THERMOPLASTIC TAPE REINFORCEMENTS FOR COST-EFFICIENT LIGHTWEIGHT AUTOMOTIVE APPLICATIONS

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Abstract

Advanced lightweight materials are a necessity to satisfy the need for efficient and safe vehicles in the face of future transportation scenarios like shared mobility and electric drives. A versatile, cost-efficient way to produce safe, lightweight components is the use of local fiber reinforcements in multi-material injection molding. With the example of a Porsche center tunnel, it is shown that the combination of unidirectional tape reinforcement, metal inserts and injection molding can lead to significant weight reductions in automotive body structure while maintaining structural integrity. Before manufacturing, a tape layup is generated by automated fiber placement based on the structural requirements and loading cases of the component. The different layers are further consolidated in a novel vacuum assisted heater into a single plate. During manufacturing, the plate is heated in an infrared heater, transferred into a mold and draped into a complex tunnel shape by the closing mold halves. Inside the closed mold, the material and the previously inserted metal parts are overmolded with thermoplastic melt into a single multi-material component. Conclusively, a lightweight center tunnel can me manufactured in a cost-efficient single shot process, which is further evaluated in full-scale vehicle testing.

Introduction

The automotive industry is currently facing drastic changes in the field of autonomous driving and alternatives drives in form of electric and hydrogen powertrains [1]. These changes, with the additional batteries, functions and sensors lead to a significant increase in vehicle weight [1]. To counter this trend, novel cost-efficient lightweight materials and production processes are needed to satisfy consumer request and regulatory requirements at the same time [3]. The mentioned requirements therefore focus on quality, comfort as well as vehicle safety and efficiency. A novel approach is presented by the joint partnership of industry and research in the government funded research project “LehoMit-Hybrid” with the example of an automotive center tunnel in multi-material design [2]. The general goal of this project is the replacement of the current steel and aluminum version by a combination of fiber reinforced thermoplastic tapes, metal inserts and injection molding in a single shot process. This not only leads to significant lightweight savings but also reduces the amount of up-front investment costs greatly, which is especially attractive for flexible low to medium volume production. During the course of the project, a prototype concept design is generated, manufactured, introduced into a Porsche vehicle body before cathodic dip coating and then fully tested according to internal testing standards regarding corrosion, long term behavior and crash. This paper focusses on the manufacturing of the hybrid component in a single shot injection molding process.

Component Design

Initially, a general component design consisting of thermoplastic tapes, metal inserts and injection molded rib structure was developed in accordance to the specification of a Porsche center tunnel [2, 3]. Due to the low intrusion and clear load paths during crash, fiber reinforced tapes are applied as the tunnel’s outside shell due to their high mechanical properties in fiber direction and full utilization of the fiber’s outstanding properties [2, 3]. A mixed combination of glass and carbon fiber reinforced thermoplastic tapes of different orientation is iteratively optimized to fulfill the required loading cases [4, 8, 9]. Especially in the center and front region, additional carbon fiber layers are applied to meet the mechanical requirements in the case of a front crash. Due to the thermal loading during the dip coating process, PA6.6 was used as tape matrix material. Conclusively, the thermoplastic tapes are processed into a single solid plate via direct fiber placement and consolidation under heat and vacuum. In addition to the fiber reinforced tapes, metal inserts are introduced into the component during processing: a hot-stamped steel front insert, multiple metal load introduction inserts and threaded inserts. These metal materials are used for both load introduction and integration into the vehicle structure. An injection molded plastic rib structure is applied to adds stiffness to the structure as well as combines. To improve the bonding between thermoplastic tapes and injection molded ribs, the same polymer material is used.

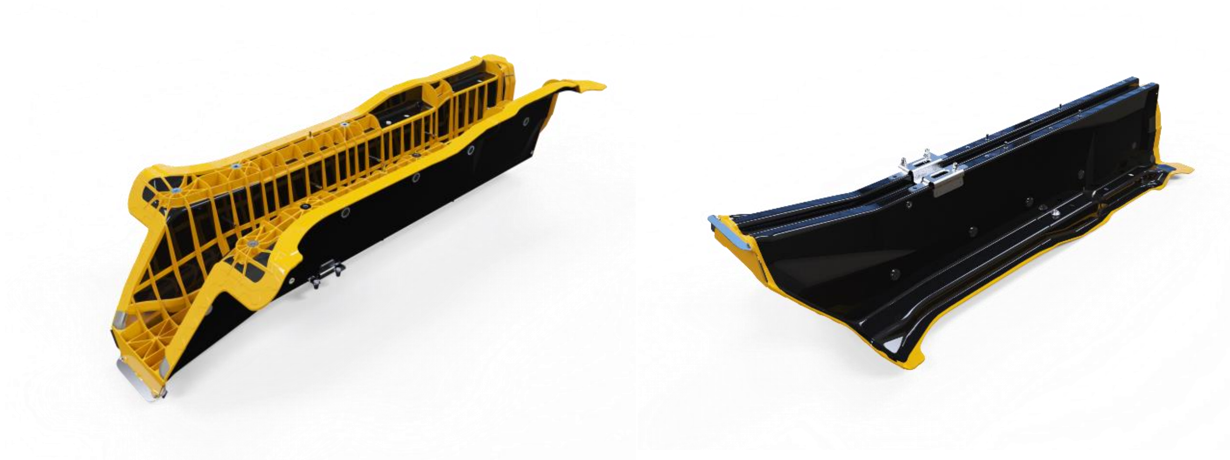

Figure 1: LehoMit-Hybrid center tunnel concept (CAD rendering)

Manufacturing

The presented multi-material prototypes are produced at the Open Hybrid Labfactory (OHLF) in Wolfsburg, Germany, as displayed in Figure 1. Core element of the manufacturing setup is a Engel Duo v-duo 3600, an injection molding machine with a vertically-opening press by Engel Austria, Schwertberg, Austria. Located inside the injection molding machine is the mold, produced by Schneider-Form GmbH, Detting unter Teck, Germany, one of the project partners, as shown in Figure 2. The heating of the thermoplastic laminates is done in a costume made infrared heating oven by Lufttechnik Bejbl GmbH & Co. KG, Babenhausen, Germany. All handling operations are conducted by a six-axis KUKA KR 270 R2700 handling robot with an additional linear unit KUKA KL 2000 by KUKA AG, Augsburg, Germany with a specially developed gripper system, which will be presented in detail.

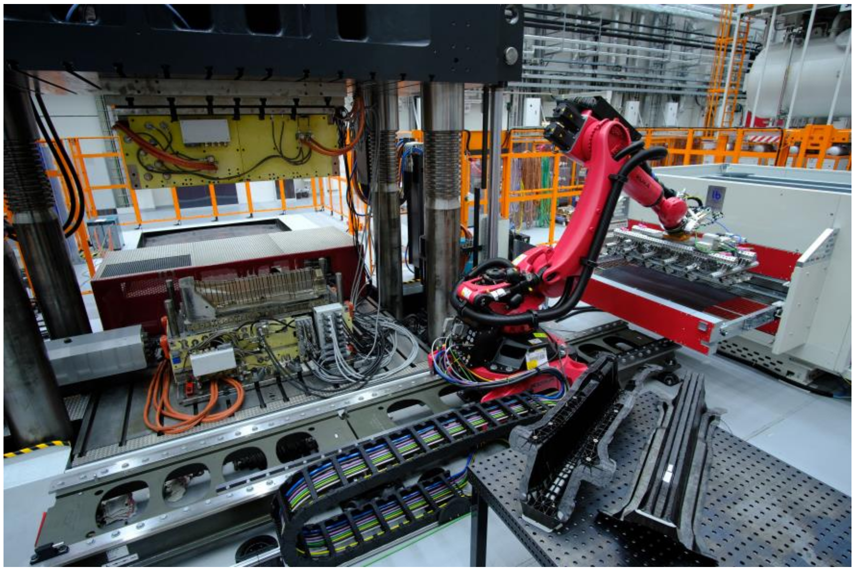

Figure 1: Manufacturing setup at the OHLF with injection molding machine, robot handling arm, mold and IR oven

Prior to production, all necessary materials are prepared and positioned inside the manufacturing cell. All metal inserts are manually placed inside the mold into their designated locations, while the tape laminate is positioned inside the infrared oven's steel wire tray by the help of positioning aids to guarantee proper positioning. Small deviations in position and angle inside the oven tray are transferred into the mold, possibly leading to problems regarding draping, filling and final part properties like distortion and mechanical properties. Prior to heating, the laminates and injection molding pellets are dried at 80°C overnight to remove residual moisture.

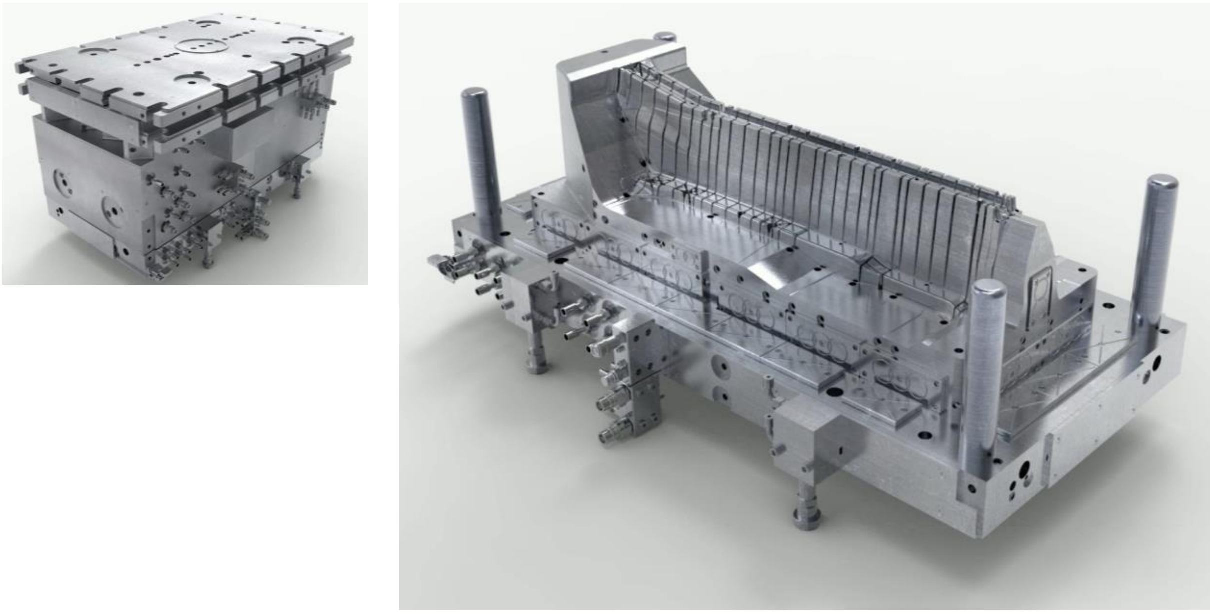

Figure 2: Mold geometry for the manufacturing of multi-material center tunnels - closed (top left) and bottom displaying the complex rib structure (right)

With the start of the manufacturing process, the thermoplastic tape laminate is introduced into the oven and heated at 300°C for approximately 2:30 min to evenly heat all tape layers inside the laminate above the polymers melting temperature. The oven consists of five heating zones inside the top and the trays, which are individually monitored and controlled by pyrometers. The heating process is vital for the draping behavior of the laminate and hence the final mechanical properties of the part. While the laminates need to be sufficiently heated, excessive polymer degradation must be adverted. After the laminates are evenly heated, they are picked up from the heating tray by the needle grippers and transported inside the mold, as displayed in Figure 3.

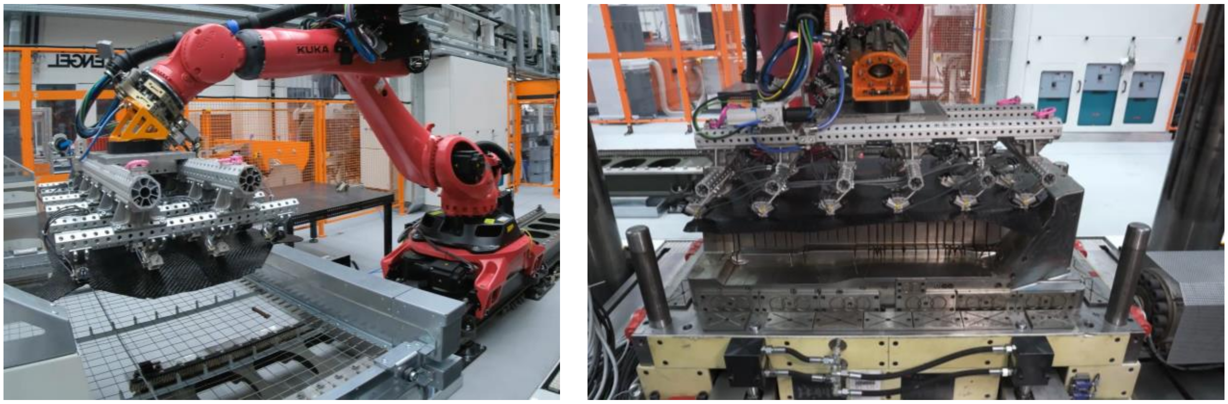

Figure 3: Pickup of the tape laminate from the oven tray (left) and drop-off inside the mold before draping (right)

During handling, the safe and fast movement of the tape layup have the highest priority. Due to the cooling of the tape laminates with the surrounding air, handling times must be kept as short as possible while laminate damage must be avoided at all costs [1]. In contrast to woven textiles, tape layups are comparably fragile during handling and can display stripping of outer tape layers, as experienced in first handling trials. To avoid any sagging or damages to the layup, needle grippers are distributed evenly throughout the plate, as presented in Figure 4. The introduction of needles into the laminates does not show any signs of fiber or tape damage and no traces inside the laminates are visible before and after molding. Inside the mold, the laminate is positioned over the exact drop location and ejected at a minimum distance.

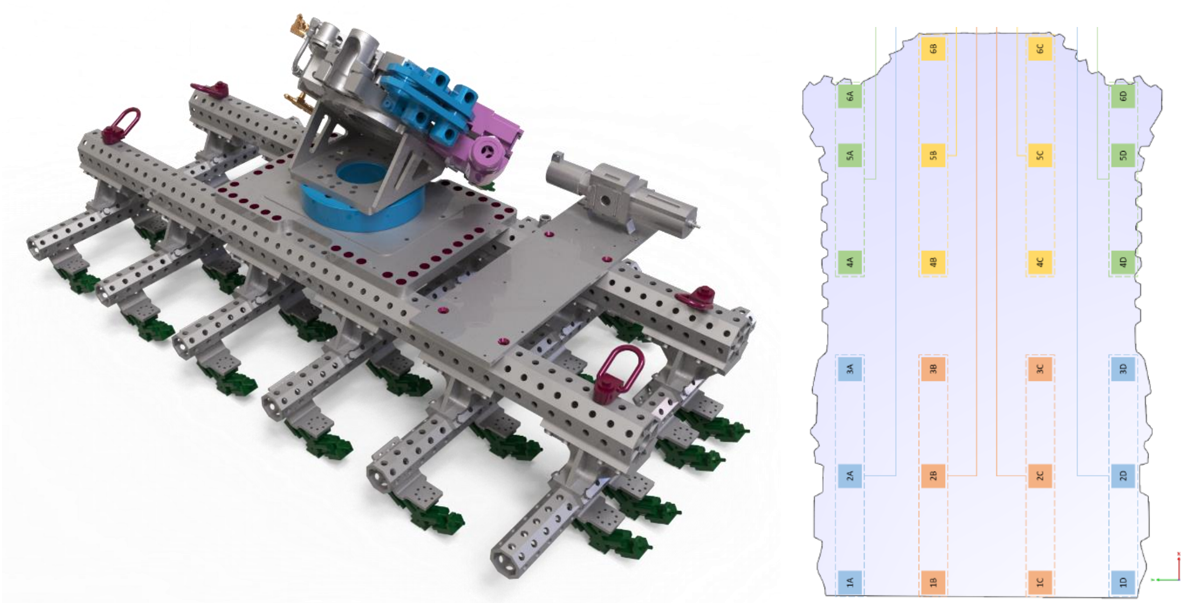

Figure 4: Needle gripper system (left) and positioning and grouping of needle grippers over the tape laminate (right)

After ejection from the needle grippers, the molten thermoplastic laminate pre-drapes into the tunnel geometry under its deadweight prior to mold closing. At this stage, sections of the laminate surpass the mold edges, as shown in Figure 5, which would be potentially sheared off by a shear edge, leading to laminate damage. Therefore, the mold is designed with an open edge border of 0.2 mm, leaving the laminate enough room for draping while still enclosed for injection molding.

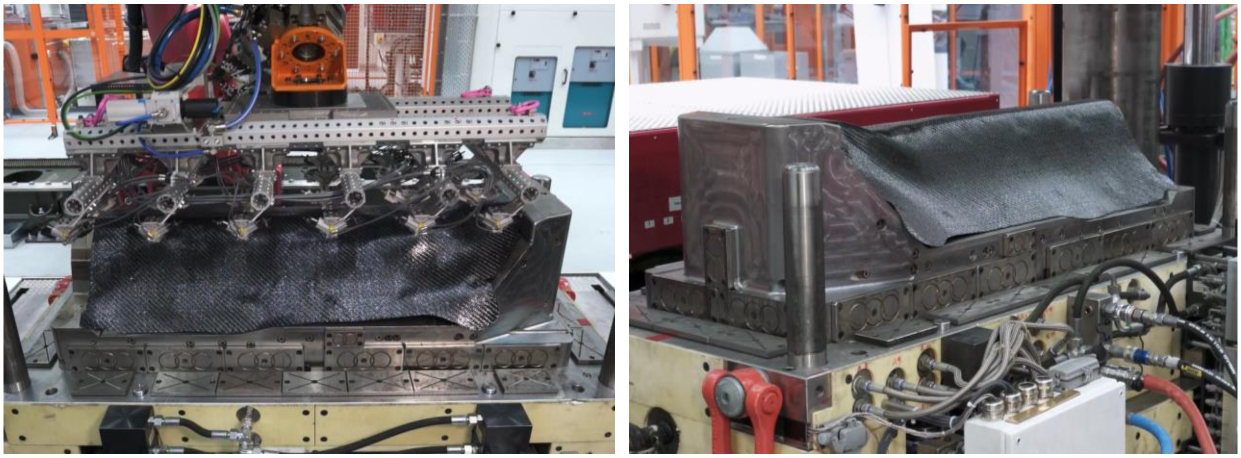

Figure 5: Laminate after being ejected by the needle grippers inside the mold, pre-draping under deadweight

During mold closing, the tape laminate is continuously draped into the predetermined tunnel geometry as displayed in Figure 6 (left). As soon as the mold is completely closed and closing pressure (1000 kN) is applied, the injection molding process is started. During the injection molding process, approximately 3500 cm^3 melt (yellow) is introduced through the hot runner system into the rib cavity of the mold, combining the laminate (black) and the metal inserts (blue) to a single hybrid component, as displayed in Figure 6 (right). After cooling, the final prototype is ejected from the mold, as shown in Figure 8.

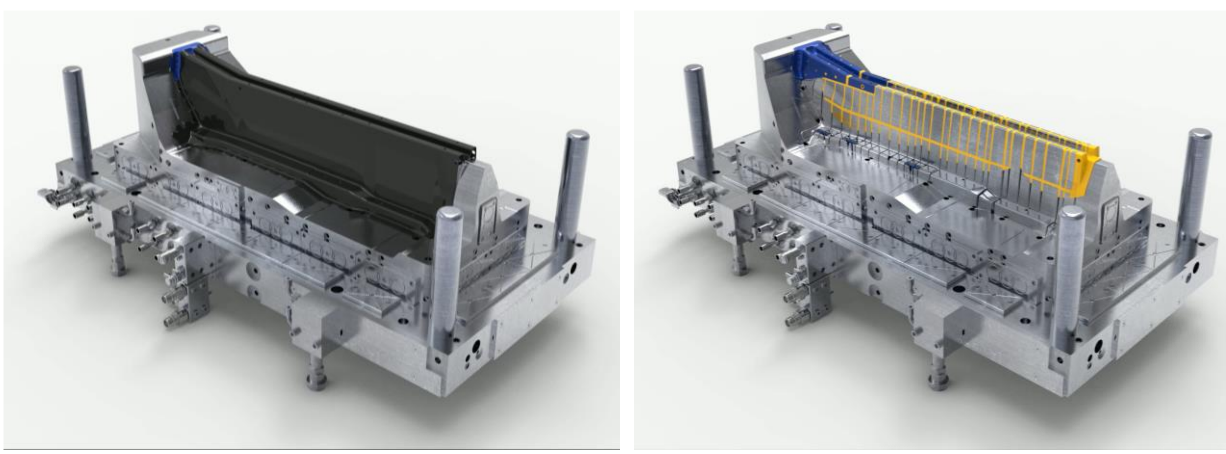

Figure 6: Tool animation inside the injection molding machine with upper mold half made invisible - draped laminate (left) and injection molding process with laminate made invisible (right) with blue metal inserts

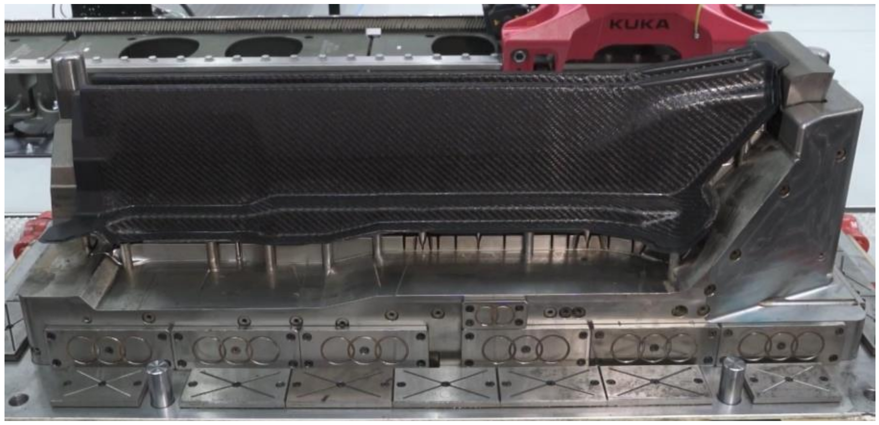

Figure 7: Part ejection of the hybrid tunnel prototype at the OHLF

OUTLOOK

The gathered prototypes, as presented in Figure 8, are introduced into Porsche Boxster 718 body for full vehicle testing regarding long term behavior, corrosion and crash testing. The joining of the components is facing the challenge of different heat deflection behavior under temperature. Since the prototypes of the center tunnel will be introduced into the vehicle body before dip coating, the temperature exposure during the drying process of up to 200°C will lead to high thermos-mechanical stresses between the center tunnel and the surrounding body structure. Novel joining technologies are applied to counter these effects and will be further evaluated in the context of the project. Results regarding component and vehicle testing will be published towards the end of the project.

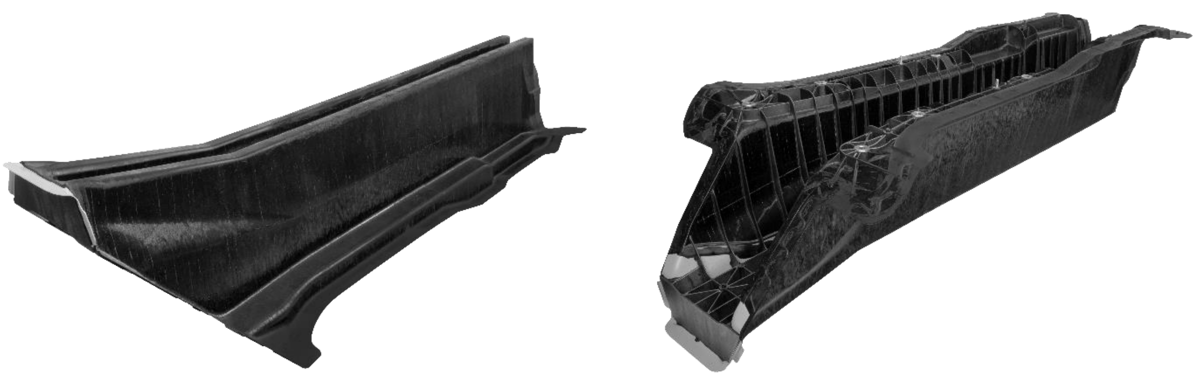

Figure 8: Multi-material center tunnel prototypes manufactured at the OHLF

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