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Process design and modelling methods for automated handling and draping strategies for composite components

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ABSTRACT

Fibre-reinforced-thermoplastics (FRT) have excellent weight-specific properties compared to conventional engineering materials. However, a wider dissemination of this technology into existing plant technologies is restrained by the low degree of automation. Complex FRT component geometries pose special challenges to gripper design and handling strategies in automated preform processes regarding limp material behaviour and fast cooling time. The preform quality is influenced by the component geometry, reinforcing fabric, and preform process. This paper presents the development of an automated handling and draping strategy, which is validated by finite-element-analysis and experimental testing to meet the requirements of large-scale preforming processes for complex geometries.
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1. Introduction

The demand for weight-saving products has increased the importance of fibre reinforced plastics. Particularly in automotive applications, the weight-saving aspect has aroused great interest. Because of their short processing time, good storage properties and better recyclability, fibre-reinforced thermoplastics are advantageous [1]. Besides long fibre-reinforced thermoplastics and glass mat reinforced thermoplastics, the so-called organo-sheet, which comes along as a continuous fibre reinforced woven fabric, provides best mechanical properties. However, the manufacturing of organo-sheet must take place above thermoplastic melting temperature. Above melting temperature, the organo-sheet changes from a rigid to a limp and therefore unstable state. Limp material properties represent a major challenge for handling in a fully automated manufacturing process. Therefore, quite complex gripping systems based on needle grippers, suction grippers and clamp grippers have been developed and were successfully used in many areas of composite handling [2,3]. There are also end-effectors with preform functionalities to enable larger forming degrees to avoid fibre failures and wrinkles in the formed part [3–5]. For example, Reinhart and Ehinger [4] introduced a barrel-shaped preforming end-effector. This end-effector works with vacuum and has an elastic drape element. This gripper provides good shape stability, but has poor properties when it comes to temperature insulation. Dröder et al. [5] presented a similar concept for form-flexible handling devices with a cushion filled with granules. The foldable gripper kinematic in Ref. [6] can adapt to either concave or convex curved surfaces. Nevertheless, the concepts presented are limited to less complexly shaped moulds and less time-sensitive manufacturing processes.

Due to the short processing time and poor malleability of organo-sheet, suitable manufacturing processes and systems for large or complex components are missing. This paper presents a holistic process design based on a new two-stage handling process to support the forming of organo-sheets for complex shell geometries (Fig. 1). In addition to a heatable robot gripper, the handling system consists of an innovative modular active clamping system (ACS), which is used for preforming of organo-sheets in short processing times. Drape simulations are used to estimate process parameters to determine the design of the ACS, i.e. the hardware configuration and the control inputs. The functionality of the ACS itself and the simulation supported design process is demonstrated with the use case of a down-scaled battery tray.

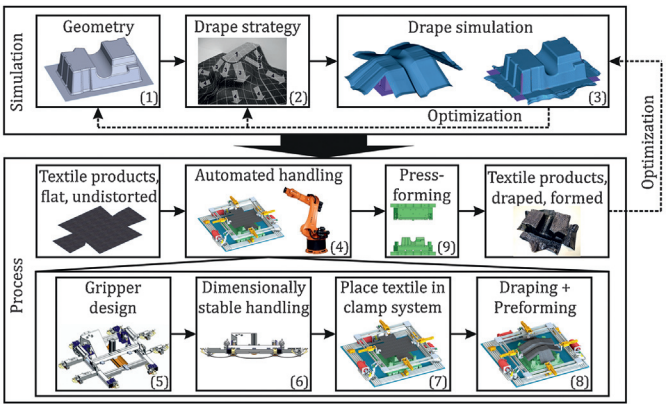

Fig. 1. Simulation and process design for complex manufacturing of organo-sheets in automotive applications.

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2. Process design for automated thermoplastic preforming

In a joint project with associated industrial partners, who are active in the field of thermoplastic manufacturing, we developed a forming process to manufacture complex FRT products, a battery tray for a plug-in-hybrid automobile serves as use-case. The forming process involves folding a cross-shaped blank into the shell and forming of a tunnel- and step geometry. The organo-sheet is fed to the forming tool by springs clamped centrally to all four sides [7]. Throughout the forming process, the edges of the cross-cut are fluidly joined (butt-joint) [8]. To overcome the difficult manual handling, the aforementioned gripper and ACS were developed for handling and preforming of the molten and limp fabric into the forming tool. In general, preforming describes the application of flat textile products on curved surfaces. Hence, the preforming process is related to an assembly process of limb textiles onto 3D moulds. The blank assembly is carried out by means of a joining operation (plugging on) and a handling operation (gripping). Finally, the fabric is formed under high pressure. Particularly gripping and handling of the limp organo-sheet presents a challenge for automation, as the material softens to be able to be draped when heated to melting temperature. During draping, woven fabrics deform in plane by means of the mechanisms: fibre stretching, fibre straightening, fibre wrinkling, and fabric shearing [1]. Due to the draping of flat rectangular woven fabrics, fabric shearing is the dominant deformation type. The maximum shearing of a fabric depends on its weave type and is expressed as the locking angle α_T. This is the smallest possible angle between the warp and weft yarns. A shearing of woven fabrics is therefore necessary to deform it. However, exceeding α_T would weaken the mechanical properties, complicate forming and thus reduce the product quality.

In order to overcome these difficulties, we have developed a process that takes the desired geometry and the size of the used fabric into account. Fig. 1 shows the modelling approach and the associated handling process presented in this paper. The drapability of technical textiles strongly depends on the desired geometry. Therefore, geometric design (1) is at the beginning of the process development. In a subsequent step, different draping strategies (2) have to be derived from the initial geometry. These draping strategies can now be used for the process modelling in a finite element analysis (3). On the one hand, the simulation results can be used to better adapt the geometry or drape strategies to the used composite material (Simulation), and, on the other hand, to provide the corresponding parameters, such as clamping forces as an input for the manufacturing process.

The manufacturing process steps (4)–(9), with the corresponding experimental infrastructure (see Fig. 2) begins with the pickup of the flat, trimmed organo-sheet off an infra-red radiator. A robot gripper consisting of 12 heatable needle grippers provides good shape stability and temperature insulation for the temperature-elevated organo-sheet (5) and (6). Eight needle grippers are arranged along the edges of the organo-sheet and four needle grippers are arranged in the middle to maintain the initial form. The robot-gripper places the limp organo-sheet into the ACS (7) (see also Fig. 3). The ACS operates like a blank holder with clamping units, which is liftable and swivels, to produce the preform (8).

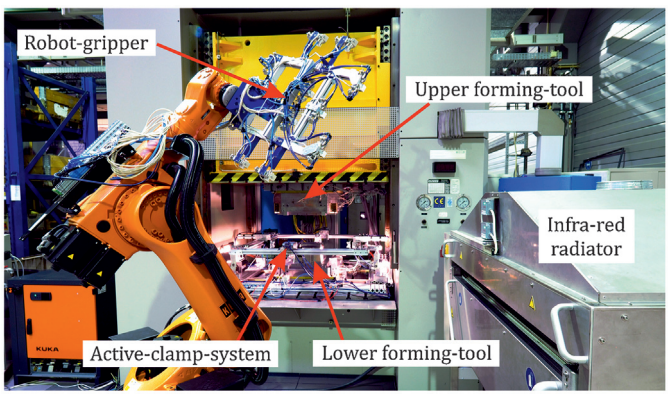

Fig. 2. Robot cell with equipped gripper, forming tools, active-clamp-system and infra-red radiator.

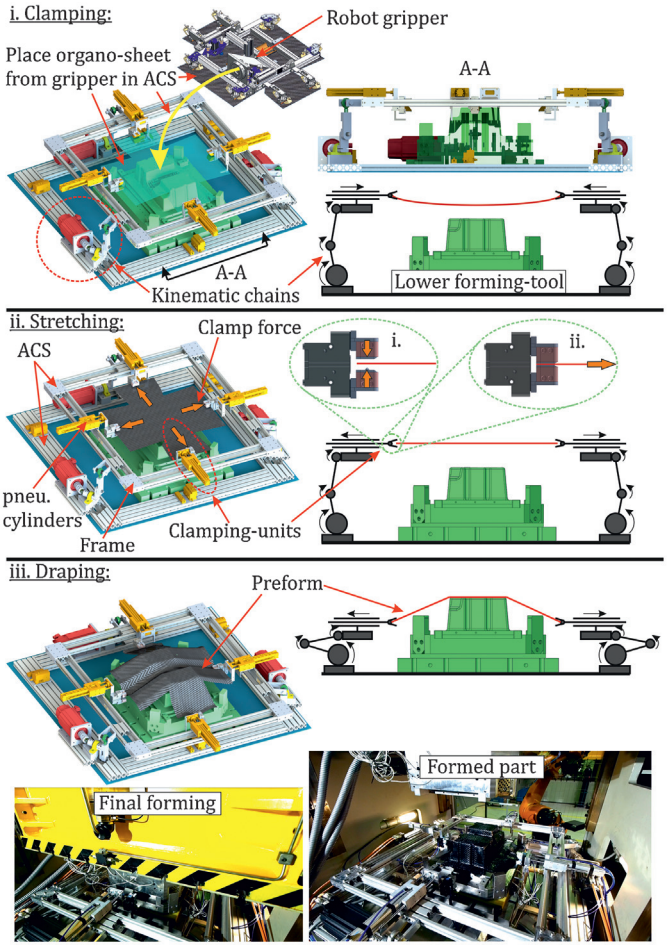

Fig. 3. ACS with four clamping units, the three preforming steps and the final part with the use case geometry of a battery tray.

3. Active-clamp-system for thermoplastic preforming

Behrens et al. [8] have proved in manual experiments that applying local restraining forces can induce local fibre shear and yarn straightening to draw surplus material out of a wrinkling area, such as the tunnel geometry. Based on these experiences we developed the ACS to apply controlled forces to the fabric via the ACS during the press forming process. By controlling the forces in amplitude and direction, we can actively influence the shearing of the fabric in order to prevent wrinkle formation, which will finally result in an improved product quality. However, the process is particularly time crucial, since the organo-sheet thickness is just 1 mm, which favours rapid cooling. To achieve a short processing time, the ACS drapes the organo-sheet directly on the lower forming tool. For that reason, the ACS with its clamping units surrounds the lower forming tool (Figs. 2 and 3).

Fig. 3 shows the ACS, which is based on a parallel kinematic structure. The ACS consists of three kinematic chains offering three degree of freedom (DOF). It is possible to lower the entire platform with the clamping units by the tools height (in this case: 160 mm) and to tilt around the longitudinal and transverse axis by $\pm 5°$. The ACS, in this configuration, has four clamping units to fix the organo-sheet in a rectangular frame. One on each side, corresponding to the experiments shown in Ref. [7]. We yield this configuration, i.e. the position and orientation of the clamping units and the applicable tensile forces to the fabric, via the drape

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