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FIXATION WITH RTM6 MAKES PREFORMING FOR DRY FIBER PLACEMENT MORE ECONOMICAL AND AVOIDS INFLUENCE OF ADDITIONAL EXTERNAL MATERIAL

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ABSTRACT

Infusion process begins with preforming, where multiple CF layers are formed into three-dimensional shape and are fixed between fibre and mould or in-between the different fibre layers. Manual fixing process with magnet is time-consuming non-reproducible step, which requires additional carrier material and higher manufacturing tolerances. For automated fixing [1],[2] the most time-consuming and cost-ineffective process is binder application onto CF. The influence of the binder's compatibility with the resin to be infiltrated and the effect of added amount of binder on mechanical properties of cured component must also be taken into account [3]. Clear evidence of not completely dissolved binder could be observed in cured component [4]. This paper introduces a new automated fixing method, which applies the adhesive force of RTM6 resin. Due to subsequent infiltration with the same resin no indication of previously applied matrix and mechanical influences could be determined [5]. First, parameter study has been conducted for identification of holding force and quantity of resin according to layer number and position. Approximately 0,094 g/m² resin is required for first layer to hold 8 subsequently applied layers. Thereafter, robot based end-effector is developed to distribute the resin and investigated theoretically and practically on 4m diameter Pressure-Bulkhead.

1. INTRODUCTION

The manufacturing of a large carbon fibre component (CFRP) in the aerospace industry requires many manual process steps. This reduces reproducibility and requires the subsequent improvements. The complex and manual production processes associated with the CFRP materials highly increase the production cost & production time. Therefore an automatic and an economical production process is required. The aim of DLR (Deutsches Zentrum für Luft- und Raumfahrt) research center, Augsburg is to reduce the production cost of the CFRP components through the development of an automatic production process and simultaneously to increase the productivity & the quality of production [6]. Figure 1 shows the out-of-autoclave vacuum infusion process chain as well as details of two of its sub-processes. The main process begins with *"process preparation"*, which consists of cleaning of the component and application of the release agent in order to detach the cured component from the tool. A part of the manual *"Handling and preforming"* process is already developed and automated at DLR [6]. In this process an automated "pick and place end-effector" picks up the 2D carbon fibres, drapes them into the desired 3D geometry. The Fixation of the draped carbon fibres cut pieces onto mould succeeds still manually by using a magnet or thermoplastic a binder. Both of these fixing methods are time-consuming and cost-ineffective processes [1], [2]. Furthermore, the influence of the binder's compatibility with the resin (RTM6) to be infiltrated and the effect of added amount of binder on mechanical properties of cured component must also be taken into account [3].

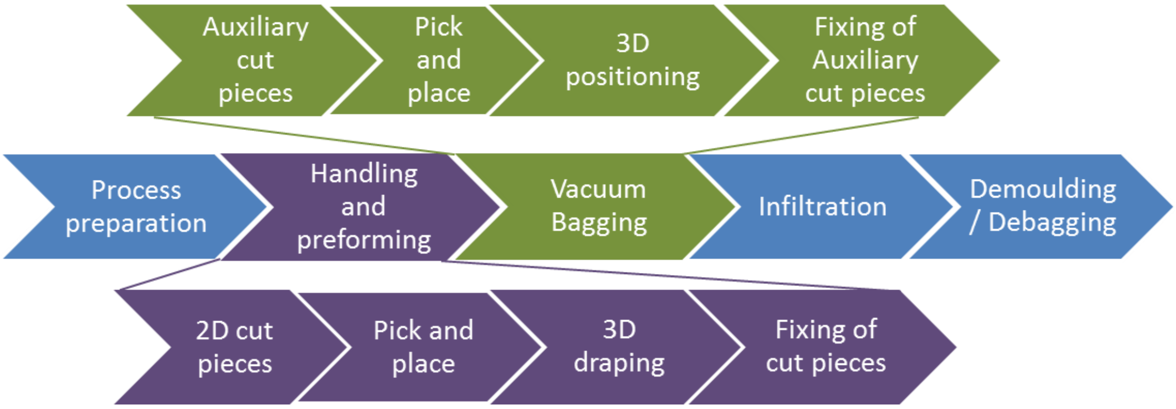


Figure 1: Vacuum infusion production process of CFRP

The conventional *"vacuum bagging"* process step (see in figure 1 the green block) of CFRP manufacturing line involves also a high amount of manual work. Therefore, in the recent years DLR ZLP (Center for lightweight production technology) has developed a new automated vacuum bagging process [10], which again involves an automated handling of 2D packages of auxiliary cut pieces and positioning them onto 3D mould. Like the 2D dry carbon fibres, also, these auxiliary packages need to be fixed onto the mould automatically. Therefore, the main focus of this work was the development of a new automated fixation method, which is applicable for both sub-processes *("Handling and preforming" and Vacuum bagging")*. After *"vacuum bagging"* process *"infiltration"* and *"demoulding"* are performed manually.

2. EXPERIMENTATION

2.1 Selection of fixing method

The selection of the method took place in the master thesis [4], in which first a concept analysis and then an experimental investigation were carried out. For this purpose, a cost-utility analysis was performed with the help of the established evaluation criterias. The physical and process relevance evaluation criteria were holding force, influence of the fixation method on components quality, automation, reproducibility, flexibility and process time. The first three criteria were most decisive. Also the criteria like process conditions for the compliance with aviation regulations were taken into account.

A plenty of fixing methods are existing. These can be categorised into 3 groups: 1) Friction joining 2) Cohesive joining 3) Positive fit-joining [7]. A part of the cost-utility analysis was performed based on the knowledge from research and industry. As a result the cohesive joining method with the following materials (Binder, RTM6, Adhesive tapes and spray adhesives) were selected for the experimental determination of the static friction coefficient, maximum holding force, holding time and component quality after infiltration. The holding force of the fixation depends on the forces acting on the preform package. A preform package consists of a number of carbon dry fibre layers with a different shapes and material properties. To prevent the downhill motion of the preform package (see Figure 2), the friction force $\mathbf{F_f}$ must be equal to or higher than the weight force $\mathbf{F_G}$. The Experiments were performed with a 556 g/m² carbon fibre layer.

Binder (Polyamid-Vlies PA 1541, Producer Spunfab Ltd) :
The binder material can be applied on a dry semi-finished CF ply for fixing it with another material. It consists of either the thin processed thermoplastic threads or the thermoplastic powder. An activation (heating) of the thermoplastic material over its melting temperature of

100 °C affects its fusion. During the cooling process, the material solidifies again, and thereby joins with the other material.

Matrix (RTM6):
The adhesive behaviour of RTM6 at room temperature (approx. 20 °C) can be used for cohesive bonding between two materials. After applying a controlled quantity of the resin material on some specific spots of a CF ply, pressure needs to be applied to fix this ply with the component or other plies. Moreover, an infiltration is carried out with the same resin material; therefore, the fixing spots on the cured component become invisible.

Adhesive tapes:
The product Saerfix EP of the company Saertex GmbH & Co. KG is used as adhesive tape. This special adhesive material is based on epoxy, which is chemically integrated into the matrix during the hardening process. The adhesive material (12 g/m²) is provided with a carrier foil on both sides and can be therefore be easily cut into the desired sizes. Compared to spraying with the additional adhesive less time is required here and a reproducible distribution of adhesive is ensured.

Adhesive Spray:
The Aerofix 2 spray adhesive from R&G Faserverbundwerkstoffe GmbH was also investigated. This contact adhesive was specially developed for the fixation of carbon and glass tissue and is available in 500 ml cans (R&G 2017).

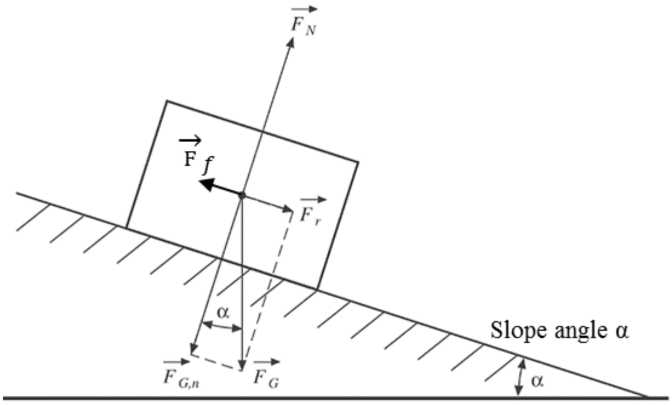


Figure 2: Forces acting on a body on an inclined plane

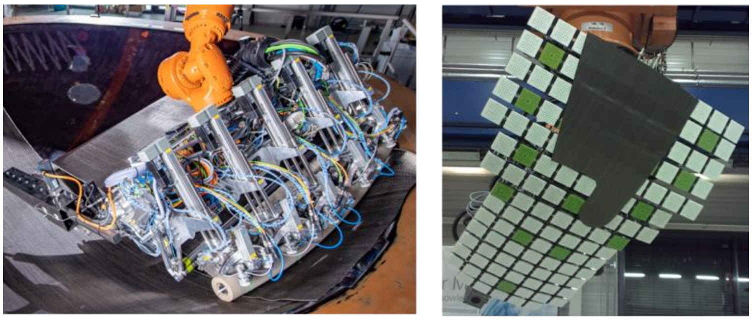
Conclusions:
The details of the experimental setup and the results are published in the master thesis [4]. In the entire test series, the Aerofix 2 spray adhesive achieved by far the highest value for fixing force, but also the highest standard deviation, as uniform dosing of the adhesive medium was difficult to achieve. Therefore, this method was not selected for further experiments. In addition, the spray adhesive is still not approved to use for aerospace components. The determined value of the friction coefficient and the maximum holding force was higher for Saerfix EP than for the Binder and the RTM6, whereby the standard deviation of the binder was higher than for Saerfix EP. The lowest standard deviation was achieved with RTM6 method. It should also be noted that in the experimental tests, although the same fixing amount were used for all methods, the achieved coated fixation area was less for RTM 6 compare to other methods. Because, after the applied pressure the distributed RTM 6 as

drops could not flow uniformly over the fixation area due to capillary effect. Therefore, the forces determined with RTM6 method were very low.

Although ascertained holding force for Saerfix EP material was the highest, the RTM6 fixing method was the best choice for vacuum infusion process. Because a compatibility of a high amount of Saerfix EP material with aerospace approved infiltration matrix (RTM6) material cannot be guaranteed. During the test, it was observed that the adhesion between the adhesive medium and the carrier film of Saerfix EP is better than between the adhesive medium and CFRP surface provided with release agent. Therefore, the Saerfix EP or binder must first be applied to the ply and then pressed onto the bottom layer. This may include additional preparing process for ply and can increase the fixing cost. Also draping of the ply with pre-applied Saerfix EP/ binder material on the multiple curved surfaces is limited due to material stiffness. Clear evidence of not completely dissolved binder as well as Saerfix EP could be observed in cured component [4]. Moreover the application of binder and Saerfix EP material on auxiliary package is difficult. In the case of RTM6, due to the subsequent infiltration with the same resin, fixing points on the cured component cannot be distinguished. Moreover no additional material is required, as the required quantity of RTM6 for fixing process is reduced from the total quantity of RTM6 for infiltration process so that the material cost can be saved directly. Regarding the fixing process time, which may influence the manufacturing cost is determined along with the other fixing parameters like quantity and processing temperature of RTM6 in the next section. The RTM6 method is also applicable without any limitation for auxiliary package.

2.2 Determination of fixing parameter

The aim of the study was to determine the influencing parameters for the RTM6 method under a production condition. Therefore, a double-curved pressure bulkhead with a diameter of approx. 4 m was selected as the target component. As a part of the project “Protec NSR” 3 different grippers (see in Figure **3**: Modular End-effector, Snake End-effector and Endless End-effector) were applied to build a Preform according to CPD design (with the different dimensions of CF-layers) on the pressure bulkhead.

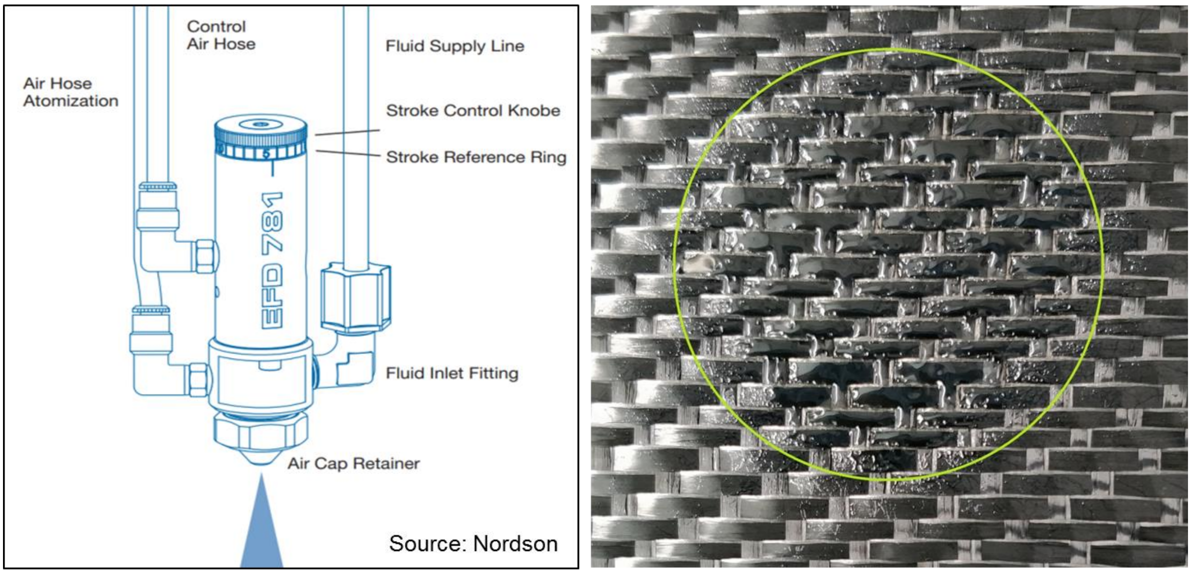


(a) Endless End-effector (b) Modular End-effector

(c) Snake End-effector

Figure 3: Gripper systems developed at DLR ZLP

Taking these CF-layers as boundary conditions, distribution and required total quantity of the RTM6 were determined for fixing CF-Layers in the master thesis [8]. Furthermore, the CF-layers should not slide until completion of the infusion process. In order to avoid the capillary effect and to increase the fixing force a thin layer of resin was made with spray nozzle (see Figure 4).



(a) Spray Nozzle (b) Sprayed RTM6

Figure 4: Spray nozzle and thin layer of RTM6

It is necessary to apply enough pressure on CF-layers after draping to increase the fixing force. Variation of the force applied (on the ply) has an effect on the fixing force [8]. Further experiment results showed increased value of the measured force by increasing the fixing area [9]. The Endless End-effector as well as the Modular End-effector to be used for the draping can apply enough pressure on a large surface through the contact area compare to the Snake End-effector, which has limited number (small area) of soft suction cups and force to apply the pressure on ply. Therefore the experiments were conducted to determine the fixing force with the minimum surface area (provided by number of suction cups) and maximum possible applied force with the soft suction cups of Snake End-effector. By considering the weight of 10 CF plies at 45° angle (ply size 340m x 340 mm and weight 432 g/m²) the required holding force will be 3.468 N, which is still smaller than average value of the measured forces 22.92 N for first layer and 16.68 N for the second layer. For the experiment 1.43 g RTM6 was used and 9.81 N force was applied with one module of the Snake End-effector (consists of 11 soft suction cups with 0.0058 m² area) to apply the pressure on ply. Thus it can be concluded that one module of the Snake End-effector is able to apply enough pressure to hold the upper plies. The required time with one spray nozzle to spray the 1.43 g is 30s. Although the spray time seems long at the moment, it was decided to develop the method for automated fixing process. Because to spray 1.43 g in less than 30s can be optimised by adding more spray nozzles or with a different spray nozzle. Also the amount of RTM 6 can be optimised in future.

Further experiments were conducted directly on the component to verify the fixing process. In this experiment 7 CF-Plies (size: 1.2 m x 0,6m) were stacked together and only the 1st CF-ply was fixed to the component with 21.7g RTM6, which was distributed with the Snake End-effector pattern. Although RTM6 was sprayed 100 mm lower from the upper edge of CF-ply (due to gripping position of Snake End-effector), no peeling effect could be observed.

No sliding effect could be noticed for any layer for more than 16 hours. These plies were detached from the component manually. In another experiment (see Figure 5) different CF-Plies were fixed onto component with the same parameters. No sliding effect was noticed for any ply for than 24 hrs.

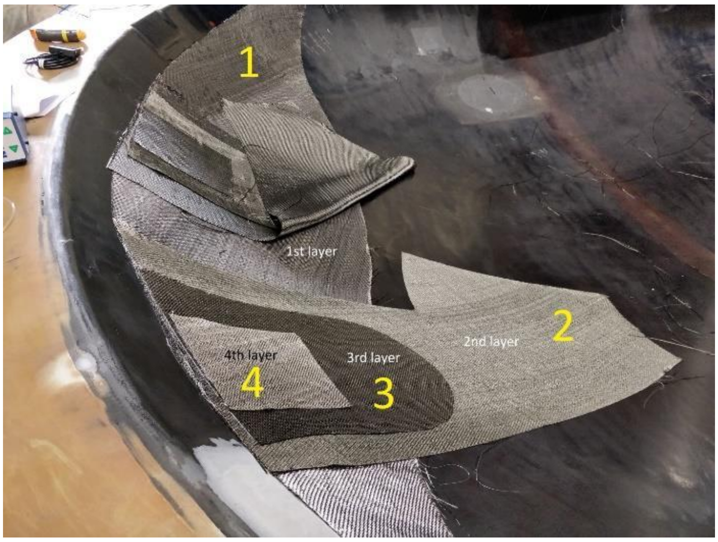


Figure 5: The combined experiment of the lower and intermediate plies

2.3 Development of the fixing End-effector

The End-effector was designed as a part of the master thesis [8]. The main components of the fixing End-effector design are cartridge for RTM6 and the spray nozzle with connecting pipe (see Figure 6). The end effector was developed for the portal robot and was able to deliver a specific amount of RTM6 in form of a thin layer. All components of the Nordson dispenser system was integrated with the End-ffector in such a way that: 1) Dispensing parameters can be easily modified any time manually & from a host PC. 2) The spray nozzle can be disassembled and assembled easily for changing the cartridge of the resin. Furthermore the load capacity of KUKA portal robot and position of the component in the robotic cell (in order to spray from 50 mm distance and normal to surface) were considered. Figure 7 illustrates the Fixing End-effector, which is 2 m long to reach every position on the component. Also the Nordson control system is integrated in the End-effector.

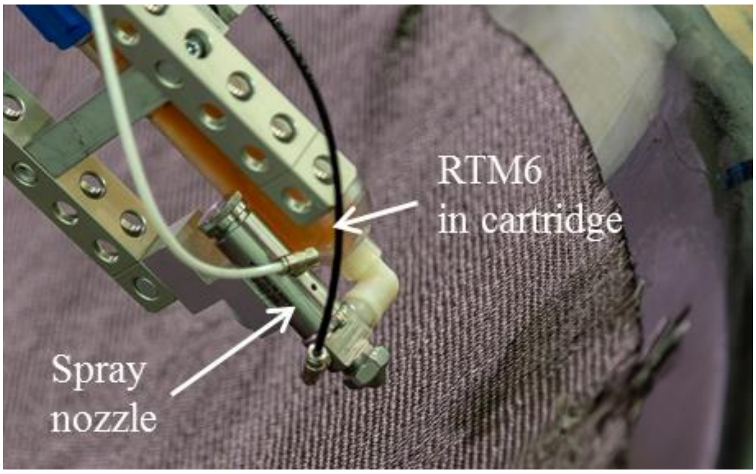


Figure 6: Main components of fixing End-effector

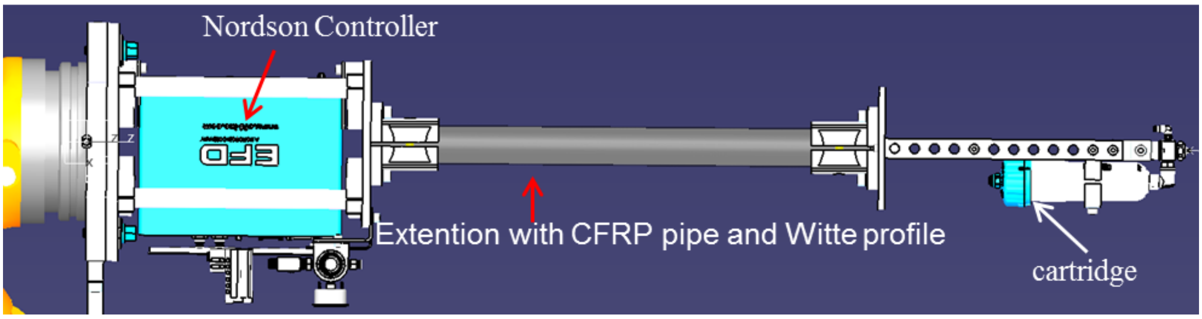
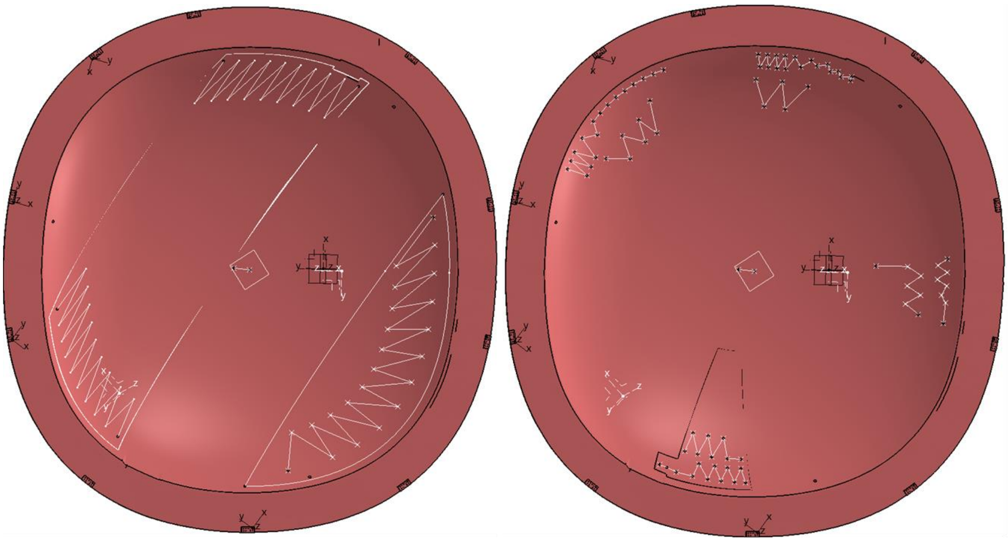


Figure 7: Design of Fixing End-effector

3. RESULTS

3.1 Automated fixing of preform package on component

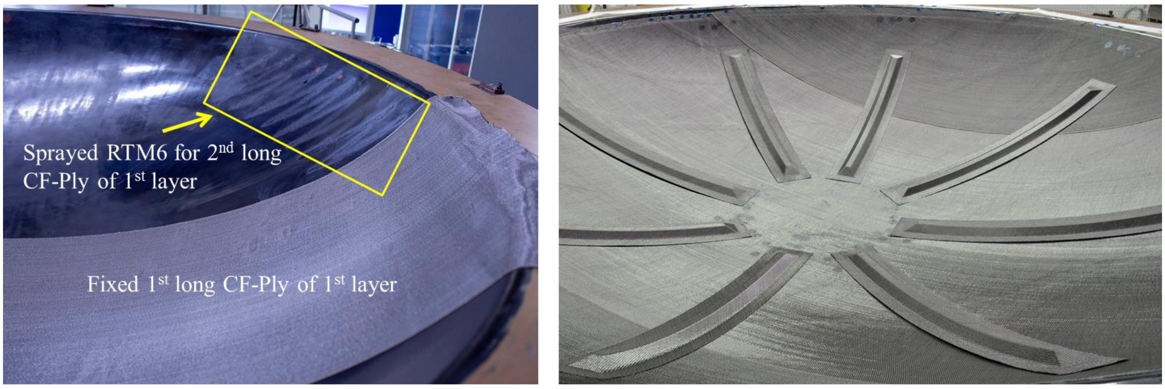
For the experiments in the section (2.2) the 781S spray nozzle from Nordson was controlled with Nordson 7140 controller, in order to spray accurate amount of RTM6 with the defined air pressure and the dispensing time. In order to reduce the fixing time for the automated demonstration, it was decided to change the spray pattern from circle (due to suction cups of the Snake End-effector) to continuous curve (see Figure 8) for all the End-effectors. Furthermore, generation of a robot program according to pattern of the Snake End-effector is difficult. Maximum 10 s time can be set with the Nordson controller for continuous spray. Therefore, with $6.0x10^5$ Pa constant air pressure, the nozzle (on/off) was triggered directly by the robot. Also the robot movement speed (0.0163 m/s) had to be defined to spray the same amount of RTM6 as determined in the section 2.2. By considering the robot speed and the required amount of RTM6, the length of the spray pattern were constructed in *CATIA*. *FASTSurf* offline-program was used to generate the robot program. Prior to this the base-position of the component and the Tool-Center-Point (TCP) for the Fixing End-effector was measured.



(a) Spray pattern for long CF-layers (b) Spray pattern for intermidiate CF-layers

Figure 8: Different spray pattern according to size of CF-pleis

To fix all 59 CF-layers with different sizes 1.2 kg RTM6 was used. For the infiltration process the same amount was reduced. Total spray time was 11 hrs. It is to be noted that only one nozzle was used for the demonstration and the quantity of RTM6 was not optimised for all the CF-layers. For the optimum case, the resin quantity would be reduced linearly from the first to the last layer. Multiple nozzles and the optimum spray quantity would significantly reduce the process time. Thus, all the CF-layers could be successfully fixed faster and automatically on the pressure bulkhead. Figure 9 (a) shows the already fixed 1st long CF-ply as well as sprayed RTM6 for fixation of 2nd CF-ply of first layer. Figure 9 (b) shows all fixed 59 long and intermediate CF-layers with RTM6.



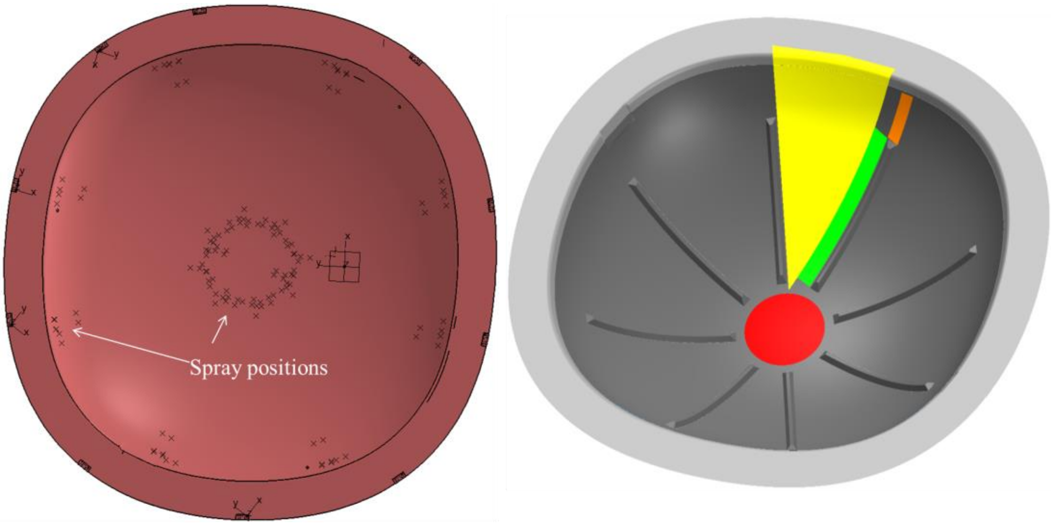
(a) Fixation of 1st CF-layers

(b) Fixed 59 CF-layers with RTM6

Figure 9: Automated fixation of CF-layers

3.2 Automated fixing of auxiliary package on component

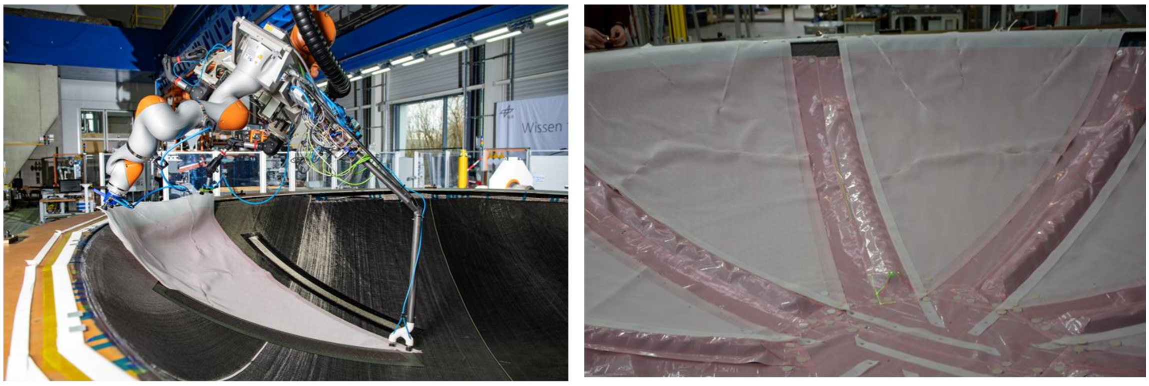
As mentioned in introduction, for the vacuum bagging process auxiliary packages were cut according to geometry and stiffeners positions. All these packages were placed on the component with a multi-kinematic gripper [10]. The spray positions (shows in Figure 10 (a)) are the drop positions of the gripper. The gripping element has 30 mm diameter to press the auxiliary package on the ply. 80 mg RTM6 was sprayed within 5.2 s by a circular motion with a robot at each position. In order to spray at 134 positions 12 min was required. The robot movement time is not considered in this 12 min. Above experiment results thus show the successful fixation of the auxiliary packages with the newly developed method .



(a) Spray positions for auxilary packages

(b) Example of auxilary packages

Figure 10: Fixing positions of auxiliary packages


(a) Fixing of auxiliary package with Multi-kinematic gripper (b) Fixed auxiliary packages

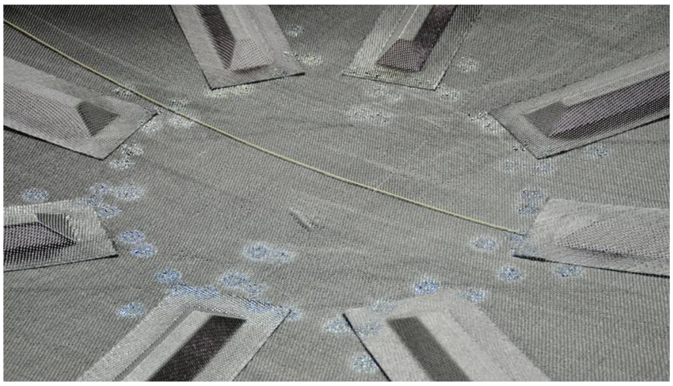

(c) Sprayed RTM6 with 30 mm diameter

Figure 11: Automated fixation of auxiliary packages

4. CONCLUSIONS

The aim of the research was to develop an automated fixing process for CF-layers and auxiliary packages. A cost-utility analysis made it possible to evaluate the possible fixing processes on the basis of clearly defined and weighted target criteria and to identify the most suitable method. The advantages and disadvantages of these suitable selected methods could be proven experimentally. It could be shown that the RTM6 method was thebest choice. Several experiments were conducted on the surface of at component to determine the distribution and the quantity of the resin to be used. From the experiments conducted to determine the fixing force of a ply increases up to a certain level as the pressure being applied on the ply is increased & the Snack End-effector is also able to bring enough pressure to fix the plies. Further dispensing parameters (quantity, time) of RTM6 were also determined for automated fixation of CF-layers and auxiliary packages. The developed Fixing End-effector was used to spray required RTM6 at defined positions on the component. All the 59 long and intermediate CF-layers were fixed with this new method. Also auxiliary packages were fixed successfully with Multi-kinematic gripper after application of RTM6. Although the spraying time for the large scale demonstration above was relatively long, the time can be reduced by implementing multiple spray nozzles and optimizing the spray quantity. The topic will be examined in detail in the coming experiments.

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