Application of transmission-based solutions for automated manufacturing of thermoplastic hybrid sandwich structures

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Abstract

One important goal of the activities in the Collaborative Research Centre (SFB 639) is to obtain a scientific understanding of open technological questions for the processing of textile-thermoplastic composites. The variety of novel thermoplastic hybrid yarn textiles, like knitted and woven spacer fabrics as well as sewed spacer preforms, requires individually adapted process technologies. Therefore, a special mold system with integrated consolidation kinematics was designed which allows short cycle times in combination with a material adapted process. For the molding of different sandwich cross section contours a modular kinematic construction kit was developed. An automated assembly and demolding process necessitates a defined alignment of the kinematic components to each other using an adapted handling system. Especially the manufacturing of single curved sandwich structures requires innovative solutions which facilitate the orientation of the consolidation tools with a slight drive effort. In this paper a special focus is on the development of a novel comb system based on a scissor mechanism with reduced number of parts.

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1. Introduction

Textile reinforced thermoplastics increase in significance for the manufacturing of lightweight structures. In addition to the good recyclability, effective automated production processes with very short cycle times show the high potential of thermoplastic composites for high series production. Especially thermoplastic hybrid yarns are of great interest to design complex lightweight components [Bernet et al., 2000; Mäder et al., 2007, Mäder et al., 2008]. In the course of the research activities of the SFB 639 at the TU Dresden, novel manufacturing technologies were developed [Cherif et al., 2009, Großmann et al., 2010]. With the use of new textile technologies the potential to produce complex 3D-textiles in automated processes by weaving, knitting or sewing can be shown [Abounaim et al., 2009, Rödel et al., 2010]. This hybrid yarn preforms show big differences compared to conventional thermoplastic semi-finished products, for example thermoplastic organic sheets. The homogenous mixed yarns allow a combined process of consolidation and forming of the part geometry in only one process step. Thereby, low compression pressures are required and hence alternative mold and manufacturing technologies are facilitated [Hufenbach et al., 2010, Hufenbach et al., 2011]. The special focus in the SFB 639 is on the development of reproducible processes for complex 3D-textile preforms using thermoplastic hybrid yarns to manufacture plane and single curved sandwich structures with open cross section geometries. Therefore, a novel modular mold system is one important point of the process and will be described.

2. Manufacturing process and mold technology

The manufacturing process for the thermoplastic sandwich structures is divided into four production steps. First, the spacer textile is pulled over the consolidation kinematics. Subsequently, the thin walled mold box is transferred to the heating station in a fast stroke press. After reaching the process temperature and holding it for a specific period of time, the mold box is transferred to a cooling station using the rail based transport system. Here, the part geometry is formed and the hybrid yarn preform is compressed. Subsequently, the consolidated spacer structure can be automated removed from the mold box in a separated station. The presented process allows the manufacturing of different spacer geometries (plane and single curved) using a novel modular mold system (see Fig. 1).

![Modular metal plate mold for forming of plane (left) and single curved (right) spacer structures](image)

Here, the part geometry is defined by exchangeable contoured metal plates. Special mold bars ensure a homogenous tempering of the top surfaces as well as an evenly transfer of the press forces. These mold bars are tempered with electric heating elements. In the cooling station a tempering medium is used. The coupling...
from plates and mold bars is solved using connection pins, which compensate the heat expansion in longitudinal direction of the mold bars. The single components of the mold system are fixed on a support carrier. This ensures the guidance of the metal plates and the clamping of the mold at the fast stroke press. This novel manufacturing process in combination with the modular mold concept allows the production of different spacer geometries only by changing the contoured metal plates.

3. Consolidation kinematics

Beside this modular mold concept special consolidation kinematics are developed for processing complex spacer textiles. The consolidation kinematics are integrated in a thin walled mold box to enable a fast heating and cooling process. For molding of the inner geometry without wrinkles the functional principle of the core system is based on a wedge kinematic (see Fig. 2). The relative movement of the kinematic components enables the linear power transmission from the vertical movement of the press stamp to the lateral crosspiece areas of the hollow sandwich structure (step 1 and 2, see Fig. 2). The axial clearance of the kinematic components to each other allows the demolding of the consolidated spacer structure. By removal of the demolding wedge angles the circumference of the core system is reduced (step 3, see Fig. 2).

![Fig. 2. Positions of kinematic elements during the manufacturing process](image1)

Compared to conventional silicon hoses, which are common used for molding of fiber reinforced hollow structures, these consolidation kinematics in combination with special polymer liners ensure an exact shaping of the inner contour. The good heat transfer behavior is another noteworthy aspect as well as the significantly longer lifetime of the aluminum kinematic components in comparison to silicon hoses. Equivalent to the modular metal plate mold, the consolidation kinematics have to be adapted to the external geometry of the spacer structure. Therefore, a modular kinematic set is used (see Fig. 3).

![Fig. 3. Variation of consolidation kinematics for molding of different spacer sandwich geometries](image2)
By combination of different profiles (rectangular and trapezoidal), plane structures with non parallel webs as well as single curved sandwich structures can be manufactured.

4. Improvement of a scissor mechanism for handling issues in spacer fabric manufacturing

For an automated assembly and demolding process it is necessary to keep a defined alignment of the kinematic components to each other using an adapted handling system. Especially the manufacturing of single curved sandwich structures requires innovative solutions which facilitate the orientation of the consolidation tools with a slight drive effort. Therefore, in Modler et al., 2011, a serial chain of cranked scissor elements was presented. Thus, pins for handling issues in the manufacturing process of spacer fabrics could be guided. In this system each scissor element carries one pin. This leads to an overall construction with five serial coupled scissor elements (see Fig. 4). But it can be seen, that this coupling is suffering by clearance problems. These cause problems in reproducibility during the assembly and demolding process.

Fig. 4. Scissor mechanism for pin guidance [Modler et al., 2011]
The experience with this handling tool shows that the basic principle works fine. But the robustness of this construction against the mentioned clearance problems has to be increased. The main goal should be a reduction of the number of elements. The underlying idea of this simplification is related to the same principle as presented in Modler et al., 2011. Here a basic slider crank mechanism $ASB$ is used to construct a cranked scissor element. The basis transformation is a rotation by $\pi + \alpha$ of the basis slider-crank-mechanism $ASB$ about joint $S$ (see Fig. 5a) to form the transformed points $A'B'$. By joining $A'SA$ to one element and $BSB'$ similarly to a second element, the result will be a scissor element. By moving $AB$ onto a fixed line $l^0$, $A'B'$ will also move onto a fixed line $l'$. By coupling this transformation with a stretch factor $\lambda$, the resulting points $A''B''$ (see Fig. 5b) will also move on a fixed line. This effect can be used to construct a new guidance mechanism with less scissor elements.

The synthesis of this mechanism by the use of symmetry can be done by applying the following steps (see Fig. 5b):
1. Draw symmetry line $s$
2. Draw guidance lines $p_0, p^1, p^2$ for the pin guidance
3. Place centre joint $S$ on line $s$
4. Construct the basic slider crank mechanism $ASB$ for minimum $\varphi$
5. Draw line $a$ through $AS$ and $b$ through $BS$
6. $\angle \alpha$ defines line $a^1$ and $b^1$
7. Joint $A^1$ is the intersection of $a^1$ and $p^1$
8. Joint $B^1$ is the intersection of $b^1$ and $p^1$
9. $ASA^1$ form the cranked scissor element $2$ which is in $S$ connected to the cranked scissor element $BSB^1$
10. $\angle 2\alpha$ defines line $a^2$ and $b^2$ which leads with $p^2$ to $A^2$ and $B^2$
11. $A^1$ extends scissor the element $ASA^1$ to $ASA^1A^2$ and $B^2$ the element $BSB^1$ to $BSB^1B^2$

Fig. 5. Cranked scissor elements: a) construction bases on the rotation of slider crank ASB by $\pi + \alpha$

b) extended scissor element by a rotation and stretching of the slider crank ASB
In the case of the pin guidance problem the cranked scissor element guides the pins on the lines \( p^1 \) and \( p^2 \). For the guidance line \( p^3 \) the mirror image of \( A^2 A^1 S B^1 B^2 \) (see Fig. 5b) by \( P^2 \) is used (see Fig. 6). The new structure enables the movement of these pins using only one central scissor element. Therefore 5 scissor elements are replaced by one with the overall reduction of 8 links.

Fig. 6. Linear actuated pin-guidance mechanism with one central scissor element; extended position (left); retracted position (right)

5. Wedge angle alignment

A very important issue in the manufacturing process of spacer structures using consolidation kinematics described in section 3 is the guidance of the wedge angle profiles. The demolding of the consolidated spacer sandwich is coupled with a separation of the wedge angles and the assembled consolidation tool. Therefore two handling tools are necessary:

- One tool for the alignment of the shape profiles of the consolidation kinematic and
- One tool for the alignment of the wedge angles.

The kinematic input for the wedge angle alignment can be provided by a scissor mechanism. Here, the joints of the scissor mechanisms are used to design a cam mechanism as seen in Fig. 7. The tool is coupled in joint \( A \). The lever rotation depends on the cam profile and the roller distance \( s = |B - A| \).
The cam profile can be obtained by the motion design of the task. The distance $s$, the angle $\varphi$ and the starting position defined by $B_1-A_1$ define the cam center-point-curve:

$$c = s \cdot e^{\varphi(s)}.$$  \hspace{1cm} (1)

The according transfer function $\varphi(s)$ (see Fig. 5) is the result of the motion task. This function clearly shows the two different tasks:

1. The dwell motion for the tool guidance between the wedge angles and
2. The ramp for the rotation in reference to $A$ to adjust the position of the wedge angles.

The cam profile is defined by the center-point-curve $c$ and the off-set $r$, given by the roller diameter $d$ (see Fig. 8).
6. Conclusion

The automated manufacturing of spacer structures using a press process with various temperatures requires adapted tools and handling concepts. Due to the use of consolidation kinematics in combination with thin walled mold boxes an appropriate quality of the forming of the open cross section geometry can be guaranteed. The requirements of the handling systems are very high particularly for the manufacturing of single curved spacer structures. For conventional technologies, this can just be realized with a high number of drive mechanisms. By using a scissor kinematic the guidance of the kinematic elements during the insertion and demolding process steps can be implemented with one driven unit. To improve the robustness of the handling systems, a concept for the adjustment of the scissor kinematic was presented in this paper. Hence, the number of parts was significantly reduced and consequently a simplification of the system was achieved. Using the example of the wedge angle guidance an innovative approach was presented. Here, in combination with the scissor kinematic, a defined movement of the forming elements by the use of an adapted cam profile was obtained.

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