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Manufacturing process for automated preforming of complex, double-curved components based on the diaphragm method

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Abstract

At the German Aerospace Center (DLR), Center for Lightweight Production Technology (ZLP) Augsburg automation solutions for manufacturing processes of extensive fiber composite components are developed. One challenge in this context is the automated preforming process of complex, double-curved geometries. Here, dry fiber cut pieces are transferred from a flat to a three-dimensional state. In order to fix the single layers of the stacking, the fiber package is being compacted and the powder binder system is activated using thermal energy. In addition, double-curved component geometries inhere particularly high requirements on the preforming process, since the fiber materials must not only be deformed, but also be draped.

With the state of the art, the production of double-curved components can only be carried out manually, due to the high process complexity. Therefore scientists at the ZLP Augsburg developed an integrated preform manufacturing process, beginning at single cut piece handling till supply of the finished preform. Focus was set on a diaphragm based preforming mechanism that can be directly controlled regarding its forming behavior on the preform to ensure an adequate preforming of the carbon fiber semi-finished product.

This paper focuses the challenges of automated production processes for complex, double-curved component geometries and presents one automation solution developed at ZLP Augsburg.

Keywords: automation; carbon fiber reinforced plastics; composite preforming; manufacturing process; draping; pick & place; gripping,

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1. Introduction

Over the past few decades Carbon Fiber Reinforced Plastics (CFRP) gained a significant dominance in the aerospace and automotive industries. To meet the increasing requirements related to a high volume production it is necessary to make improvements related to the efficient manufacturing, production and automation techniques.

This paper presents an automated preform production concept for an Aero Flap Support (AFS). The geometry of this component has an elongated, double-curved shape, which tapers in the rear section and thus causes strong curvatures (see **Fig. 1**). These double-curved surfaces and curvatures pose a particular challenge during preforming with dry fiber materials.

Fig. 1: Male AFS Tooling used for the development of an automated preforming process

2. State of the art

The production of preforms with carbon fiber semi-finished products, like fiber fabrics or non-crimp fabrics (NCF) in aircraft industry is predominantly carried out by hand. This means that a fiber cut-piece with a predefined geometry is picked up by at least one expert and placed on a tooling geometry. For this purpose, laser projections are usually used to facilitate the positioning of the cut-piece. After deposition of the material, it is draped into the desired shape. In order to perform a draping of the material, forces are applied manually to the material by pulling or pressing. The layers are fixed with the help of a binder fleece, which is located between the layers and activated by an industrial iron. To ensure a sufficient compression, appropriate contour of the preform shape and radii, intermediate compaction steps are performed. For this reason a compaction step is necessary after manual preforming a small number of layers . This can be done for example by heating the stacking in an oven for several hours under applied vacuum pressure To ensure an appropriate compaction of the stacking and to reduce the risk of fiber wrinkling an intermediate compaction after each 3^{rd} – 4^{th} ply at a fabric aerial weight of 550g/m² is recommended.

The manual process with its high effort for draping and compaction bears a lot of problems with respect to a production in high cadences. Some problems are namely non value creating work like buildup of a vacuum bagging or long intermediate heating cycles. But also the waste generated through one time useable vacuum bagging excipients is an issue. On the other hand, the repetition accuracy at manual draping process steps depends on the experience and mood of the expert. As a result, the mechanical properties vary due to manufacturing deviations. .

These disadvantages can be reduced using automation techniques that increase the reliability and speed of the process, thus reducing production costs. Monotonous and non-ergonomic work is a predestinated environment for robotic automation processes. Furthermore, the automation of the intermediate compaction is essential in order to achieve a production rate that allows high quantity manufacturing.

3. Preliminary experiments

For the development of an automated process detailed knowledge of the manual process is required. For this purpose manual draping tests were performed. To gain experience about the process flow, the manual handling of the fiber materials and the draping strategies were the aim of the manual draping tests. The latter is a central point in the implementation of an automated preforming process since the draping strategy dictates in which direction and sequence forces have to be introduced into the fiber material in order to achieve a reliable and wrinkle-free draping. In order to perform the tests, a double-curved male tooling and three different NCF materials: 0/90, +45/-45 and -45/+45 were used.

3.1 Draping simulation

One challenge at the test preparation was the creation of the cut-piece geometry. Therefor draping simulation techniques were used to define the flattening geometry. A Kinematic Mapping Approach, implemented in ANSYS® Composite PrepPost (ACP), was used for this purpose. It considers the fabric as an idealized network of fibers with crossover points acting as fixed pin-jointed nodes. As input parameters, this method requires only the the tooling geometry, the initial draping point, and the draping direction at that point. The initial draping point is therefore of particular importance since its position on the tooling surface has a significant effect on the draping result. Depending on the initial draping point or seed point (SP) differences in the maximum deformation of the ply by induced shear stress are one result. A good simulation result is defined by a draping process that shows as low shear values and therefor small deviations according to the predefined fiber orientations. For the performed experiments four possible initial draping points on the tooling top surface were defined. Therefor the parameters for an optimal draping process were identified. The initial draping points are shown in Fig. 2. [1]

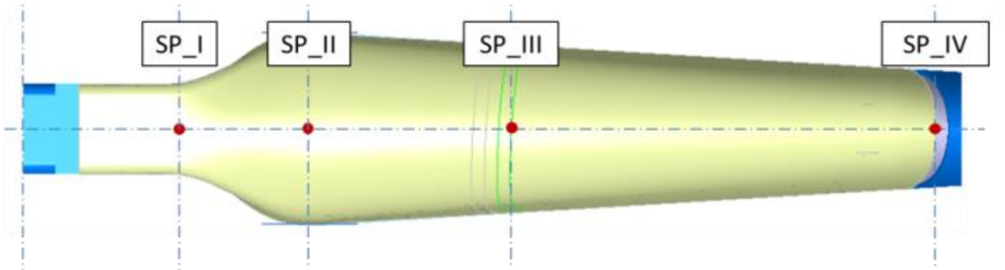


Fig. 2: Predefinition of four possible initial draping points on the top of the tooling

The simulation has shown that the outer points SP_1 and SP_IV have a poor draping result with higher shearing effects than SP_II and SP_III. Reasons therefor were the long draping distances. Result of different shear values depending on the tooling seed point are shown in Fig. 3. SP_III is located in the center of the tooling which minimizes the draping distances to the edges and therefore the shearing effect. Nevertheless, the simulation showed that the shearing increases in the taper area between SP_I and SP_II because of high curvatures, especially with increasing distance to the initial draping point. The point SP_II located at the widest point of the tooling, directly next to the problematic taper region. This eliminates a great amount of shear stress in the taper region, but is accompanied by an increase of shear stress in the left tooling area. Since the taper region is more difficult to drape due to the small area and high curvatures, SP_II was determined as initial draping point for cut piece or flattening generation.

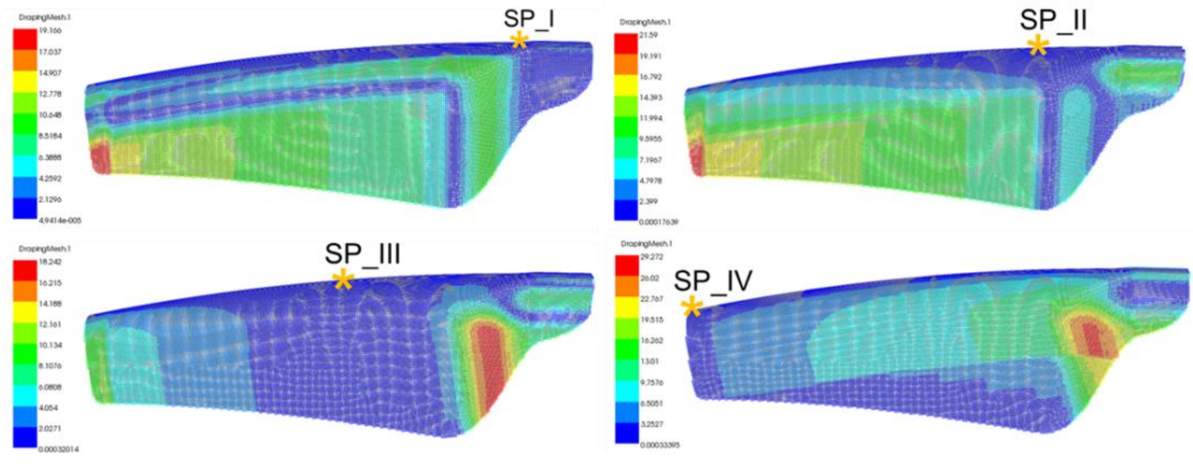


Fig. 3: Shearing effects based in location of initial draping point [1]

3.2 Manual draping test performance

For the draping tests the cut-pieces were deposited on the tooling according its predefined seed point position. To facilitate the depositing process, NCF`s were positioned flat on and between rigid boards, which are lowered beside the male tooling. During lowering of the rigid boards the NCF ply has the possibility to slide between the boards and perform a preforming and prepositioning on the tooling surface.This way, it can be ensured that the cut-piece is placed symmetrically and evenly on the tooling without application of high shear forces to the cut-piece. At the positioning of the single plies a first ply-tooling contact was ensured at the defined seed point position. In this way a placement of the deposited ply on the tooling could be realized without applying undesired forces.

In the second step, a glass-fiber reinforced plastic caul plate was placed on top of the tooling and pressed tight. This procedure was intended to ensure a pre-fixation and pre-compaction of the ply on top of the tooling. In the next step, the fiber material was manually draped and handling steps were documented. Performance of manual draping tests lead to a definition of a draping strategy for the each of the NCF`s.

The results of the tests have shown that all three materials can be draped manually. The different NCF´s showed small differences for best draping strategies at the present tooling geometry. **Fig. 4** shows the sequence of the draping strategy for a [0°/90°] NCF. One could see that the main direction of force application is from top to bottom. In the region with high double curvature on the right hand side next to the seed-point a slight horizontal component was necessary to perform an adequate draping. This movement was intended to transport exceeding material away from the curvature area, apply fiber shear and avoid wrinkling. The effect can also be seen in the left area of the initial draping point, but to a lower extent. The automated process must therefore be able to apply a comparable fabric shear and draping movement from top to bottom, but also from the initial point to the right- and left hand side.

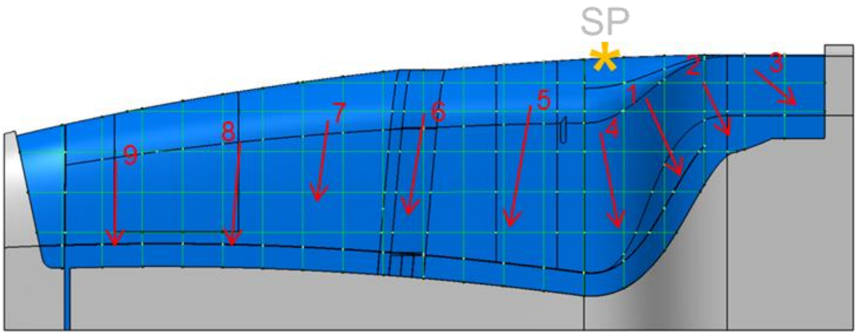


Fig. 4: Principle of the manual draping process, as an illustration of the force application steps

4. Approach for automated preforming

Based on the results and experience gained in the manual tests, a concept for automated preforming of the AFS contour was developed. It can be subdivided into the following four process steps, which are shown in the following figure (**Fig. 5**) and furthermore described.

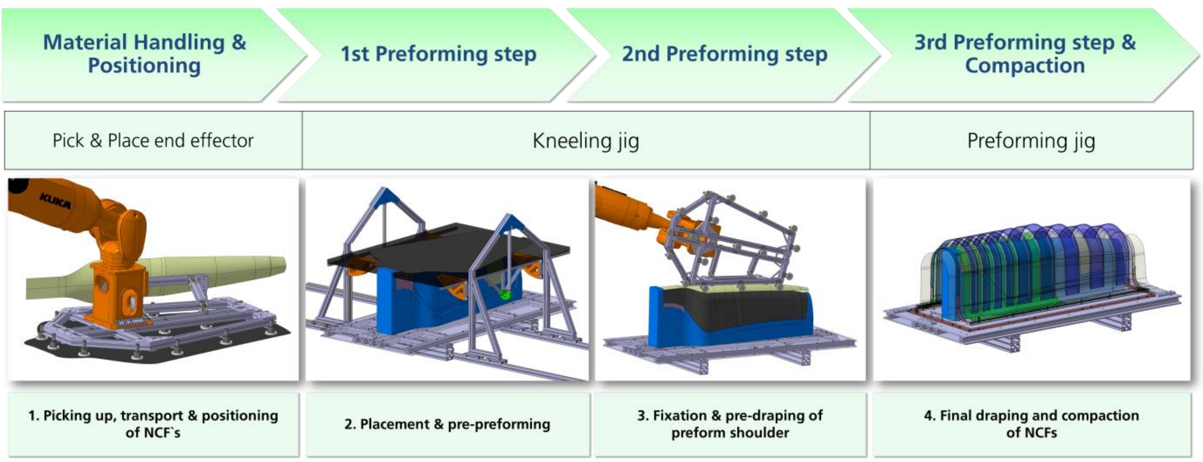
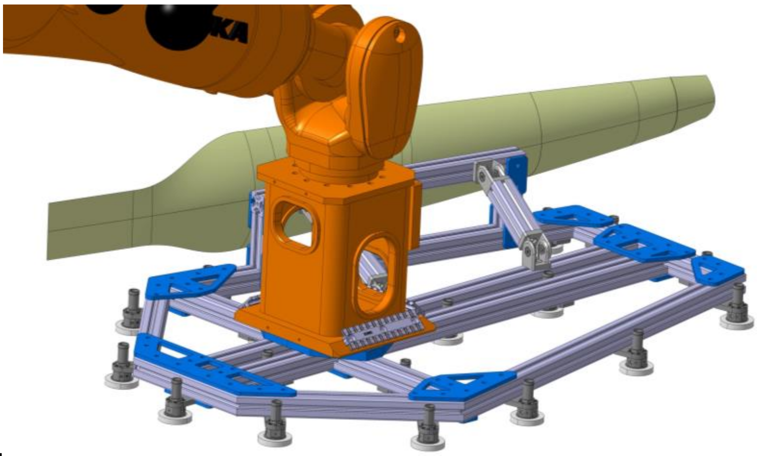


Fig. 5: Process sequence in four steps

4.1 Picking, transport and positioning

The aim at picking, transport and positioning was to keep this process step as simple as possible. The end-effector is based on an aluminum profile structure which corresponds to the edge geometry of the cut-pieces. A number of 16 Schmalz® coanda grippers ensure a reliable handling of the materials (see Fig. 6).

The coanda grippers are characterized by simple operation and a high gripping force for air-permeable textile materials. They are operated by compressed air, which makes them cost-effective and flexible. The gripping units are able to generate a high volume flow which enables a reliable handling of permeable textile semi-finished products. [2]



[3]

Fig. 6: Transport and deposition end-effector [3]

4.2 Positioning on the tooling

The principle of flat deposition was proven in manual preliminary tests and will also be applied in the automation concept. Equivalent to the lower rigid boards, upper rigid boards are placed on top of the lower ones and the cut-piece. This means a sandwiching of the NCF and provides the possibility to perform a controlled deposition process. The rigid boards in the automation concept can be lowered using linear floating bearings. At lowering this surface-fiber sandwich is guided as close as possible to the tooling surface, so that the fiber material already approaches its final geometry when it is deposited. The clamping and lowering method was tested during a manual draping test series and performs a good predefinition of the NCF in the shape of the tooling contour (see **Fig. 7**). In order to achieve a uniform and controlled lowering, pneumatic cylinders are attached. Lowering speed can be adjusted using a throttle valve. Further horizontal floating bearings enable the rigid boards to be switched besides the tooling.

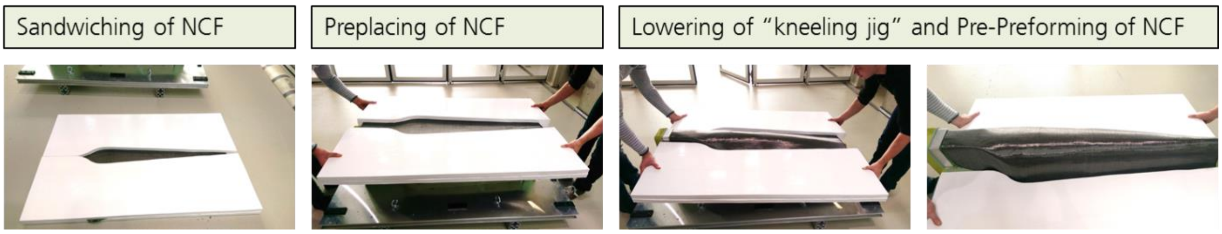


Fig. 7: Preliminary test of the deposition of cut-pieces with the clamping method

4.3 Fixation and precompaciton using a caul plate

The handling end-effector is based on the principle of the reversible gripper, which enables several functions to be combined in one system. In this case, the caul plate is attached laterally to the end-effector structure (see Fig. 8). It is planned that the caul plate fixes the cut-piece during the lowering of the depositioning surfaces. For this purpose, the handling end-effector will rotate so that the caul plate is able to apply force to the upper region of the preform. On the one hand this is necessary to fix the cut-piece on the tooling to prevent it from slipping sideways. On the other hand it is necessary to apply a pre-compaction of the NCF in the upper preform area.

This process requires a rolling movement of the end-effector on top of the tooling.

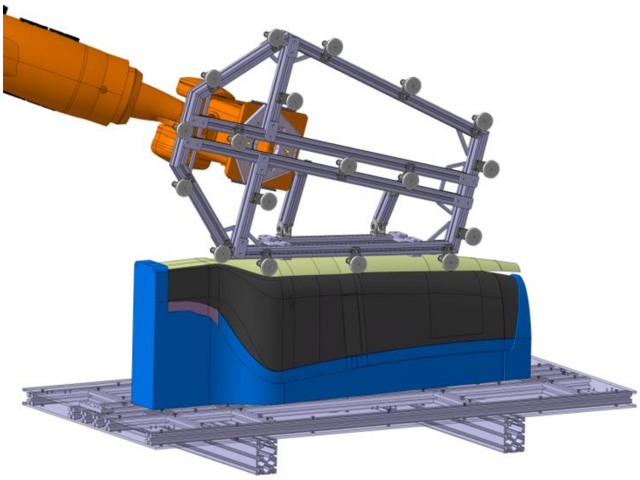


Fig. 8: Pre-fixation und compaction of the preform using a caul plate

4.4 Draping and compaction unit

In order to realize the draping and compaction automatically, a concept of a controllable preform unit was developed to drape the dry cut-pieces into the three-dimensional shape of the tooling contour and to perform a compaction step with binder activation.

The controllable preform unit consists of several individual components (see **Fig. 9**). This includes a housing (1), which is enclosed on one side by a flexible diaphragm (2). At the inside of the housing an inner control contour (3) with a comparable outline like the tooling geometry is fixed. A heating device (4) enables a later activation of the binder system. . The active vacuum effectors (5) can be controlled sequentially by shut-off valves (7). An air inlet (8) and vacuum fitting (9) enable faster process velocities.

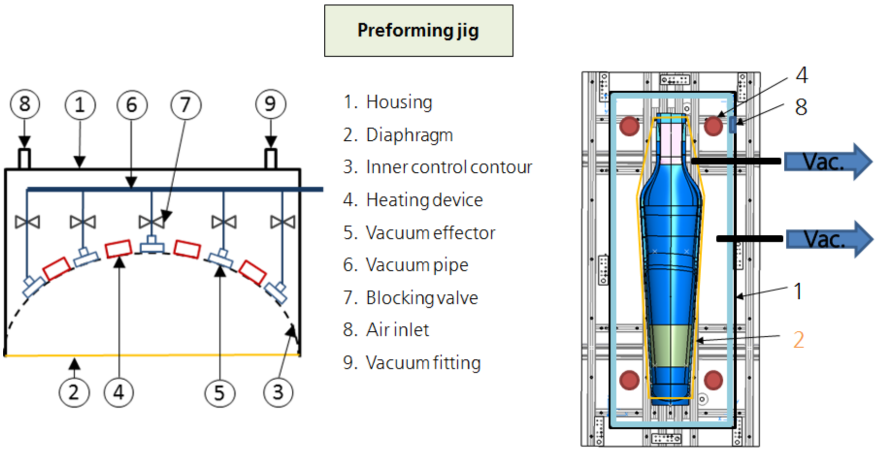


Fig. 9: Design of the compacting unit [3]

A possible process flow using the draping and compaction unit (preforming device) is described below and is illustrated in stepwise (see **Fig. 10**):

The textile cut-piece is deposited manually or automatically on an evacuatable tooling (1). The preforming device (3) is placed above the cut-piece (2). By evacuating the housing (4), the diaphragm deforms elastically and attaches itself to the internal control contour by the help of the integrated vacuum surfaces. The cavity created this way enables the preforming unit to be moved over the textile cut-piece as well as over the contour of the tooling (5). Subsequently, a vacuum (6) is applied to each of the active vacuum surfaces, whereby the diaphragm is hold sucked into the inner side of the control contour. The diaphragm is released from the active vacuum surfaces by removing or reducing the vacuum of each vacuum cell (7). A ventilation opening on the housing (8) allows fast pressure adjustment.

The diaphragm is released sequentially due to the sequential switch ability of the active vacuum surfaces via shut-off valves (9). Subsequent evacuation of the cavity between the controllable preforming device leads to a targeted, sequential preforming of the textile fiber cut-piece (10). In this case, the draping of the textile can be controlled by a specific arrangement of the active vacuum surfaces and the controllability of the surfaces. Process step (11) shows the complete removal of the vacuum at the active vacuum surfaces, whereby the diaphragm contacts the contour of the tooling completely and deforms the textile cut-piece by applying pressure on it.

A subsequent heating step (12) using the heating device ensures that the preform is fixed in the desired contour. After a heating cycle has been completed, the vacuum between tooling and diaphragm is detached. A new evacuation of the enclosure places the diaphragm against the internal control contour and the controllable preforming device can be removed (13). The preform can then be removed or further cut-piece layers formed over it.

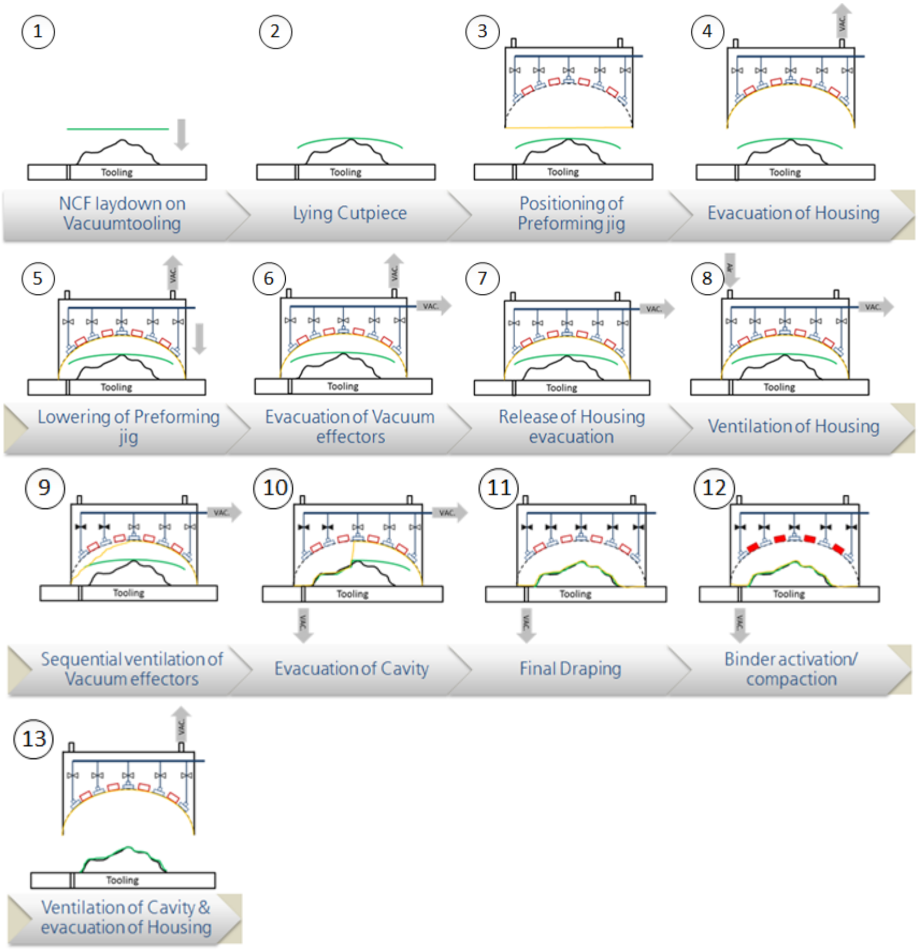


Fig. 10: Sequence of the automated drape and compacting process [3]

5. Conclusion

The preliminary tests have shown that automation of the preforming of such a component can be implemented with reasonable effort. For this purpose, the ZLP Augsburg has developed a process concept that is oriented to the challenges and boundary conditions of the process. The aim of the automated process is to demonstrate a solution for reliably and cost-effectively performing of double curved components.

In the current phase of the project, the test vehicle will be assembled. With its help, tests are carried out to validate the automation concept and identify the need for optimization. The aim of the project described here is to lay a foundation stone for a technology that enables the automated production of structural fiber composite components with complex geometries in large quantities.

Acknowledgements

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