INTEGRATION OF TEXTILE REINFORCEMENTS IN THE INJECTION-MOULDING PROCESS FOR MANUFACTURING AND JOINING THERMOPLASTIC SUPPORT-FRAMES

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ABSTRACT

As part of the research project *TherMobility* - sponsored by the German Federal Ministry for Economic Affairs and Energy (BMWi) - the project partners REHAU, Storck Bicycle and the Institute of Lightweight Engineering and Polymer Technology (ILK) developed an innovative design for thermoplastic support-frame-structures. The frames can be manufactured highly automated in an integrative injection-compression-moulding process with a subsequent joining-process.

By creating a hollow structure from two half shells structural reinforcements made from organic sheets can be integrated load-optimised. Furthermore, functionalised elements can be integrated on the inner side of the structure due to using injection-moulding. This way load-adapted ribbed structures or elements for the assembly- or joining-process can be integrated. In order to obtain a connection of the half shells the warpage and shrinkage behaviour was analysed. In addition to that the joining of the shells with electric resistance welding using carbon fibre tapes was examined.

On that account extensive fundamental studies were conducted to analyse arising challenges when integrating textile reinforcements in the injection moulding process. Thus, a complex testing programme was conducted to investigate the pulling-load, the matrix-exchange and the surface quality of injection-moulded ribbed structures for several material combinations. Especially the design of the connecting structural rib and the manufacturing temperatures show the biggest effect on the connection- and surface-quality.

In a subsequent step the functionalised half shells have to be combined to a complex hollow support-frame. Conventional joining technologies intrinsically create weak areas where the parts are connected. Thus, a resistance welding technology with the use of carbon fibre tapes was developed to join the half shells. First results show the high potential of this technology by creating a material-homogenous connection in the bonding area. In these studies the joining technology is applied on the frame structures of the *TherMobility*-project.

1 INTRODUCTION

Currently, a considerable number of research projects in all of Germany are focused on the integration of continuous-fibre-reinforcements in conventional thermoplastic processing techniques [1-5]. The load-adjusted use of textile reinforcements in injection- or compression-moulding-components makes it possible to meet growing load requirements for future applications, for example in the area of electric mobility. The thermoplastic processing techniques offer a wide range of forms and thereby constitute an ideal method to build functionalised, highly integrative structures. Especially the combination of short- and continuous-fibre-reinforced semi-finished-materials enables the implementation of complex support-frames that are perfectly adjusted to the relevant requirements specification. Figure 1 shows different vehicle classes of the electric mobility with different load-requirements and their dependence to the use of continuous fibres [6].

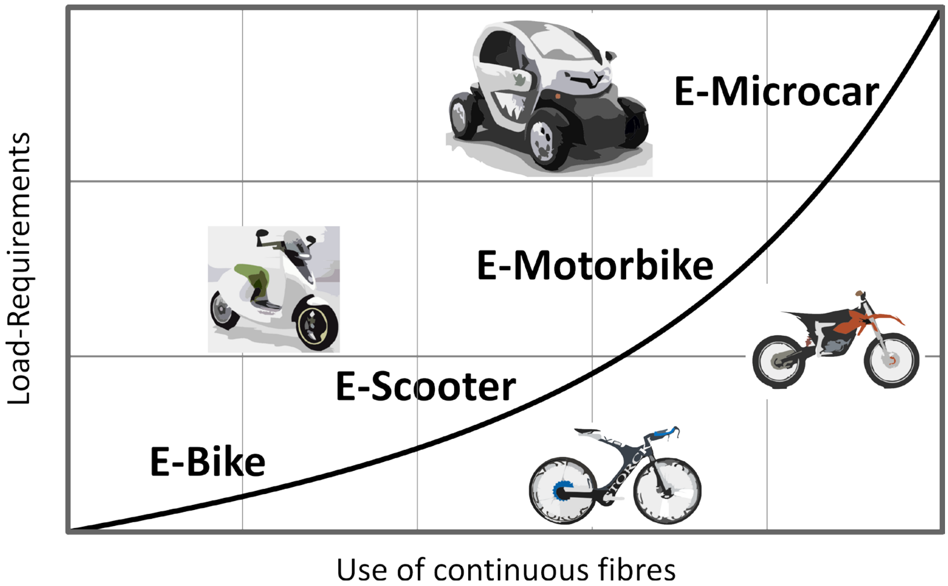

Figure 1: Load-adjusted combinations of textile reinforcements for support-frames of various vehicle classes based on electric mobility

The technological implementation of function-integrative thermoplastic hollow structures in particular, offers a high potential for various applications. This publication presents a process of making textile-reinforced cavernous structures and functionalising them using injection-moulding. The integration of textile reinforcements within the injection-moulding process poses a number of questions regarding handling, mould-design and process parameters. Therefore, extensive simulations and experiments have been carried out in various research projects. This publication presents excerpts of the *TherMobility*-project.

2 CONCEPT OF THERMOPLASTIC COMPOSITE FRAME STRUCTURES

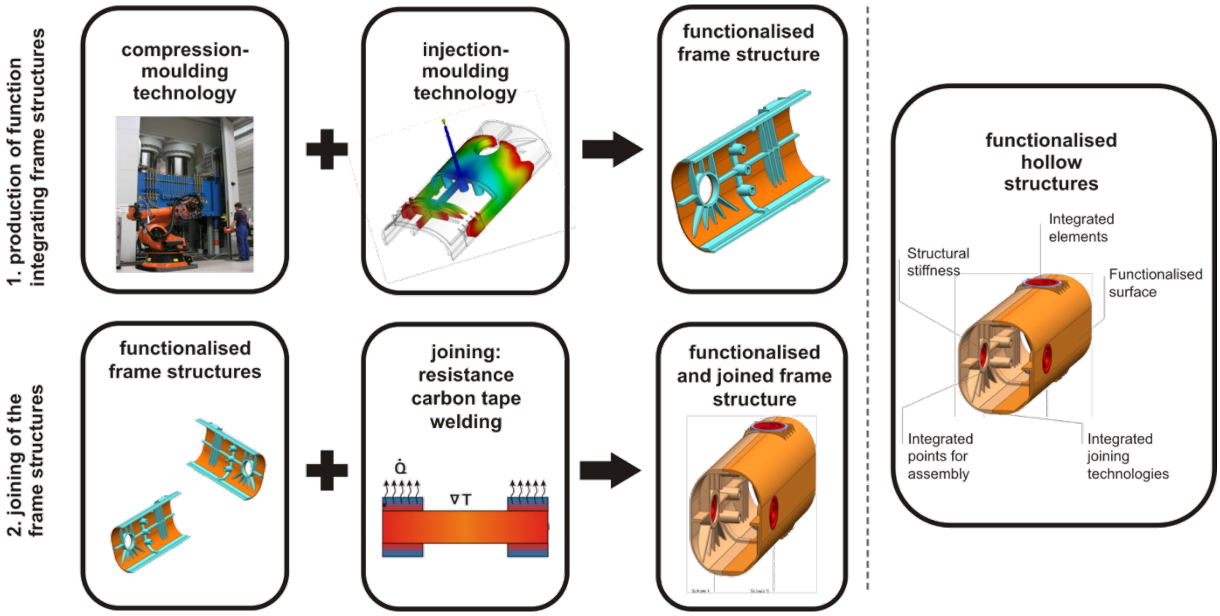

Figure 1: Two-step manufacturing process for functionalised thermoplastic frames

As part of the research project an innovative design for pedelec-frame-structures has been developed. The frames can be manufactured in an integrative compression-/injection-moulding process. By creating a hollow structure out of two half shells, structural reinforcement elements made from organic sheets can be integrated adjusted to the load. Furthermore, the injection-moulding technology makes it possible to integrate functional elements at the frame structure (figure 2) – for example ripped structures on the inside or assembly elements on the outside. Material-homogenous connections between the elements and the matrix of the organic sheets can be realised even with a matrix interchange as shown later in this paper. By using thermoplastic carbon fibre tapes in an innovative resistance welding process the two shells can be joined together to create the final hollow structures as shown in figure 2.

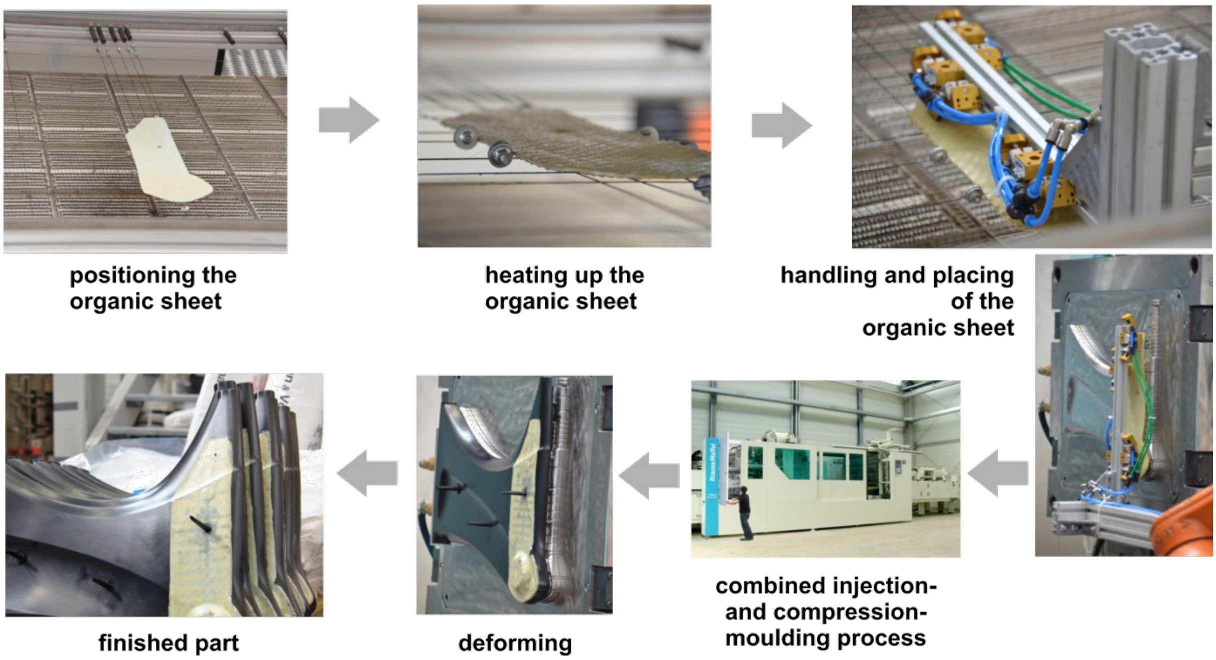

Figure 3: Steps of the manufacturing process

The novel manufacturing processes of the hollow structures made of two functionalised half shells were tested on a minibike-demonstrator-structure. A continuous process chain beginning with the production of function-integrated shell structures up to the joined and painted hollow structure has been investigated and realised in the *TherMobility*-project. In order to keep the production costs low and be able to reproduce the components at a maintaining high quality, a high degree of automation and manufacturing processes suitable for industrial production were considered when this concept was created. The manufacturing process - as seen in figure 3 – begins with the cutting of the semi-finished sheets. The prepared sheets are then brought to a preheating station where they are being warmed up above the melting temperature of the thermoplastic matrix. Following this, they are transferred into the mould by an automated handling system. In the mould the organic sheet is then being formed before the thermoplastic melt will be injected. After deforming the thermoplastic half-shell with an integrated continuous reinforcement is completed.

3 BONDING BEHAVIOUR OF TEXTILE REINFORCEMENTS AND INJECTION-MOULDED RIBS

For the adjustment of the component geometry and the processing parameters, the connectivity of various rib-geometries and the surface defects caused by them on the organic sheet has been tested. Thus an adapted testing-mould has been designed including four different rib geometries. The fitted organic sheets are fixated on the positioning needle on the side of the nozzles and are then heated up on one side by an infrared heating system. When the heating of the organic sheet has finished, the heating panel comes out of the machine, the mould closes and the rib structure is moulded onto the sheet (figure 4).

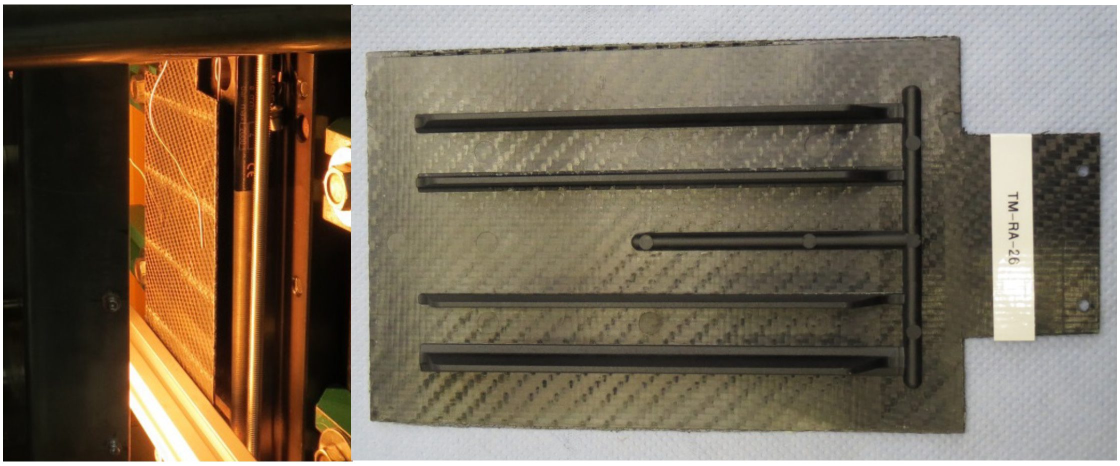

Figure 4: Heating of the organic sheet inside the mould (left); the organic sheet with the injection-moulded ribs (right)

The connectivity between the sheet and the injected-moulded rib was analysed with selected semi-finished products. For the analysis of the connectivity a variety of materials were used and the settings of processing parameters like the temperature of the mould and organic sheets at the start of the injection process were varied. In addition to that the connectivity of glass fibre reinforced injection moulded ribs onto carbon fibre reinforced sheets was tested. The rib geometries include a medium-high, medium-flat, narrow and wide-flat design, as shown in the figures 4 to 9.

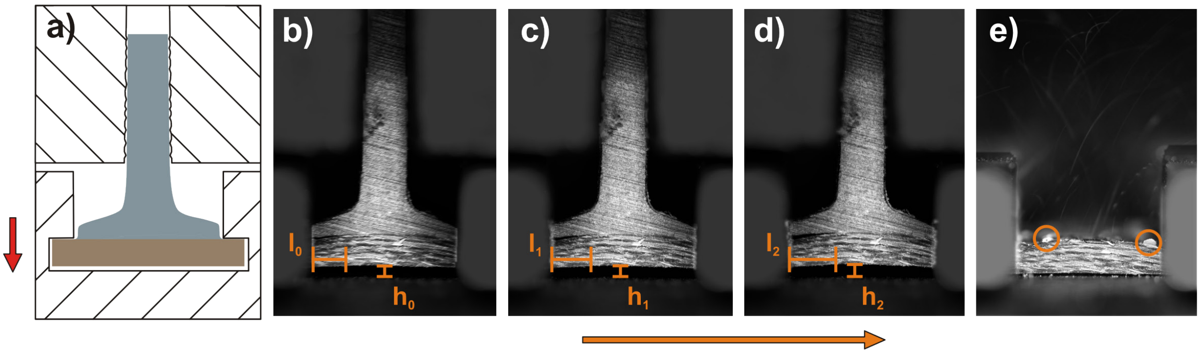

Figure 5: Testing setup (a), applying load onto the specimen (b-d), rib is pulled off (e)

Specimens were cut out of the testing plates in order to evaluate the connectivity on the basis of pull out tests. During the tests the sheet-part was fixated in the base plate of the machine while the ribs were fixated on the other side by means of a gripping device. The testing setup and an exemplary test are shown in figure 5 a). The mode of failure can be seen from b) to d). The rib is peeling of the buckling sheet (h_0 - h_2)and the crack is growing slowly (l_0 - l_2)until the rib abruptly is pulled off. Picture e) in figure 5 shows the fibres from the sheet being ripped off as well as some matrix material from the rib is left on the sheet.

A comparison of the different rib geometries made of carbon fibre reinforced polyamide (PA) is shown in figure 6 while figure 7 shows the effect of the sheet temperature on the pull-out-load. In this case of the narrow rib geometry carbon fibre reinforced polyphenylene sulfide (PPS) is used and the best connection quality is reached with a sheet temperature of 320 °C. A lower sheet temperature of 310 or 300 °C results in a diversification and reduction of the pull-out-load by up to 20 %. Comparing different material combinations for the medium-flat rib the similar performance of the PA-CF and PPS-CF combination can be recognised. In contrast to that the combination of glass fibre reinforced ribs with carbon fibre reinforced sheets leads to a significant lower pull-out strength.

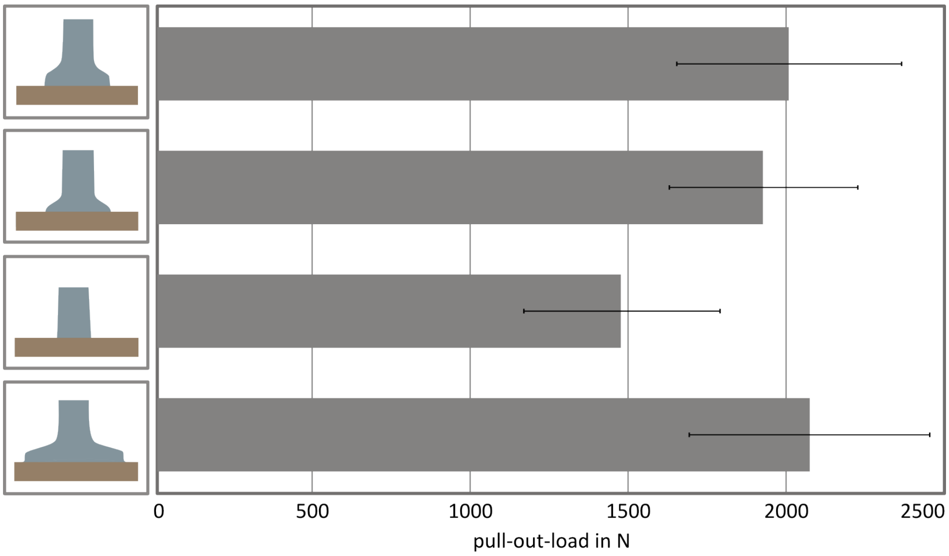

Figure 6: Pull-out-load for different rib geometries (PA-CF)

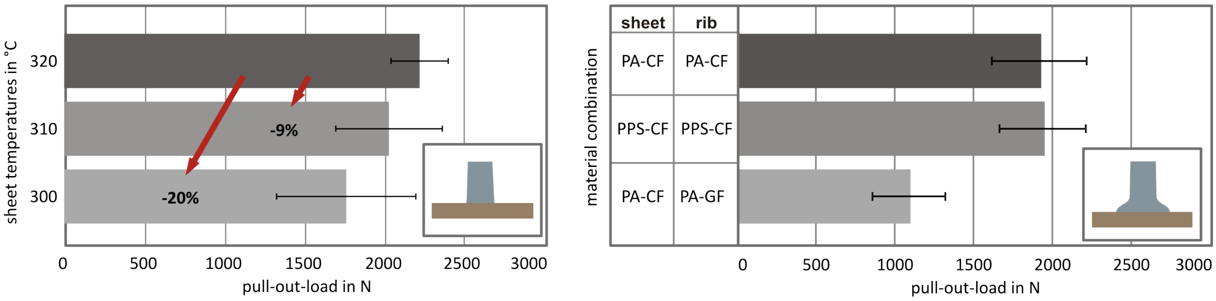

Figure 7: Pull-out-load for different temperatures of the organic sheet for the narrow rib geometry (PPS-CF) (left) and different material combinations for the medium-flat rib (right)

Besides the pull-out-loads, the interaction between the sheet and the rib is to be analysed as well. Therefore, the cross sections of the specimen were made using microscopic analysis (figure 8). Both the matrix exchange from the sheets as well as the bulges of the fibres facing the ribs are interesting in that context. The microscope images show that the bigger the rib connection, the smaller the bulges of the fibres are (figure 8 a-d). Moreover it has been noticed that the combination of particular materials occasionally causes movement of the thermoplastic matrix from the sheet to the rib connection. In contrast to that the combination of glass fibre reinforced ribs on carbon fibre reinforced sheets leads to a thin interface layer in between (figure 8 e-g). This might explain the low pull-out strengths (figure 7, right).

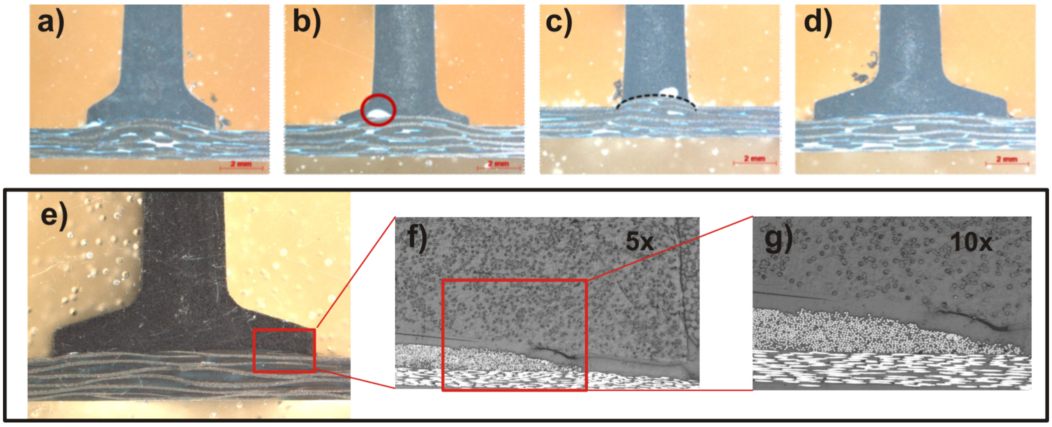

Figure 8: Microscopic images of multiple cross-sections showing diverse rib geometries (a-d) and the PA-CF sheets combined with the PA-GF ribs and the resulting thin interface layer (e-g)

Finally, the rib-connectivity tests were also meant to examine the surface waviness of the various ribs on the opposite side of the organic sheet. A laser profilometer measured the surface topology on the opposite side of the ribs (figure 9). The measurements show that the narrow rib as well as the wide-flat rib leave the smallest waves at the surface. On the other hand, the profile of the other ribs causes distinct waves.

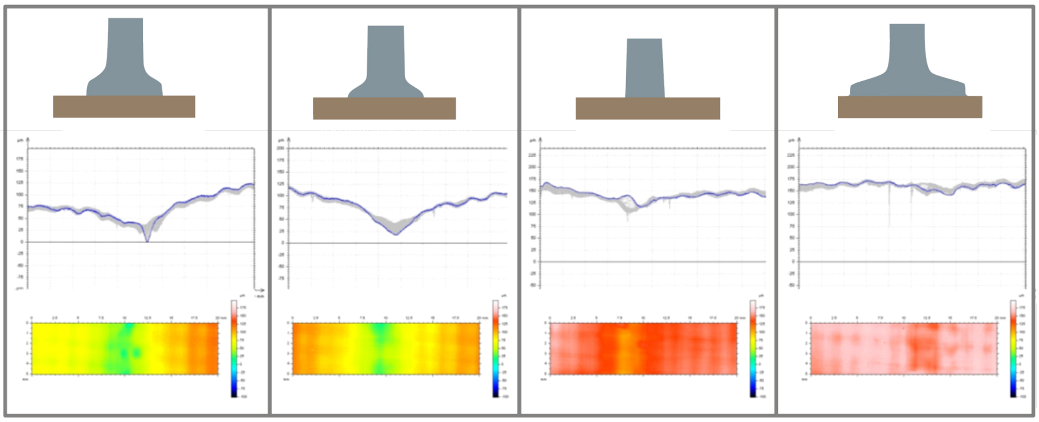

Figure 9: Measured surface defects on the opposite side of the ribs

4 JOINING OF THERMOPLASTIC SHELLS USING RESISTANCE TAPE-WELDING

The principal of the resistance tape-welding is to utilise Joule’s law and use the generated heat from an electrical conductor to locally melt the joining partners. Usually a copper wire is used for this resistance welding technology. Using the carbon fibre tapes as an electrical conductor has great potential due to the short cycle times and the fact that the thermoplastic material of the tapes can be the same as in the joining partners [7].

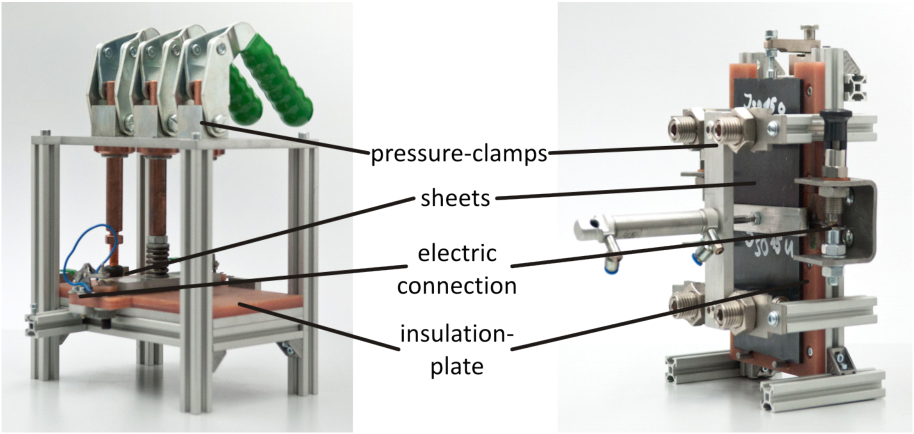

Figure 10: Devices to join thermoplastic sheets with a carbon fibre tape

Figure 10 shows two different joining devices to weld two thermoplastic sheets with a lap joint (left) or a butt joint (right). In between those two sheets a carbon fibre reinforced thermoplastic tape is positioned. After applying electric power to the conductor the thermoplastic melts in the area of the tape. The melted thermoplastic of the sheets and the tape blends together while pressure is applied from the joining device to press the sheets together. After turning off the power, the thermoplastic cools down and the sheets are connected. Advantages of this technology are the material-homogenous connection of the two joining partners, the heat generated directly in the welding zone, the welding elements’ low density and their minimum gain in weight. This is highlighted in figure 11 showing three images with different enlargements of the cross section of the joining area. It can easily be seen that a non-porous and material-homogenous connection can be achieved.

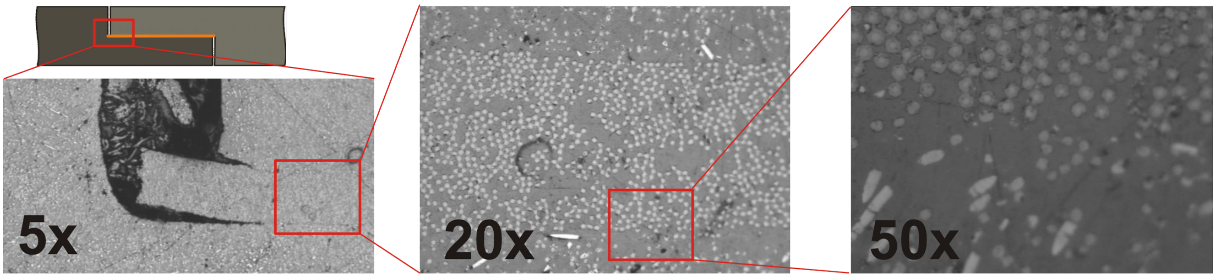

Figure 11: Microscopic images of the joint using carbon fibre tapes for resistance welding

To achieve the best results of the joint the welding parameters as well as the geometry of the welding zone had to be optimised. During the *TherMobility*-project the tape-resistance-welding technology was used to combine the thermoplastic bicycle frames. Therefore a joining device had to be designed that is shown in figure 12 (a). The connection was splitted into four parts resulting in four welding seams (figure 12 b). The biggest challenge was to apply the necessary pressure on the joining area without being able to reach the inside of the frame. Thus, an adjusted rib structure on the inside of the frame was designed to direct the pressure directly to the joining area. The joining device in combination with a circumferential pressure tube ensures the pressurisation of the welding partners to each other (figure 12 c). The final welding time of each seam was around 90 seconds.

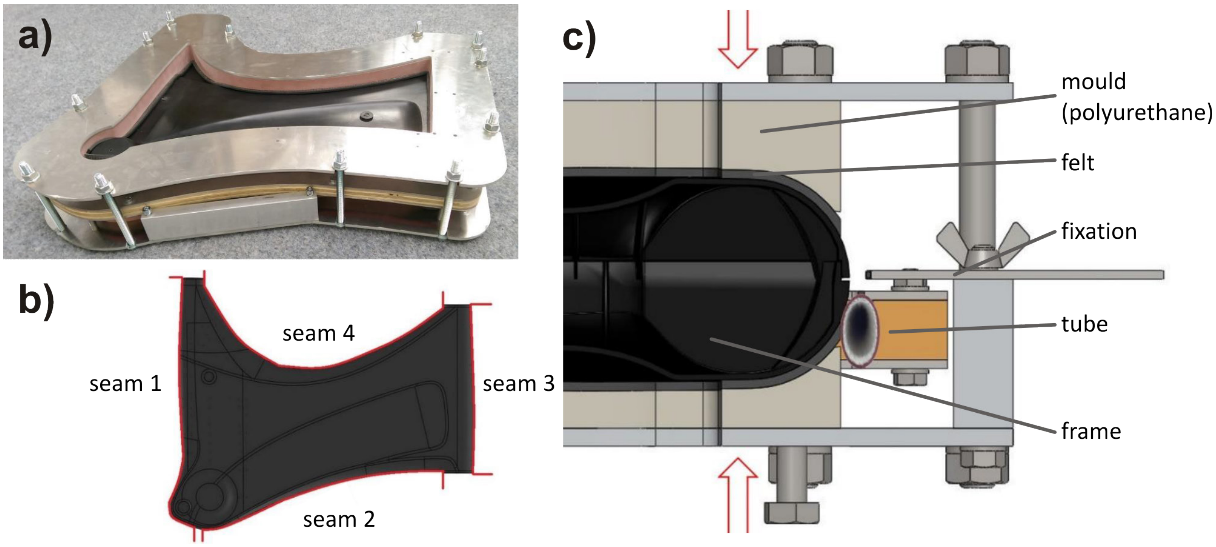

Figure 12: Joining device to combine the minibike frames

5 CONCLUSION AND OUTLOOK

The results show that the design of the rib, the material combination and the processing parameters effect the quality of the structure and the surface. Depending on the requirements of the component recommendations for a suited rib design can be given, based on these studies. In addition to the rib design the rib arrangement can have a severe effect on the structural behaviour of the part or can be useful for additional functions. One of those functions is the stabilisation of the structure during the joining process of the minibike-frame. These results can be easily adapted to complex hybrid structures with the use of organic sheets as shown in the demonstrator of the *TherMobility*-project. These studies described in this publication were one small element of diverse experimental investigations and simulations to develop and design the *TherMobility* minibike demonstrator shown in figure 13.

Figure 13: *TherMobility* minibike demonstrator

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