MANUFACTURING SOLUTIONS FOR HYBRID OVERMOLDED THERMOPLASTIC UD COMPOSITES

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Abstract

Hybrid overmolding of thermoplastic composites is considered to be one of the most promising technologies for enabling the use of structural composites in order to facilitate further weight reductions in cars. This is especially true in the case of unidirectional (UD) tape-based inserts, which, together with a smart design, can fully exploit the lightweight potential of composites while keeping costs competitive.

However, due to the nature of UD based materials, handling and fixation of local inserts poses an additional challenge compared to their woven counterparts. The main reason for this is that in or near the melt state, the physical integrity of tape-based materials perpendicular to the fibers is very weak as it is only maintained by the resin. Consequently, low forces may result in splitting and other forms of damage. Taking this into account, new methods for handling during transfer from the heating oven to the mold as well as for fixation in the mold after hand-over have been developed. These patented developments have taken place in close cooperation with a tool builder Georg Kaufman Formenbau AG, Switzerland, and are explained in this paper. A fully automated production process for production of a dedicated large-scale technology demonstrator was established in partnership with KraussMaffei Technologies. With this new technology, a major hurdle towards mass production of hybrid over-molded structures using tailored UD tape-based inserts has been overcome.

Introduction

The automotive industry is working on solutions to reduce the weight of their fleet in the light of current, and more importantly, upcoming legislation on reducing emissions. One of the most promising material-based solutions are continuous fiber reinforced thermoplastic composites, which feature excellent mechanical properties, lightweight, design freedom and perhaps most importantly very fast production cycles and re-cycling potential. Especially the possibility of hybrid overmolding to make very complex parts in a cost-efficient way is one of the main drivers to adopt thermoplastic composites. Due to the nature of thermoplastic resins, semi-finished products like fiber-reinforced tapes and laminates can be processed only by heating and shaping (thermoforming). It is conceivable that the conversion of tapes into laminates and further shaping of laminates into a thermoformed and overmolded part can be all done in a single step. Such versatility is hard to find in other composite material systems.

Laminates based on UD layers usually outperform fabric based laminates in terms of stiffness and strength [1, 2]. This is due to the fact that the fibers do not experience geometric undulations as in the case of textile based fabrics (architectures shown in Figure 1). In terms of weight savings potential, this poses a clear advantage, especially in the case of single load paths where full UD laminates can be applied. However, this poses new challenges on the manufacturing technology especially when automation is involved.
Unidirectional tapes and laminates feature excellent mechanical properties in fiber direction; however in transverse properties are reduced significantly. This is even more pronounced at forming conditions where typically the temperature in the laminate is above the melt temperature to allow for large geometric changes. As a negative consequence, however, small loads in transverse direction may also lead to unwanted deformations, like splitting of the laminate. This needs to be prevented by the development of new gripping and fixation systems applied during the critical stages of heating, handling, forming and overmolding of the laminate.

In this paper, the production process of a hybrid overmolded technology demonstrator will be discussed. A new solution for processing UD laminates without the previously mentioned drawbacks is presented. Furthermore, simulations of the different steps of the processing chain are discussed and process settings optimized. The material system in focus is glass fiber reinforced polypropylene (UDMAX™ tape from SABIC [5]).

**Technology demonstrator**

In order to develop and validate predictive engineering capabilities as well as the processing technology for UD-based laminates, a unique in-house technology demonstrator was designed. The large-scale beam structure combines one or more UD laminates overmolded with a long fiber injection molding grade. Different variants of the demonstrator are designed in order to facilitate the measurement of mechanical performance for a variety of laminate shapes and lay-ups. In addition, the demonstrator was developed to assess performance under quasi-static, dynamic, fatigue and creep conditions; as well as under different stress states such as tension, compression and shear. Finally, this beam can also enable evaluation of joining techniques and their performance. The demonstrator features a lower cross-section in the center in order to provoke failure at this area.

*Figure 1: Fabric based laminate (left) and UD-based laminates with different lay-up (right)*
Figure 2: Injection overmolded technology demonstrator (left) and two typical variants dedicated to (right) tensile and compression testing of full UD and (top right) full-width multi-axial laminates (bottom right)

The part features large dimensions, 1000mm x 160mm x 40mm, representative of automotive applications. The materials used are UDMAX™ GPP45-70 tape with 45% by volume of continuous glass fiber and STAMAX™ 30YK270E resin with 30% long glass by weight.

The focus in this paper is on Variant 1, which involves using full UD inserts of different thickness as shown in the top right area of Figure 2. In terms of reinforcement, this beam features a 12 ply, 3mm thick insert in the center section of the “omega” section and 3 ply 0.75mm strips in the flanges. The part has been designed such that under a 4-point bending load, tensile or compressive failure will be driven in the insert sections as opposed to the overmolding resin. Variant 4, on the other hand, features a full-width insert comprising 0 as well as ±45 plies to enhance the torsion stiffness.

**Manufacturing of demonstrator**

The process of overmolding, a hybrid process based on a combination of press forming of thermoplastic composite laminates and classical insert overmolding, can be considered a special variant of assembly welding. Using compatible resin systems, the overmolding can be performed without special pre-treatment or additional bonding layers. Cycle times of 60 seconds are within reach because, in contrast to their thermoset counterparts, no curing reaction is involved.
The process cycle of an automated injection overmolding process is illustrated in Figure 3. During this process a pre-consolidated laminate is picked up by a robot with a dedicated gripping unit (1). The laminate is transferred to an IR-oven in which the laminate is heated to forming temperatures (2). After the laminate is heated, the robot transfers the now hot laminate to the injection molding molds and places it inside (3). Here a system is needed that fixates the laminate in the desired position prior to complete closure of the mold. The laminate is shaped during the closing movement of the tooling (4). After full closure of the tools and build-up of the tool closing force, the mold is filled employing a standard injection molding procedure comprising filling, holding and cooling stages (5). In order to secure good adhesion properties between overmolded resin and continuous fiber laminate, the laminate surface temperature should still be high enough. After cooling down, the part is ejected (6) and a next cycle can start. In a production environment, the cycle time is mainly depending on the injection overmolding cycle, since heating of the laminate will generally take place in parallel.

The technology demonstrator consists of UD based laminates overmolded with an LFT grade material. The laminates have been produced using double belt consolidation technology in different thicknesses and lay-ups. Although the focus in this paper is on Variant 1, reader should note that the remainder of this paper also applies for the other variants. It is a good habit to employ numerical simulation of the design and the processing methods deployed. The second part of this section will discuss the solutions that have been developed for handling and fixation of UD-based inserts in the overmolding process, which will also be shown based on the technology demonstrator.

**Handling and fixation of UD laminates**

Continuous fiber reinforced pre-preg tapes feature excellent mechanical performance in fiber orientation. This makes these materials ideal to increase the mechanical performance of parts by applying them along the load paths. The reduced properties transverse to the fiber orientation, however, pose challenges for handling and fixation during processing at elevated temperatures.
Available solutions, like needle grippers or vacuum grippers proven for woven fabric based laminates and dry fabric, do not give feasible results for UD laminates at forming temperatures. Initial trials showed severe local deformations with fiber movement and buckling, delamination and ply splitting. See Figure 4.

![Figure 4: Local damage to the fiber structure using conventional needle grippers](image)

The developed solution to prevent damage of the insert and enable robust handling is based on large contact surfaces of the grippers to reduce the contact pressure. Ideally, the grippers are covering the whole width of the insert, which is especially important in the case of full UD inserts. Furthermore, grippers are used opposite each other to clamp the laminate. The grippers should be able to move to align the insert to one of the tool surfaces for subsequent overmolding.

![Figure 5: Principle of tool gripping system](image)

Figure 5 shows the principle of the developed solution for fixation and positioning of the composite insert in the mold. The robot that holds and transfers the heated laminate positions the laminate between both mold halves. Subsequently, the tool grippers (yellow) are moved out and take over the laminate. As all tool grippers are in position, the robot grippers release and the robot is getting ready for a new cycle. Now the tool is closed and the laminate is positioned to its final
position in the mold, using the controlled movement of the tool grippers.

Furthermore, for production of the technology demonstrator, a system that is flexible enough to position the laminate to either the fixed or movable tool side has been developed. A further advantage of the developed controlled gripper system is that the individual grippers can be retracted as the flow front passes. Subsequently, the resin pressure will provide the necessary pressure to keep the laminate bound to the opposing mold surface.

The tool as well as robot grippers feature a large surface to prevent for unwanted deformations during processing. Since the laminate is fixed on multiple positions during the molding process, underflow of the laminate can be prevented for during molding of the demonstrator. The FiberForm† cell at KraussMaffei Technologies in Munich has been used for production of the technology demonstrator. In the next section, state-of-the-art simulation possibilities for analysis of filling, warpage and structural performance will be discussed.

Process simulation

For the adoption of new material systems and productions technologies in the automotive industry, availability of predictive engineering methods is a must. In this paper, two topics concerning process simulation will be highlighted: draping simulation and injection molding simulation.

Blank size optimization

Draping software is employed to analyze and optimize the forming process of the laminate. One of the main goals is to predict the fiber orientation after forming because small changes may have a large influence on mechanical performance. Furthermore, the risk of defects such as wrinkling, ply shearing or tearing can be analyzed.

To analyze the draping behavior of the second variant under consideration – the first one does not feature double curvatures – a draping study with ESI’s PAM-FORM† software was performed.

![Figure 6: Draping of the insert for full width variant with original blank dimensions (left) and optimized dimensions (right)](image)

It should be noted that the tool features a shear edge such that the injection-compression overmolding process for homogeneous consolidation and packing and reduction of warpage can be carried out as well. This feature, however, reduced the effective width of the insert as seen in Figure 6 (left). In the case that the full insert width as designed is used, the software predicts that a small section of the insert is captured in the shear edge.
After reducing the laminate width, the insert can be formed in the tool cavity. Since the tool gap is larger than the laminate thickness the laminate is free to move to some extent. Outside the gripping areas defects as fiber waviness and deconsolidation are observed, which can negatively influence the resin flow. The prediction of the interaction between resin flow and laminate is one of the remaining challenges.

**Gating optimization**

The fiber orientation in the LFT overmolded resin plays a significant role in the mechanical properties of the part. Since the fibers are to large extent aligned with the flow direction, predictions of the filling pattern are essential to optimize performance. The filling pattern can be influenced by the number and position of the gates, gating sequence and timing. The tool of the technology demonstrator features a film gate at one end of the beam, combined with three gates evenly distributed over the part. The center gate has not been employed in this study.

The initial gating sequence consisted of side cascade filling starting from the film gate. A central gating was expected to provide random fiber orientation just in the critical center area. The Autodesk™ software Moldflow™ has been used to predict and evaluate the fiber orientations.

![Figure 7: Average fiber orientation in center area for variant (1) with side cascade filling and packing on all gates (left) and with optimization of the gate timing during packing (right) H.png](image)

Although a side cascade filling sequence was used, predictions of the final average fiber orientation in the part showed near random orientation in the center area, causing a potential weak spot. The fiber orientation pattern after filling yielded optimal results; however, during packing – which was equally performed on all active gates – unfavorable re-orientation of the fibers in the center area arose. Therefore, it was decided to perform packing at only one of the off-center gates. This results in improved fiber orientation with pronounced alignment in bending direction, as shown in Figure 7 (right).
Finally, it was possible to produce defect-free demonstrator parts (see Figure 8) that could meet the requirements on position of the inserts as well as suitability for evaluation of the previously mentioned loading cases.

Conclusions

Overmolding of UD tape based laminates provides a process feasible for automated mass production of weight optimized composites parts. It was shown that current manufacturing simulation software provides powerful solutions for single process optimization. In addition, Yaldiz, et.al. [3] show that the integration of these software solutions in a simulation chain is able to provide high quality predictions of the part performance, incorporating the main processing effects.

The newly developed technology allows for robust handling and fixation of full UD laminates during overmolding processes. Different variants of a technology demonstrator were produced using an automated process feasible of cycle times in the range of 60 seconds. Together with advanced process-chain modeling of the tape-based materials, new possibilities for large-scale application in automotive industry open.

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Bibliography


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