforms are molded using melt pressure and, in the same cycle, are further molded using **f**luid **i**njection **t**echnology (gas injection technology). The subsequent heat dissipation consolidates the component. The enormous degree of design freedom offered by the injection molding process means that additional passive and active functional elements and modules can be integrated. Figure 3 illustrates the manufacturing process principle.

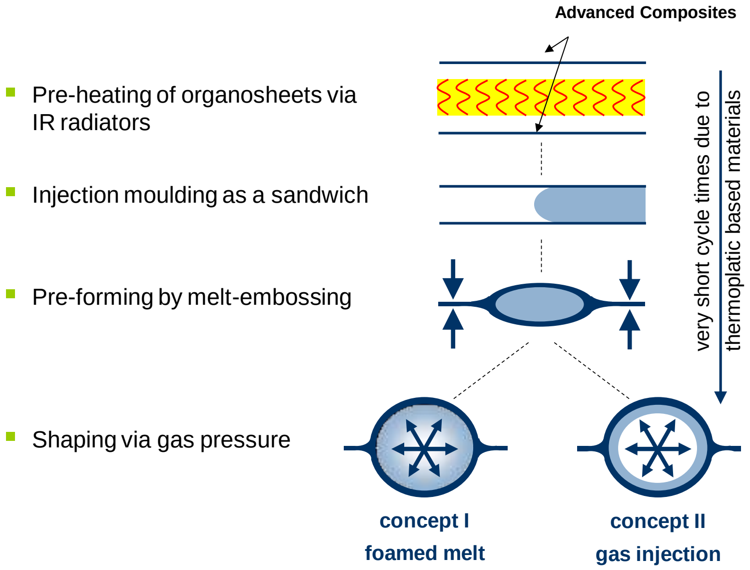

Figure 3. Procedure for manufacturing hollow components using FIT Hybrid technology [LKT]

In the first step, advanced composite sheets (woven fabric reinforced thermoplastic sheets, **F**ibre **R**einforced **P**lastic, FRP) are preheated so that they can be formed. The subsequent assembly injection molding process joins the FRP sheets thus producing a sandwich preform. Here, the creation of a high-strength positive material bond by the assembly injection molding process is a necessary prerequisite to manufacture a lightweight structure with optimal mechanical performance. During the process, assembly injection molding strategies and the corresponding compatibility principles for the creation of positive material bonds are adhered to. To a significant extent, the quality of the bond is determined by the temperature of the bond counterparts (FRP sheet and injection molding compound) at the effective interface, and the effective joining pressure. During the injection lifting process, the joining pressure is used to both bond and premold the FRP sheets. The same tool is used in this process to premold the hollow profile. To form the hollow profile, internal gas pressure is applied using Gas Injection Technology (GIT). During the first step, the technology employed drives out the thermoplastic material being used to join the FRP sheets. Thereafter, the internal pressure can take effect to complete the molding of the FIT tube.

It was possible to transfer the results on processability and material behavior obtained from the first scaled samples to a reference component (see Figure 4).

The design and integration of bonding elements into the manufacturing process presented the reference component with a particular challenge. These bonding elements have to be able to join the lightweight thermoplastic structures to other supporting structures, e.g. a supporting steel frame, to facilitate the transfer and transmission of the effective forces. State-of-the art form-closure joining technology was used to resolve the matter of the design and integration of passive and active functional elements. This technology made the one-shot integrative manufacture of this component possible.

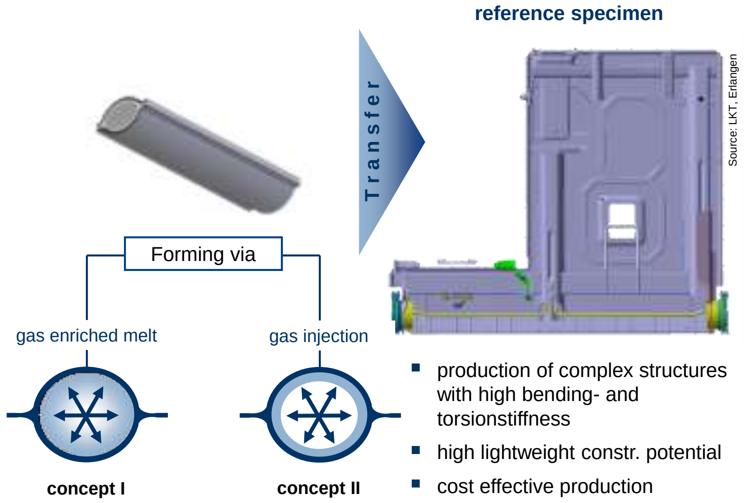

Figure 4. Technology transfer from sample to application [Source: LKT]

The diagram in Figure 5 illustrates the design of the reference component. Here, four custom-cut FRP sheets are used. Two of the FRP sheets are used to mold the hollow profile (FIT tubes I and II) according to the process described above. The remaining two FRP preforms are used for torsional stress absorption and as a cover layer. The diagram also shows the aluminum insert which is used for the transmission of forces into the component, as described above. Using assembly injection molding, ribs can be formed and the bond between the individual joining parts is created in compliance with the calculated compatibility principle specifications for optimum bond quality.

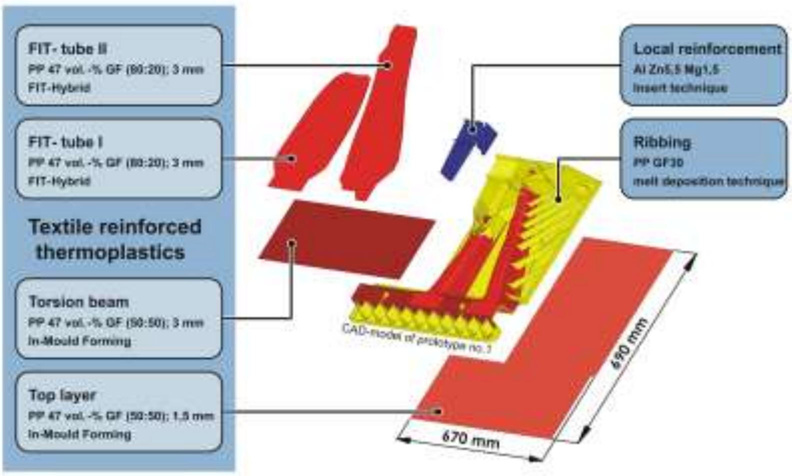

Figure 5. Reference component design [source: NMF/LKT]

Figure 6 illustrates the reference component. This clearly shows the ribs and the aluminum component joined using a form-closure bond. On the left, the hollow profiles are shown in magnified form. The evenness and accurate contours of the profile molding can also clearly be seen.

FIT Hybrid uses process integration to shorten the process chain. This results in shorter cycle times and, thus, the manufacture of FRP components suitable for mass production. Combining different component properties in one concept results in greater functional integration and optimal space utilization.

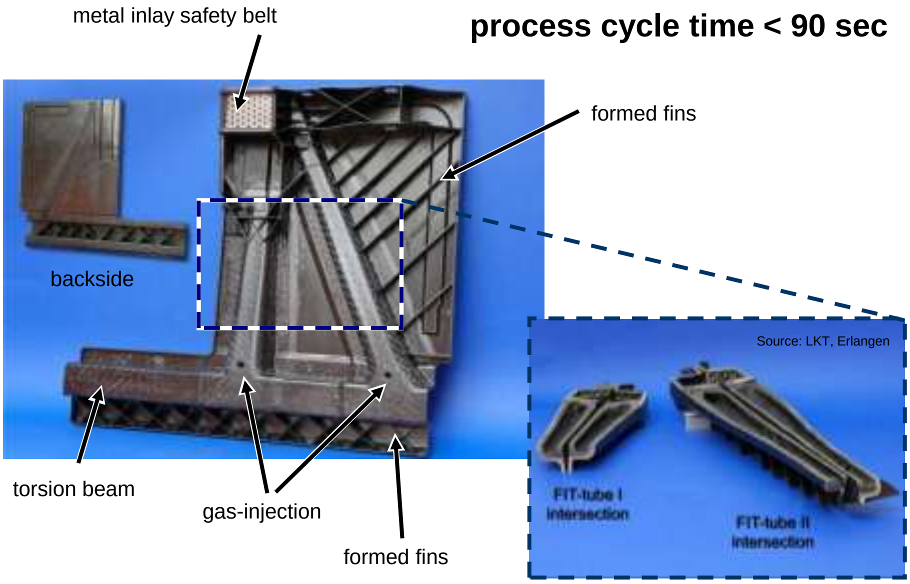

Figure 6. Technology transfer from sample to application, left: reference component with FIT hollow profile I and II, right: cross-section of FIT hollow profile I and II [source: NMF]

In principle, by combining lightweight structures (hollow profiles) with lightweight materials (FRP), the FIT Hybrid process results in greater lightweight construction potential. Furthermore, the use of thermoplastic-based FRPs increases recyclability.

2.2 Open Structures / SpriForm

As with the creation of hollow profiles, in the production of open structures using process combination and integration, the main focus is on the cost-efficient manufacture of thermoplastic-based FRPs suitable for mass production. The process described here combines thermoplastic injection molding and continuous fibre-reinforced thermoplastic thermoforming **SpriForm** (from the German for injection molding + thermoforming ‘Montage**spri**tzgießen + Thermo**form**en’) is a process combination that unites the benefits of the individual processes in a single robust process. Preheated textile preforms are pre-shaped using an injection molding tool’s closing movement. In the same cycle, using assembly injection the products are further molded by applying a reinforcing structure - in this case ribs. The subsequent heat dissipation consolidates the component. The immense design freedom provided by the injection molding process makes the integration of additional passive and active functional elements and modules possible.

This process is described in more detail below (see Figure 8). A simple M-shaped bending beam made from an FRP sheet with back-injection molded longitudinal ribs serves as a sample (see Figure 7).

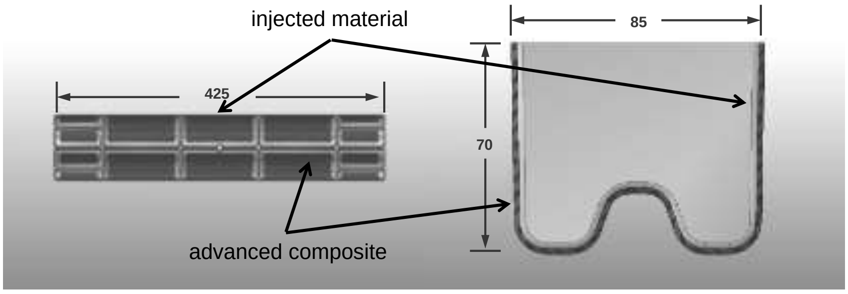

Figure 7. Bending beam

The first step is to preheat the FRP sheet outside the tool. Follow-up steps are then conducted synchronized with the primary cycle time in order to prevent the preheating period from determining the cycle. Infrared heat is used to heat up the FRP sheet, making it malleable. Needle grippers mounted on a handling system remove the preheated FRP sheet from the heating zone. Using the adapted handling system (linear or 6-axis robot), the preheated FRP sheet is transported to the tool. Handling time is a process relevant parameter and is, therefore, decisive for component quality and must be kept to a minimum. In order to optimize the molding of the FRP sheet, during preliminary tests the adapted heating curve is calculated allowing for heat losses.

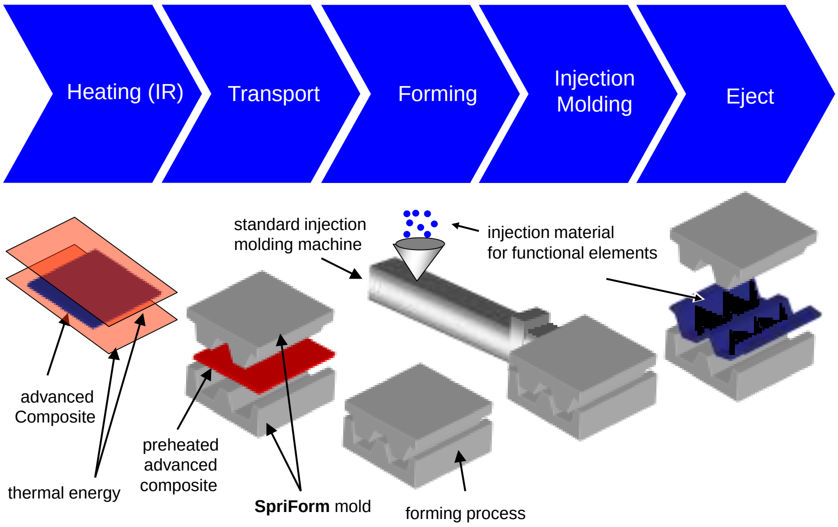

Figure 8. SpriForm process

Optimal temperature at the point of insertion ensures good FRP sheet molding and guarantees (according to the compatibility principles) good bond strength between the rib structure (injected material) and the FRP sheet (matrix material) during the subsequent assembly injection molding (see Figure 9). Good bond strength optimizes the overall mechanical properties of the finished component. On the left in Figure 9, we can clearly see good bond strength between the injected material and the thermoplastic matrix material on the exposed FRP sheet fibres following a rib stripping test on the sample manufactured in the SpriForm process. The bond was so strong that the matrix material was stripped from the fibres. On the right we can see a sample that failed the rib stripping test as its ribs were cold molded between the injected and matrix material.

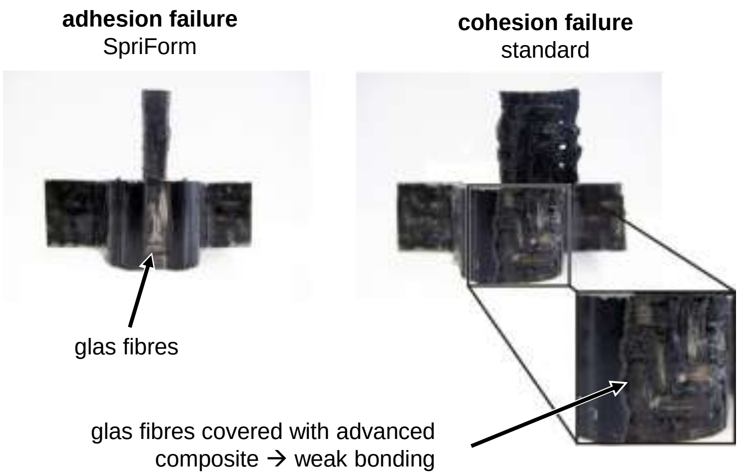

Figure 9. Left: SpriForm process; right: standard

In the next step, the FRP sheet is transferred to the tool using the handling system. Special devices keep the FRP sheet in shape in the partially open tool. The grippers which, up until this point, have kept the FRP sheet in place, open and withdraw from the tool in order to complete the transfer of the preheated preform to the SpriForm tool. The gripper is now free to pick up a new preform which is being preheated in the furnace. The result is an optimized process with primary cycle synchronization similar to an inline process.
By using the tool’s closing function, the preform is pulled and draped over the tool die. This draping process molds the FRP sheet into its final form. Heating the FRP sheet to a sufficiently high temperature guarantees good formability. Lastly, inside the closed tool, a reinforcing structure (ribs) is created using back injection of thermoplastic material. Here, too, an even positive material bond is required. As previously mentioned, the quality of the bond is largely determined by the temperature of the bond counterparts (FRP sheet and injection molding compound) at the effective interface.
By using injection molding, none of the component edges are left open as they can be fully overmolded. Furthermore, by optimizing the FRP sheet flat projection as well as through optimum adaptation to the component processing, an off-tool component can be manufactured. A downstream separating (e.g. cutting) process to manufacture the component is not required.

The process successfully implemented on the first samples was transferred to an application-oriented demonstrator (see Figure 10). Here, a side impact beam was used. The injected rib structure prevents early opening of the profile under stress or in the event of failure and transmits the forces directly into the underlying structures. As with the FIT Hybrid process, with SpriForm, it is possible to integrate metal inserts which facilitate force transmission into attached metal structural components (e.g. a car body). Currently, the bond between thermoplast and insert is created using a form-closure. In principle, however, it is also possible to add a metal insert in a post-process.
This demonstrator (see Figure 10) is used as an example to demonstrate the complex process chain. The type of demonstrator selected should enable the transfer of the properties identified and analyzed, and the processing parameters, to scaled geometrically-complex components.

Figure 10. SpriForm – leading-edge technology

An essential prerequisite for the implementation of this process is an appropriate, complex handling system comprising clamping, heating and tracking systems. The handling system must allow the fibres to be kept stretched during the entire handling process, thus ensuring time-optimized handling of the FRP sheet.

Possible applications are geometrically complex, stiff, large-scale components used in the transport sector. The process is particularly suitable for the near net shape, main cycle-synchronous manufacture of structural components with improved energy absorption properties and greater lightweight structure potential.

3 Conclusions

The technologies described here have significant commercial potential. This is due to the fact that the innovations presented can be used in many of those market segments which require products that are lightweight yet meet considerable mechanical property demands at the same time. The entire automotive industry, medical technology, the sport and leisure industry as well as aerospace technology are but a few of those segments. Thanks to their functional integration potential, these processes can fulfill many different demands, whether on the part of the end user (e.g. attractive design and additional comfort) or the manufacturer (e.g. reduced costs), thus replacing existing components. A further benefit is the economical production of new products with unique features.

For the manufacturer there are real economic benefits because production using these systems is energy-efficient and highly automated and, therefore, suitable for mass production. In addition, the shorter process chain boost overall process robustness. Furthermore, the consistent use of thermoplastic materials based on a single polymer type enables inexpensive recycling. The end user receives a highly functional product combining many different functional elements. This offers a host of benefits in terms of product use, fields of application and effective product utilization.

4 Acknowledgements

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