AUTOMATED NEAR-NET-SHAPE PREFORMING OF CARBON FIBER REINFORCED THERMOPLASTICS (CFRTP)

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Abstract: This paper aims to show, that the preforming process of parts made of Carbon Fiber Reinforced Thermoplastics (CFRTP) can be improved, when using several technologies like near-net shape cut-piece generation with forming simulation, automated cut-piece detection, robotic gripping and laydown of fabrics. Thereby the authors of this paper want to contribute to the increase of CFRTP applications in modern aircrafts, which generally should lead to an increasing lightweight design of such aircrafts.

Keywords: *CFRTP, thermoplastics, composites, preforming, near-net-shape, robotics, automation*

1 Introduction

Carbon Fiber Reinforced Thermoplastics (CFRTP) have several technical advantages compared to Carbon Fiber Reinforced Thermoset Plastics. Nevertheless, there have been only few applications of CRTPs for structural parts in the Aerospace sector yet, as shown in Fig. 1.

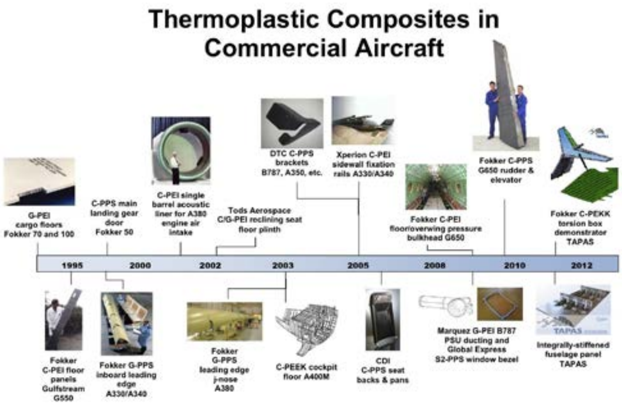

Fig. 1: Overview of CFRTP applications in commercial aircrafts [1].

One reason for this are probably the higher material costs of high temperature thermoplastics compared to their thermoset relatives. At the DLR Center for Lightweight Production Technology in Augsburg research is focused on the automation of high volume production, in order to reduce the process costs of such parts significantly.

2 Technology Demonstrator / Application

Our research group decided to demonstrate our process advantages by building a generic technology demonstrator. Therefore we chose a sinus wave beam (see Fig. 2). This wave beam consists of three component types:

- One upper and one lower flange
- One web and
- Four angle connectors (two for each flange), which connect the upper and lower flange with the web

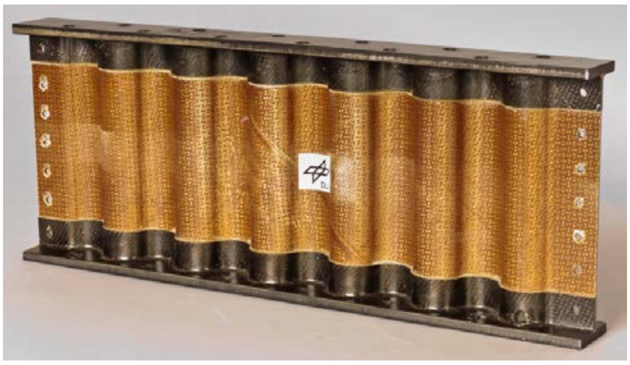

Fig. 2: Sinus wave beam of the DLR BK.

This wave beam can be considered as an all-purpose linear stiffening element with good crash behavior for applications in the modern aircraft construction, as shown in Fig. 3.

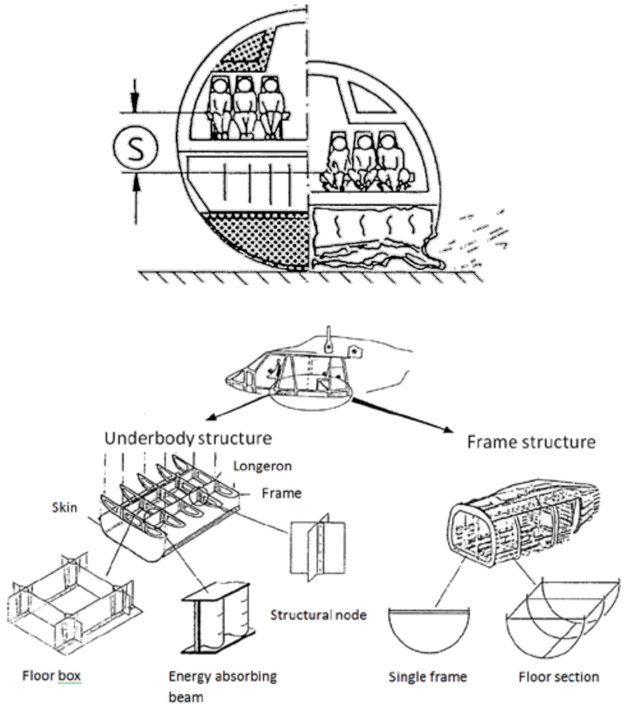

Fig. 3: Possible application of a wave beam as a structural crash-absorbing stiffening element in the under-floor structure of an airplane fuselage (top) and a helicopter (bottom) [2].

2.1 Considered material

The considered materials are woven fabrics (powder impregnated or film stacking) with 50” width and unidirectional (UD) Tapes with 12” width of Carbon Fibers and Polyether ether ketone (PEEK) of aviation-approved material suppliers. In the already built version of the wave beam from Fig. 2, Kevlar Fiber reinforced Thermoplastic woven fabrics were used for the web as top layers.

2.2 Geometry and Plybook of the wave beam

The geometry of the sinus wave beam as shown in Fig. 4 is based on two reference wave beams of MBB, Ottobrunn, which were provided to the DLR within a research project in April 1987 (see Fig. 4). The applied ply sequence is shown in Fig. 5 [2].

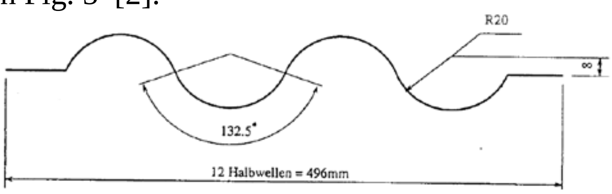

Fig. 4: Geometry of the DLR wave beam based on a reference wave beam of MBB, Ottobrunn [2].

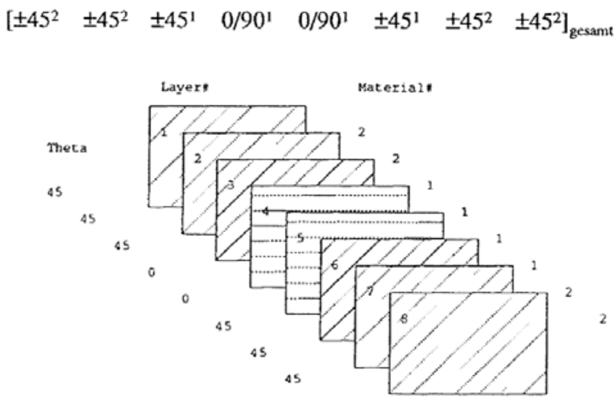

Fig. 5: Ply sequence of the DLR sinus wave beam’s web [2].

2.3 Near net-shaped Preforms with Forming Simulation

The geometry of the individual cut-pieces was generated by forming simulation with the FEA Software PAM-Form from ESI. Therefore, the net-shape of the 3D part was projected on the formed preform, whereby the 2D contour of the 3D net-shape could be recalculated (see Fig. 6).

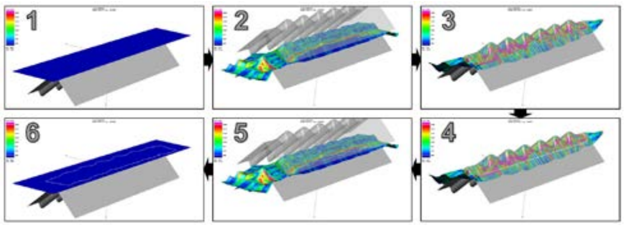

Fig. 6: Generating the 2D net-shape of the 3D angle connector part for the flat preform with Forming Simulation.

2.4 Cut-piece detection by means of computer vision

As mentioned above the demonstrator’s design aims at optimal shaping of the 2D-cuts in order to achieve a good approximation of the later on desired 3D-shape. Due to the resulting complexity of the layup expensive care has to be taken to correctly grip and thus place the individual cuts. The use of conventional robotic grippers implies well known positions and correct alignment of every single cut, hence leading to a situation where productivity gains during layup are lost in turn for the previous alignment of the cuts by manual work.

A computer vision approach can produce relief: The 2D-shapes, well known from design, are passed to an algorithm generating a digital representation of the shapes matching the resolution of a camera system mounted to the gripper. The resulting bitmap is matched to the camera image yielding coordinates and rotation of the more or less randomly placed cuts in the camera's coordinate system. After transforming the obtained coordinates correctly into the robot's coordinate system the cuts may be picked and placed in turn without further user interaction.

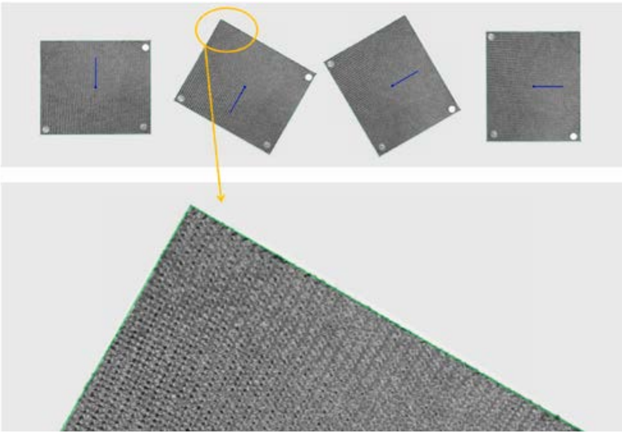

Fig. 7: Obtaining coordinates and rotation of cut.

In the DLR labs tests were performed investigating the achievable accuracy of the system considering determination of coordinates and rotation as well as picking and placing the cuts. The tests are continuing and accuracy is still an object of thorough investigation because there turned out to be a manifold of influences of high complexity, amongst others namely optical effects like lens distortion or imaging imperfectness, paired with mechanical deviations caused by e. g. backlash or thermal drifts.

At today's state of knowledge it can be clearly stated that the results are very encouraging: concerning overall accuracy a standard deviation in the range of 0.2 mm may be obtained under optimum test conditions. Under poor conditions the system is still working properly and robust, albeit with a reduced overall accuracy in the range of 1-2 mm. DLR's future goal is extending the high accuracy operating range to the variety of conditions found in a typical industrial environment.

2.5 Gripping technology of the cut-pieces

As gripping technology vacuum gripping was chosen, in order to avoid damage and contamination of the gripped material, as it could occur with e.g. needle, freezing or adhesive grippers, or electrostatic charging, as it will occur with electrostatic grippers.

In order to find the most suitable vacuum grippers for the considered materials, several vacuum and pressure charged grippers were tested, regarding their holding forces and gripping efficiencies (holding force over required air flow, see Fig. 8 to Fig. 10). The results showed, that the pressure charged Bernoulli and Coanda grippers are better suited for the more porous powder impregnated woven fabrics, probably due to their higher vacuum flow rate, whereas the vacuum charged grippers are better suited for the more dense materials like the fully impregnated UD tape or the PEEK foil, probably due to their ability, to better sustain the vacuum.

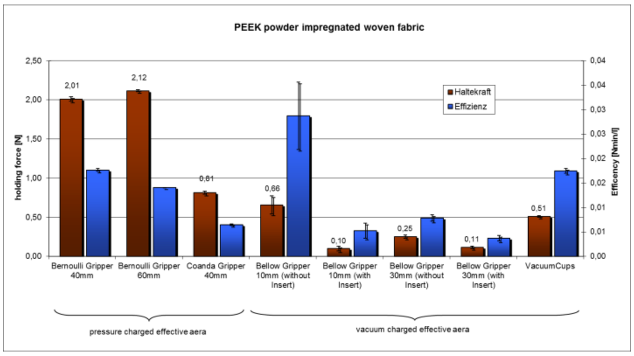

Fig. 8: Test results showing holding forces and gripping efficiencies of different grippers for **PEEK powder impregnated woven carbon fabric**.

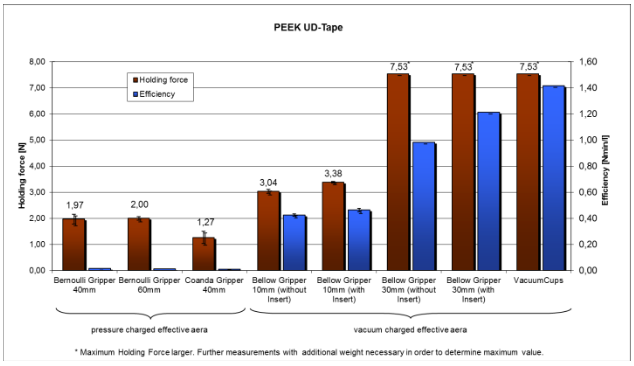

Fig. 9: Test results showing holding forces and gripping efficiencies of different grippers for **CF/PEEK UD tape**.

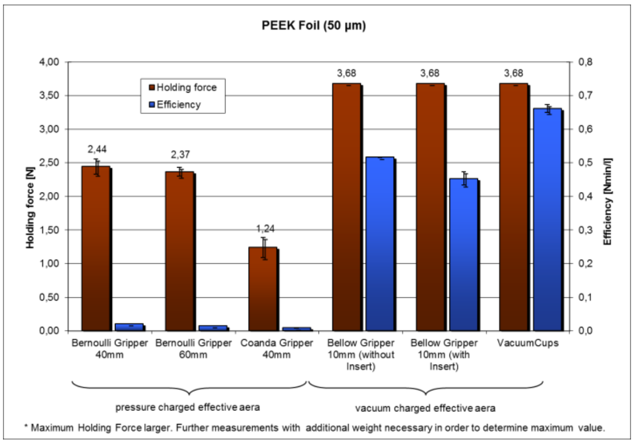

Fig. 10: Test results showing holding forces and gripping efficiencies of different grippers for **PEEK foil**.

Within the vacuum charged grippers, the Vacuum Cups were preferred to the Bellow grippers due to the better stability and lay-down accuracy in lateral directions and the better gripping efficiency. In order to equal different laminate thicknesses, the combination of Vacuum Cups and spring followers was chosen (see Fig. 11).

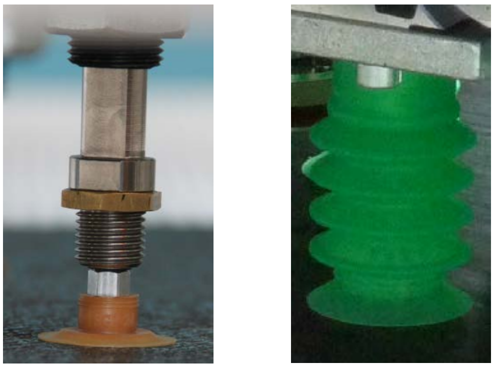

Fig. 11: Vacuum Cup on spring follower (left) and Bellow gripper (right).

2.6 Fixation technology of the cut-pieces

For the fixation of the cut-pieces, several technologies were considered (see Fig. 12). Finally Ultrasonic (US) welding was chosen because of the following advantages compared to other heat inducing technologies:

- Required time for heat induction
- Locality of heat generation
- Quality and Damage of weld and near-weld zone

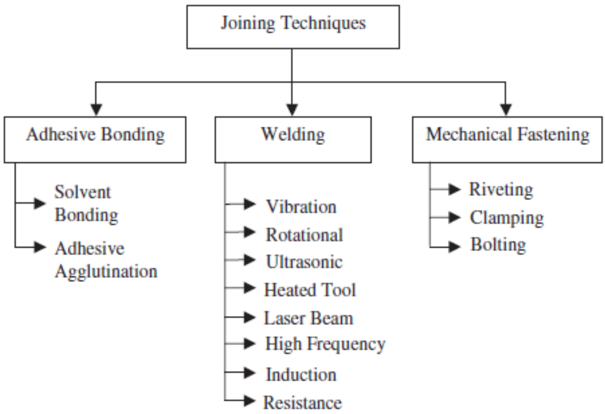

Fig. 12: Joining techniques for fiber reinforced thermoplastics [3].

For the US welding several horn geometries have been considered. Hereby the catenodial horn geometry was chosen due to a small stress level and a good amplitude distribution (see Fig. 13).

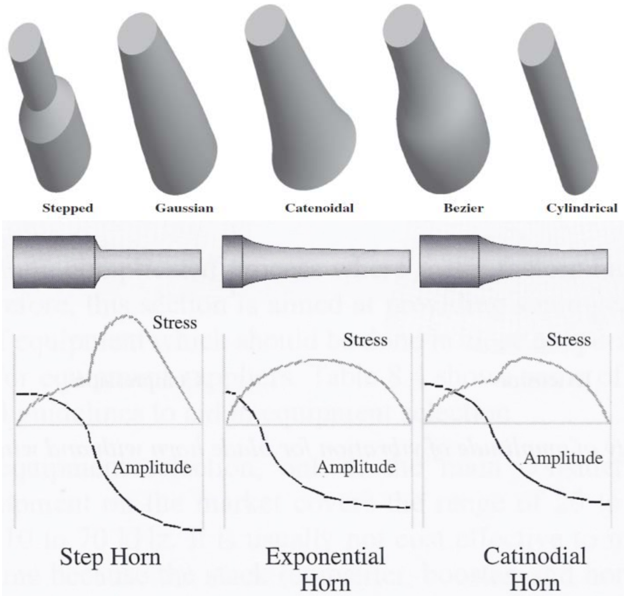

Fig. 13: Different horn geometries (top, [4]), stress level and amplitude distribution over horn length (bottom, [5]).

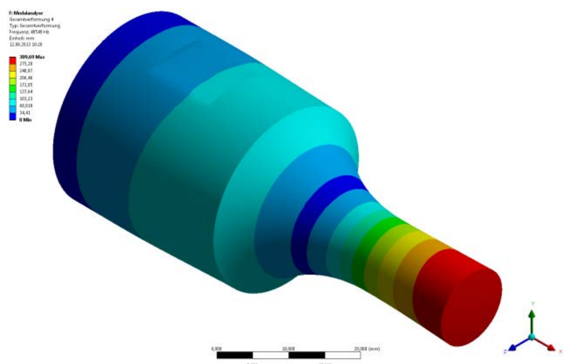

Fig. 14: Mode shape of the utilized horn [6].

The Ultrasonic frequency was defined to 40 kHz as a compromise between energy absorption capacity, hammering behavior and the horn’s error rate [6].

In order to investigate the behavior of the fabrics during welding, combined gripping and welding tests were conducted. The results showed that the swimming of the fabrics due to the ultrasonic stimulation could effectively be avoided by the friction force of the grippers (see Fig. 15).

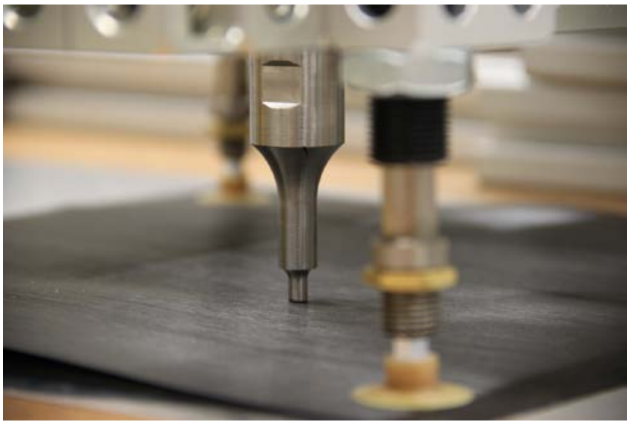

Fig. 15: Fixation of the fabric via Ultrasonic welding during lay-down.

2.7 End effector construction

For the construction of the robotic gripping end effector, the following steps have to be iteratively passed through:

1. Cut-piece distribution of the Plybook
2. Gripper distribution on Cut-piece distribution
3. Alignment of welding unit between Gripper distribution

In a first shot, step 1 and 2 were conducted in order to build a robotic end effector, which can autonomously detect, grip and lay-down cut-pieces of a previously defined dummy plybook. Therefore a frame construcion of Witte profiles was equipped with a vacuum pump, a valve cluster, 10 grippings units with Vacuum Cups on a spring follower and the automated cut-piece detection unit (see Fig. 16). This end effector was mounted on the Thermoplastic robot cell of the DLR where first promising tests could be conducted (see Fig. 17).

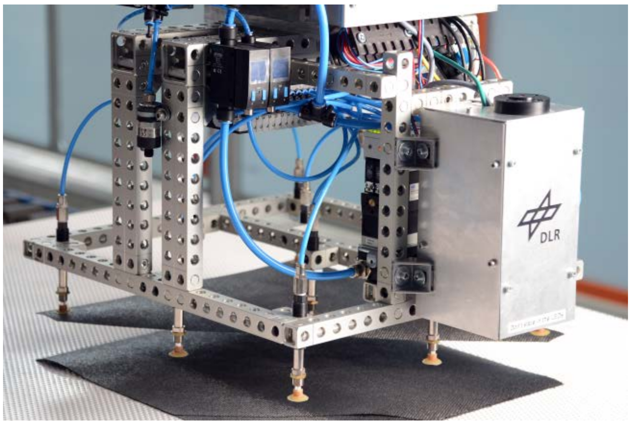

Fig. 16: Robotic end effector with gripped cut-piece.

Fig. 17: Robotic end effector with automated cut piece detection for gripping, lay-down and fixation of CFRTP fabrics.

3 Conclusion and Outlook

It could be shown, that the robotic lay-down of fiber reinforced thermoplastic fabrics is a promising technology with a high grade of flexibility, which can be – when combined with forming simulation and cut-piece detection – well used as a highly automated, near net-shape preforming technology. Nevertheless there are still tasks left, in order to show the full implementation of the automated process chain. At the DLR-ZLP these upcoming tasks are:

- Integration of the welding unit in the robotic end effector
- Automated production of wave beam preforms
- Recording of the whole process time and energy and reducing of the main energy and time consumer
- Integration of the robotic preforming process in the complete manufacturing chain

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