MANUFACTURING STUDIES FOR 3D HYBRID YARN BASED TEXTILE-REINFORCED COMPOSITE TRAYS

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SUMMARY

Hybrid yarns consisting of thermoplastic filaments and reinforcing glass filaments offer a high potential for highly efficient manufacture technologies for composite structures. The development of an adapted manufacturing technology for thermoplastic 3D shaped textile-reinforced composite trays is presented. In this context a manufacturing concept was developed, the drapability of different textiles made of hybrid yarns was investigated and first prototypes were manufactured using hot pressing technology.

Keywords: hybrid yarn, textile-reinforced composites, thermoplastic, manufacturing, drapability

INTRODUCTION

The use of new hybrid yarns offers broad possibilities for the efficient production of textile-reinforced composite structures [1]. Especially, textile processing of these hybrid yarns allows realising near-net-shape preforms [2]. The homogeneous distribution of the reinforcing glass filaments and the thermoplastic matrix in the fibre cross-section as well as the special adjusted sizing of the glass filaments provides a very good wetting of the whole hybrid yarn during the consolidation process. These characteristics lead to high composite properties and short flow paths during manufacture, which are necessary to achieve short cycle times. Here, the pressing technique is considered to be a predestinated method for middle and high quantity production. Within this work, a manufacturing concept based on hot pressing technology is developed suitable for the production of textile-reinforced thermoplastic composites made of hybrid yarns.

An essential precondition for an efficient production process is the implementation of a quick and material adapted preheating of hybrid yarn preforms. Furthermore, the difficult handling of the preforms at working temperature as well as the high sensitivity to temperature of the hybrid yarns requires special moulding methods.

In the course of the Collaborative Research Centre SFB 639 “Function-integrated multi-material design with textile-reinforced thermoplastics”, at the TU Dresden detailed investigations for close-to-production manufacturing technologies of textile-reinforced thermoplastic composite components are a main focus. Hybrid yarns made from glass fibre and polypropylene are processed to 2D and 3D flat knitted and woven hybrid yarn semi-finished products (Hybrid Yarn Thermoplastic Textiles – HGTT). These preforms are processed to complex shaped structures like a 3D composite tray (see Figure 1).

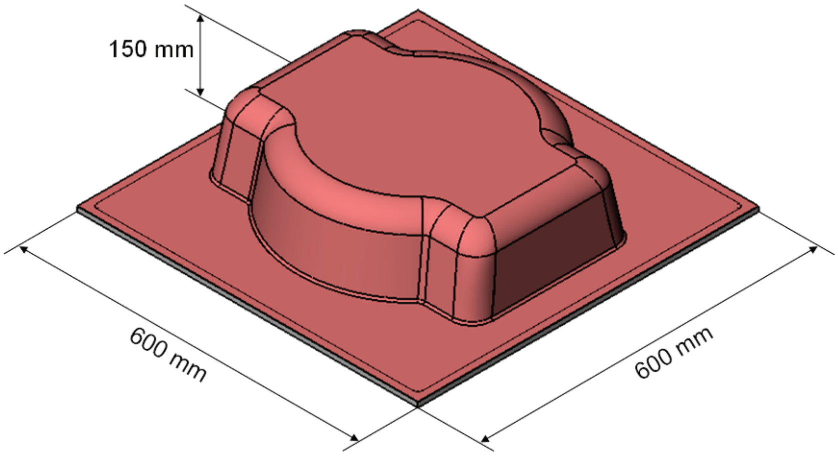

Figure 1: Geometry of the manufactured composite trays

The composite tray has a base area of 600 mm x 600 mm with a cavity height of 150 mm and several different curvatures to investigate the drape behaviour of selected textile preforms and the manufacturing process. A main challenge was the consolidation of all vertical side surfaces.

MANUFACTURING CONCEPT

At present, the manufacture of thermoplastic textile-reinforced lightweight structures is based on processing of consolidated organic sheets using hot pressing technology. The formability of these semi-finished products is significantly influenced by the drape behaviour of the used textiles, the fibre volume fraction of the composite and the melt viscosity of the used thermoplastic matrix material. In contrast to the processing of organic sheets, the high drapability of hybrid yarn based textiles allows the production of complex shaped structures without additional preform cut outs [3]. This novel manufacturing technology needs no preconsolidation, because forming, compression and consolidation are done in one single press process (see Figure 2).

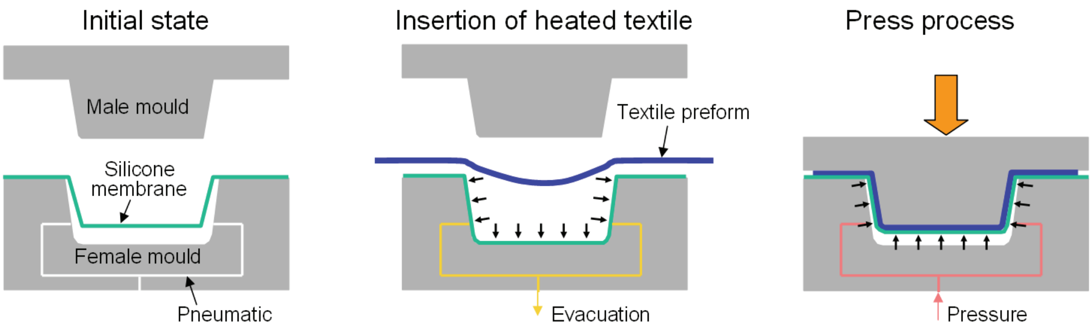

Figure 2: Schematic of the manufacturing concept

The hybrid yarn textiles are heated to process temperature with infrared radiation (compare next chapter and [10]). Subsequently, the heated preform is transferred to the tool. Complex 3D part contours combined with the big compression ratio of the hybrid yarn based textiles require an adapted manufacturing concept to avoid fibre distortions and wrinkles during the press process. Thus, an adapted silicon membrane in the female mould part is used providing a homogenous pressure distribution in vertical mould areas. Finally, the tool is closed and the structure consolidated.

PROCESS PREPARATION AND PRELIMINARY TESTS

For the preparation of the press process, a multifunctional fast-stroke press was equipped with a flexibly adjustable tool (see Figure 3).

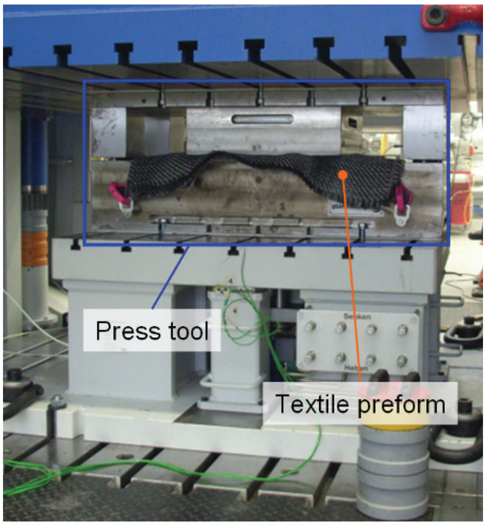

Figure 3: Multifunctional fast-stroke press with installed mould

In order to get a high and uniformly distributed compression of the textile it is necessary to investigate different silicone membranes and its suitability for the process. For this purpose, several tests with different silicone membranes were performed. These silicones include different liquid silicones as well as silicone sheets with different thicknesses (see Figure 4).

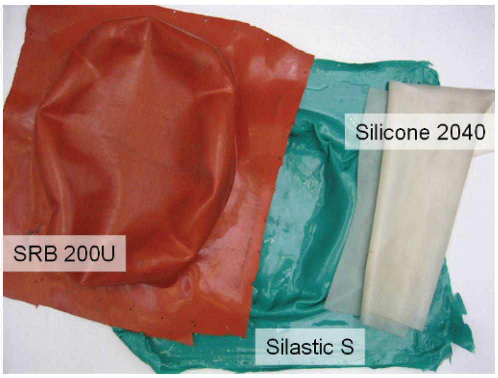

Figure 4: Investigated silicone membranes

A first possibility was to cast the male mould with the liquid silicone to get a shaped and undilated silicone membrane with a constant thickness. For this, the silicone components were mixed and applied onto the contour of the male mould of the tool. To reinforce corners and areas, which are expected to tend to high strain and consequently potential failures, small patches of glass mat were integrated. In contrast to this near-net-shape membrane, silicone sheet material with thicknesses between 1 mm and 5 mm were investigated. This silicone sheets are commercially available and exhibit a homogenous material of constant thickness. Table 1 contains the basic properties of the used silicones.

Table 1: Basic properties of the used silicones

Name	Silastic S	SRB 200U	Silicone 2040
Initial condition	liquid, 2 components	uncured mat	fully cured mat
Shore hardness	approx. 25 [1)]	approx. 60 [2)]	approx. 42 [1)]
Max. use temperature	approx. 250 °C [1)]	approx. 240 °C [1)]	approx. 200 °C [2)]
Elongation	850 % [1)]	700 % [1)]	750% [2)]

[1)] from Material data sheet; [2)] estimated

The investigations show a high influence of the thickness and the Shore hardness of the membrane on the quality of the manufactured trays. With a low Shore hardness of the membrane the thickness of the tray bottom is varying. Silicone membranes with a thickness higher than approx. 3 mm are pressed on the bottom of the female mould and consequently are squeezed into areas with low pressure. Thus, the thermoplastic matrix of the heated fabric is pressed non-uniform, which leads to different thicknesses of the composite (see Fig. 5).

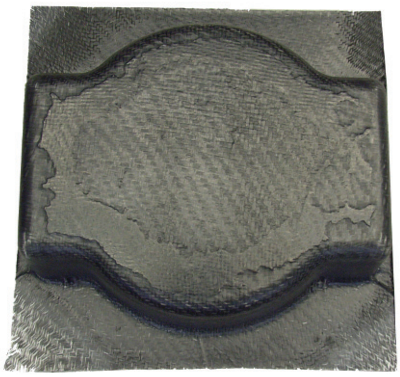

Figure 5: Matrix accumulation and non-uniform thickness at the bottom of the tray

The use of a material with a high Shore hardness leads to composite trays with a constant laminate thickness but the membrane will be worn after a few attempts. This is due to the comparable low failure strain at higher material hardness (compare Table 1). Finally, the silicone material Silastic S was used for further manufacturing studies of composite trays with different fibre orientation of the used hybrid textile preforms.

HEATING OF HYBRID YARN BASED TEXTILES

An essential precondition for an efficient production process is the implementation of a quick and material adapted preheating of hybrid yarn preforms. Detailed analyses of classic manufacturing processes for long fibre reinforced (LFT) or glass fibre-reinforced thermoplastics (GMT) have shown that short cycle times can only be achieved by the physical separation of the heating and moulding process steps [4, 5]. Heating technologies for hybrid yarn textiles are principally based on the three fundamental physical principles of convection (heating of circulating air), thermal conduction (contact heating) as well as thermal radiation (laser, induction, microwave and infrared heating). Previous investigations have shown that heating by means of infrared radiation possesses the highest potential for heating of thermoplastic composites [6, 7]. These systems are characterized by their extremely short start-up times, high output by area and an exact and fast power control. Further to that, by adapting the radiators to the optical properties of the materials it is also possible to achieve a defined energy input into the textile structure [8, 9]. In detail, the performed studies advice an infrared heating using short wave emitters [10]. Figure 6 shows the heat penetration times of a short wave emitter (optimum power for a wavelength between 1000 and 1400 nm) and a carbon emitter (widespread spectrum, optimum power at approximately 2000 nm) for heating a different number of Twintex layers to temperature of 200 °C in the middle of the preform.

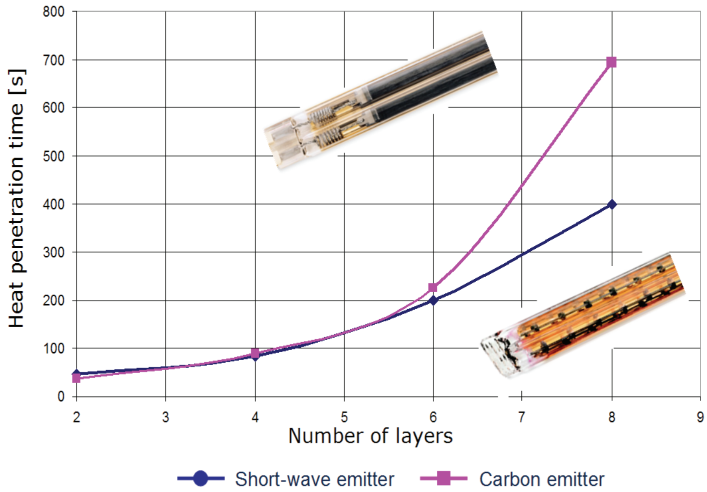

Figure 6: Heat penetration times of short wave and carbon emitters

Up to 4 layers no significant difference between these two emitters is observed. Whereas, for thick walled preforms (>6 layers) the transmissive effect of the short wave infrared radiation can explicitly reduce the heat penetration times.

DRAPABILITY OF 3D KNITTED AND WOVEN TEXTILES

With the woven and knitted fabrics several investigations with regard to the drapability were performed. First tests were done using only the male mould of the tool in combination with vacuum assistance to ensure a good visibility of the fibre placement (see Fig. 7).

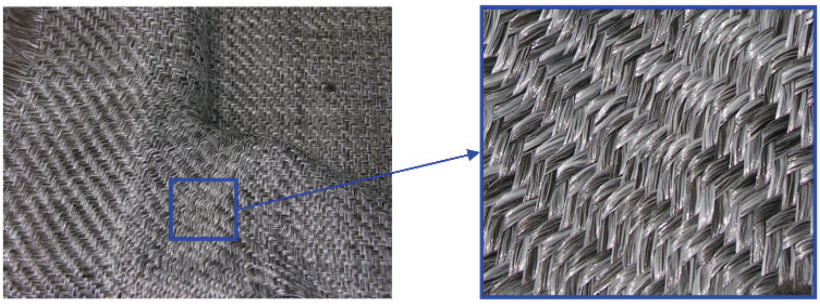

Figure 7: Wrinkles during preliminary investigations (left) and draped textile with adapted feed and high fibre distortions (right)

Figure 7 shows the results of the drape investigations of the woven fabric with a 0°-fibre orientation. Particularly in the corners of the tray are drawn the highest fibre distortions caused by the highest deformation of the fabric. With increasing fibre orientation the fibre distortion slips from the corner to the middle of the side edges.

Within a second step, both parts of the tool were used to drape the textile in shape. Therefor, the composite lay-up was put on the female mould and subsequently the tool was closed (compare Figure 8).

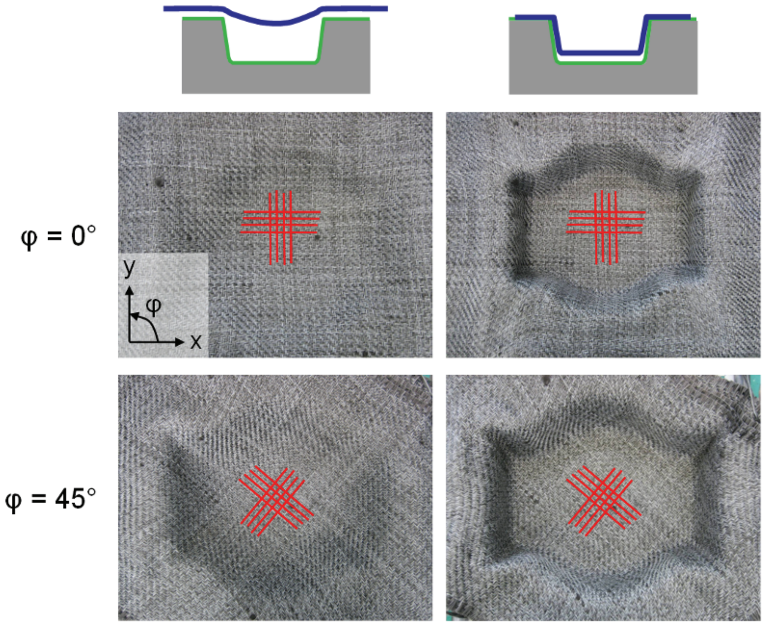

Figure 8: Drape investigations of woven fabric with different fibre orientations

During closure of the tool the composite lay-up was drawn into the cavity and the textile preform was draped into the mould. As shown in Figure 8, different fibre angles lead to different areas of high fibre distortion. With these investigations the results of the first tests were approved. Depending on the used textile and composite lay-up, different areas with high local fibre distortion and a high risk for wrinkles could be identified.

MANUFACTURING STUDIES

Within first manufacturing studies, the developed concept as well as the drapability of the used textiles was tested using the hot pressing technology. For the manufacture of the composite trays a tooling mould was designed. Figure 9 shows the male mould and the female mould with the used silicone membrane.

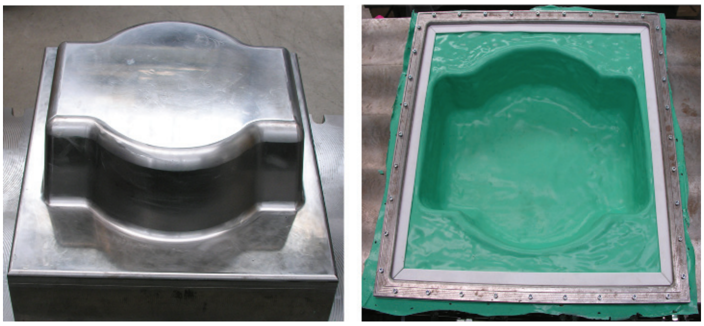

Figure 9: Tool with male and female mould

With this tool several trays with different textiles and composite lay-ups were manufactured. The first trays showed different manufacturing errors in the laminate e.g. fibre distortion or leakages in corners (see Figure 10).

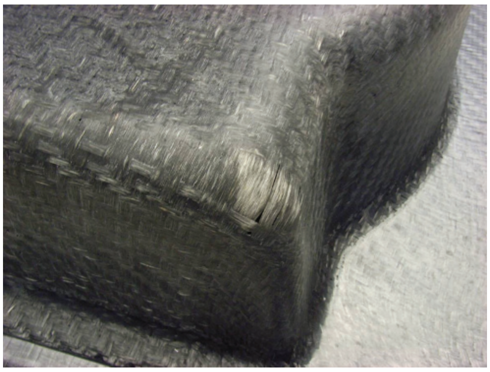

Figure 10: Manufacturing error due to undefined fibre distortion

Caused by low pressure and temperature several unconsolidated parts of the preform appeared in the border area of the tray. With increasing process temperature and pressure the manufactured trays gain in quality (see Fig. 11).

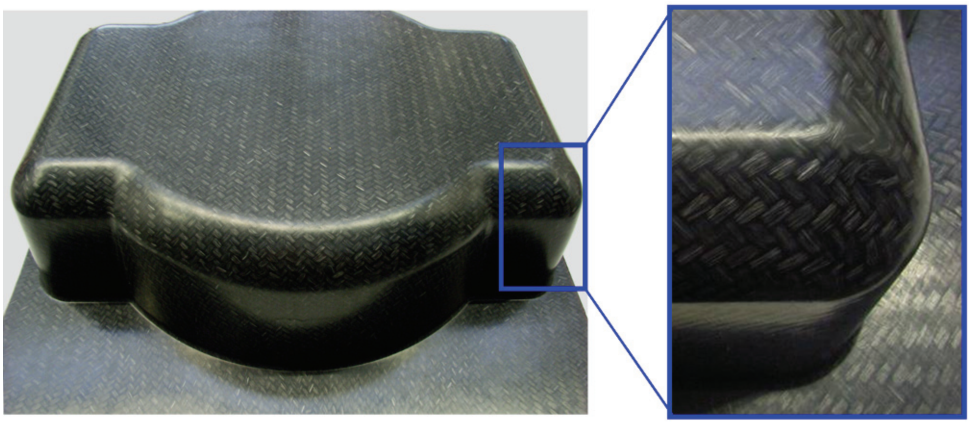

Figure 11: Manufactured 3D tray with well formed corners

The optimization of the process parameters enabled the manufacture of thermoplastic composite trays without any failures. By using the right silicone membrane material the corner and edge areas were formed with high quality. With the verified manufacturing concept several trays with different textile preforms, laminate lay-ups and fibre orientations are manufactured and subsequently used for extensive experimental studies on their static and vibro-acoustic behaviour.

CONCLUSIONS AND OUTLOOK

The rapidly progressing development of new function integrating lightweight structures leads to an increasing use of weight reduced solutions with high performance textile composites. Here hybrid yarns consisting of thermoplastic and reinforcing filaments offer new possibilities for the production of textile-reinforced structures. These textiles can advantageously processed using a press technology.

A new adapted manufacturing technology for thermoplastic 3D shaped textile-reinforced composite trays has been developed. The manufacturing concept is based on the hot pressing technology in combination with a vacuum bag technology to create high composite properties and short flow paths, which are necessary to achieve short cycle times.

In preliminary manufacturing investigations a suitable silicone membrane was identified to consolidate vertical side surfaces of the 3D shaped composite tray. In addition to that a special handling system was designed in combination with a material adapted preheating method based on infrared radiation for the used hybrid yarn textiles. Furthermore, the drapability of woven and knitted fabrics and the influence of different fibre orientations were tested in the mould. For example the woven fabric shows a good drape behaviour especially at a fibre angle of 45°. With an increasing fibre orientation the areas with the highest fibre distortion in the laminate lay-up are shifted from corners to side surfaces.

Finally, several manufacturing studies with different textile preforms and laminate lay-ups were performed. With these studies the high potential of the developed manufacturing technology was shown to produce complex 3D shaped thermoplastic composite structures.

ACKNOWLEDGEMENTS

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