

Highly Flexible Automated Manufacturing of Composite Structures Consisting of Limp Carbon Fibre Textiles

Gunther Reinhart, Gerhard Straßer and Claudia Ehinger
iwb Technische Universität München

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ABSTRACT

Due to the conventional autoclaving of pre-impregnated materials causes high costs in the production of carbon fibre structures, new injection methods have become more and more relevant. The research project “CFK-Tex” focuses on the automated handling and processing of preforms out of dry carbon fibre textiles. Regarding the advantages in quality improvement and process time, an automation of all process steps is getting enforced. The major challenge, in addition to the difficult handling-properties of the materials and high quality demands, is the enormous variety of outline variants caused by small production quantities but many different textile cuts per part.

In the first step the requirements of an automated system are exactly analyzed considering the specific material properties as well as process and product based characteristics. Since the automated processing of the limp material is based on a reliable handling process, one main aspect of the research work focused on physical principles to grip the carbon fibre textiles. Therefore, a broad range of different gripping methods like needle grippers, hydro-adhesive grippers, vacuum-based systems and other innovative possibilities were examined. In addition to experimental tests, also theoretical analyses on the profitability contribute to the choice of a specific vacuum principle with very low pressure but high volume flow rates. Based on this fundamental research work, a first prototype of the later end-effector for the automated sorting of cut parts from the cutter table to the stockyard could be developed, which offers great flexibility regarding different contours and materials by an automatized reconfiguration based on CAD-data.

Furthermore, the automation of the preforming process with the defined placing, draping and crabbing of a single carbon fibre textile on special 3D-moulds is a main objective of the research project. Hereby the single process steps are examined separately and proper strategies and principles are analyzed. Through several experimental tests on different possibilities, a capable combination was found, which offers great potentials regarding process reliability and flexibility.

INTRODUCTION

The use and spread of fibre reinforced parts has increased enormously during the last years. In addition to a remarkable growth in several established industrial sectors, like building and marine industry, mainly the transportation, sport&leisure and wind energy branches apply the innovative materials, due to their convincing advantages [1, 2]. In particular modern airliners like the Airbus A380 or Boeing 787 use composite parts to a large extent and hence mark the latest dots in the extensive increase of the last 30 years as shown in Figure 1.

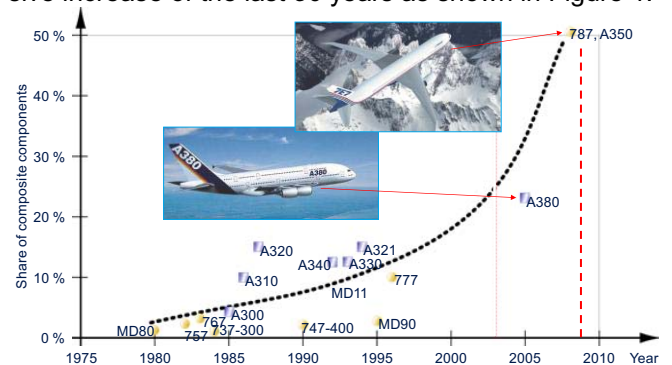


Figure 1: Growth in the share of composite components in civil airliners [3]

Especially structures made of carbon fibre reinforced plastic (CFRP) provide a big range of positive properties. This predestines them for the use in highly stressable light weight constructions, whereby a trend to this fibre system could be noticed. This results in a predicted growth of the CFRP production between 9% and 12% in the next years [2]. Basically two different manufacturing strategies exist simultaneously in the industrial use of this material. Either pre-impregnated semi-finished products (prepreg) are processed in an expensive autoclave or non-resinous dry carbon fibre textiles are manufactured to preforms prior to their resin infiltration in an oven. Concerning production costs the use of dry carbon fibre textiles (woven or non crimp fabrics) holds several positive effects due to lower capital investment, especially the autoclave, and minor current cost regarding semi-finished products and stocking efforts [4, 5]. Although prepregs so far offer some advantages in fibre content and accessible part strength, within carbon fibre structures a movement to the appliance of dry textiles is not to be negated [6].

Despite the advantages of carbon structures and its increasing relevance, the efficient use and spread of this technology is limited by high cost of production [3]. So far manual steps, which negatively influence cost and reliability, dominate the manufacturing process, due to complex handling properties of the materials and a highly diverse selection of different parts and geometries. In order to achieve higher capacities and to establish the necessary requirements for an automated production of carbon parts, the research work presented in this paper focuses on new automation solutions for the processing of limp carbon fibre textiles based on the development of highly flexible robot end-effectors [7].

CHALLENGES AND OBJECTIVES

The major cost driver of industrial production in high wage countries like Germany, the United States or Japan is labour cost. Especially the manufacturing of carbon structures is currently dominated by manual, work intensive process steps [5, 8]. Exemplary figure 2 shows a part of a typical process chain from the allocation of the semi-finished products, over the processing of the dry carbon fibre textiles to preforms to the injection procedure.



Figure 2: Basic process chain in the manufacturing of dry carbon fibre textiles

Whereas the allocation and CAD-based cutting is completely automated, the clearing of the cutter table, the lay-up of the single cut parts as well as the creation

of the vacuum build up are exclusively manual operations. The presented research work focuses on the first two manual steps and therefore targets an automated handling system for the efficient clearing of the cutter table and further an automated lay-up system for the draping of the carbon textiles on special moulds to establish a layered perform.

CHALLENGES - The achievement of the ambitious goals holds several challenges, due to various requirements concerning the process, material and geometry (see Figure 3). Most of all handling properties of the carbon fibre textiles are difficult to satisfy as they are limp, permeable to air and highly anisotropic depending on the fibre orientations [9]. Furthermore the structure of the fabric and tapes is mainly instable and therefore the initiation of the holding force has to be careful and plane. Besides the material properties the deployed geometries cause additional requirements because many carbon structures are of a complex, load-capable 3D-shape in addition to their large scale. Therefore little reinforcements and big cut parts of mostly complex shapes are both necessary to create a layered perform on various 3D-moulds. Conjoined with the process based requirements the boundary conditions get extremely complex. Often several different components in an airplane or helicopter are made of CFRP-structures, but the number of units per period is very low. This leads in connection with the various blanks per component to a highly diverse selection of different parts. Additionally depending on the load capable design, all sorts of semi-finished carbon fibre materials form one preform [5]. Furthermore to fulfil the high quality demands within the manufacturing of composite parts especially in the aerospace industry the automated processes have to be extremely reliable and the structure integrity of the cut parts must be assured and contamination has to be preserved.

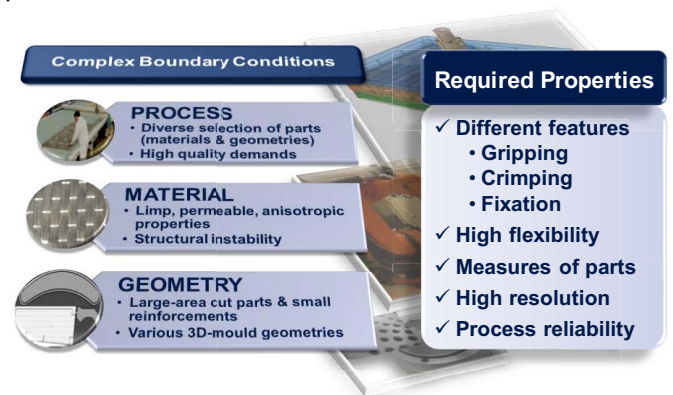


Figure 3: Challenges and required system properties based on complex boundary conditions

REQUIRED PROPERTIES - The constituted challenges result in a choice of required properties for the handling and preforming end-effector (cp.). The last one even has to fulfill three basic features in one: The gripping of the textiles, the crimping or draping onto the 3D-mould and their fixation by melting a thermoplastic binder fleece

between the preform layers. The handling system has to be able to grip any shape of cut-part without any interaction to the other blanks or blends on the cutter table while clearing it. Besides the complexity of this functions itself, due to the material properties, geometry conditions and demanding process steps, the given facts above all require highly flexible systems concerning the processed materials and shapes, as specialized approaches can not be deployed economically [5].

STATE OF THE ART - So far various approaches for the automated handling of limp material exist in diverse branches, while the highest emphasis is on automatic manipulation of sheet material in applications concerning garment or fabric for the textile industry. Only a few research works are conducted in the field of composite structures and still the 3D-manipulation is the least researched area in this domain [10]. Although early research work on theoretical and experimental aspects of the forming of fibre fabrics are done [11], a flexible forming system for a diverse selection of mould geometries and cut parts is not available at the moment. A German research group lately presented a preforming end-effector system based on single hydro adhesive or needle grippers and a convex roll for the final draping [12]. Although the system offers a solution for the draping of lightly shaped convex or concave moulds the different functions still require different robotic tools and show a limited flexibility. The special requirements of clearing the complex and diverse shaped cut parts from a cutter table are not answered. Concerning the gripping principle used in such systems many different appendage could be found in the literature, mainly based on needle or suction gripping as well as innovative cryogen methods [13]. But yet none of them could be implemented in a robot end-effector system which meets the requirements regarding flexibility and material integrity. Therefore in 2007 Szimmat reported the result of a survey in industry, which stated that the clearing of the cutter table is in none of the asked 39 companies automated so far [14].

APPROACH

The deployment of highly flexible robot end-effectors for automated handling and preforming of dry carbon fibre textiles is structured by a methodical approach. Figure 4 shows the first three steps from the definition and analysis of a reference scenario to the system design and the realization of the first prototypes. As the used active principles have to meet the essential functions and in case of gripping define the important interaction between the gripper and the work piece the research work puts a great emphasis on the selection of the optimal physical principles [15].

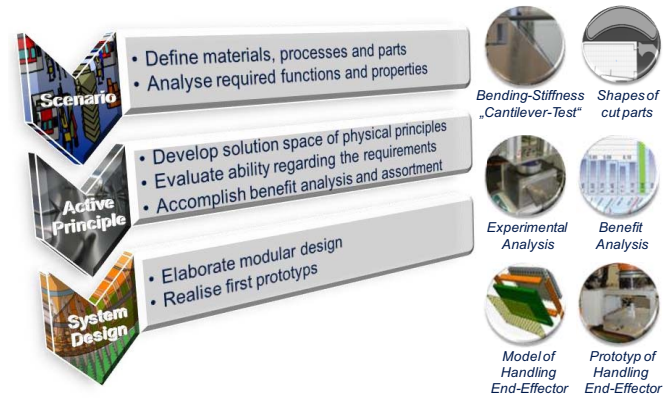


Figure 4: Methodical approach for realizing the first prototypes

SCENARIO - In the first step a scenario with different materials, products and a reference process is defined. Therefore three aviation parts (e. g. a helicopter roof panel and an airplane strengthening frame) and four different dry carbon fibre textiles are chosen in order to represent a broad choice of applications. The geometries of the reference parts also include 3D-shapes with moderate free-form surfaces as well as right angles and further cover extensive cut parts in addition to little reinforcement sheets. The materials cover different semi-finished forms, as a woven fabric and three non crimp fabrics (NCF; uni-directional and bi-directional) are investigated with a big range of grammage from 220 g/m^2 to 556 g/m^2 (see Table 1). The definition of a full automated process scenario based on aspects concerning logistics, product range and especially quality demands in aviation industry completed the basis to extract all relevant requirements. Over all, the claim for a high degree of diversification ruled the first definition step.

Table 1: Choice of investigated materials (carbon fibre textiles)

Nr.:	Type	Fibre orientation(s)	Grammage [g/m^2]	Thickness [mm]	Binder Fleece
1	Multi-Axial NCF	$0^\circ/90^\circ$	556	0,8	Thermoplastic 9 g/m^2
2	Unidirectional NCF	0°	290	0,3	Thermoplastic 9 g/m^2
3	Multi-Axial NCF	$+45^\circ/-45^\circ$	256	0,45	Thermoplastic 9 g/m^2
4	Woven Fabric	$0^\circ/90^\circ$	220	0,35	Thermoplastic 9 g/m^2

In an analysing step the different materials are examined in regard of handling or preforming relevant properties, such as

- bending-stiffness,
- permeability,
- structure stability,
- anisotropy and
- fixation attitude.

Further the 2D-and 3D-shapes of the single cut parts and mould geometries are analyzed to extract

- dimensions,
- smallest radius,
- size of little cut-outs,
- fibre orientations and