OPTIMISING HIGH-THROUGHPUT, AUTOMATED PREFORM PRODUCTION WITH NON-LINEAR SIMULATION OF THE PICK AND PLACE PROCESS FOR TECHNICAL FABRICS

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ABSTRACT

The serial manufacturing of high performance composites parts is based on the lay-up of textile cuttings with subsequent resin impregnation. For industrial applications the cuttings are produced on automated cutter systems [1, 2, 3, 4, 8]. The existing difficulty for a complete automated process is the "pick and place"- process of these cuttings [1, 2, 3, 4, 8]. The process step is a main challenge for high throughput and quality. The textiles have a low stiffness, high sensitivity against mechanical loads and great range of the mechanical properties depending on the fabric structure [5]. The production of high performance parts is dominated by non-crimp fabrics with single- or multi-layer structure. Currently the handling of textile cuttings is done manually. These leads to challenges in the handling process if the cuttings become larger or the handling times have to be reduced for a more effective production [1, 2].

Automated "pick & place" will avoid structural defects and speed up the production [1, 2]. Currently handling of textile blanks is dominated by grabbing of the entire cutting surface [2, 3, 8]. More flexibility of such gripping devices can be achieved by multiple picking points with relatively small contact areas instead of the entire fabric area. Apart from the challenge of choosing a feasible gripping principle, the number and the positioning of gripping units have to be known for a successful handling. Because of the different shapes and variation of mechanical properties a practical evaluation will need time and resources. This can be reduced by a virtual model for the handling process. The approach of this work is focussed on non-crimp fabrics. Existing simulation approaches of the handling process are based on the complex modelling of textiles substructure [6, 7]. The proposed solution is based on FEA –approach with existing elements by modelling the integral textile structure. The non-linear FE-model requires a relatively small number of material properties which can be acquired with a minimum effort by using standard measuring equipment [5]. An integrated Software-Tool based on the FE-Method for the calculation of optimized handling configuration has been developed. For given material parameters, cutting geometries and the number of picking points the optimized picking position can be calculated. The verification of the tool and some optimization results for different cuttings showing very promising results to support the design of devices for automated handling.

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1 INTRODUCTION

High performance composites are mainly produced with non-crimp fabrics, either single or multi layered for high throughput in the production. Especially in the production of rotor blades of wind turbines a lay-up of tons of textile cuttings have to be managed in certain time.

Wind turbines for rotor blades fulfill a very diverse and conflicting set of requirements: Low weight, high strength, precise outer free-form shape, a long design lifetime of 20 years with little or no maintenance and high fatigue loads, all while posing a significant, 20-25% share of total wind turbine costs.

Currently the rotor blade production is still dominated by manual labor, which leads to high tolerances, requiring high safety factors and a less-than-optimal blade design, and which reaches its limits with current and upcoming blade dimensions. The size of wind turbines is expected to increase up to 10 MW with rotor diameters up to 180 m within the near future, as the total production cost per kilowatt-hour of electricity decreases with increasing wind turbine size. Fraunhofer IWES has investigated the production process of typical wind turbine rotor blades and developed a cost model to compare the current manual production process to new industrialized production concepts. The cost model for larger blades than 40m shows a big impact on the manufacturing and for the mould occupation time by automated textile handling. The aim is identifying key methods to reduce blade cost: Development of cost-effective rotor blade materials with similar properties, reduction of manual labor and increase of production reproducibility or robust quality, as quality costs pose a significant part of blade costs. Fraunhofer IWES will show methods to achieve cost-effective production and present industrialized fabric handling and finishing processes as one of the key factors for blade quality.

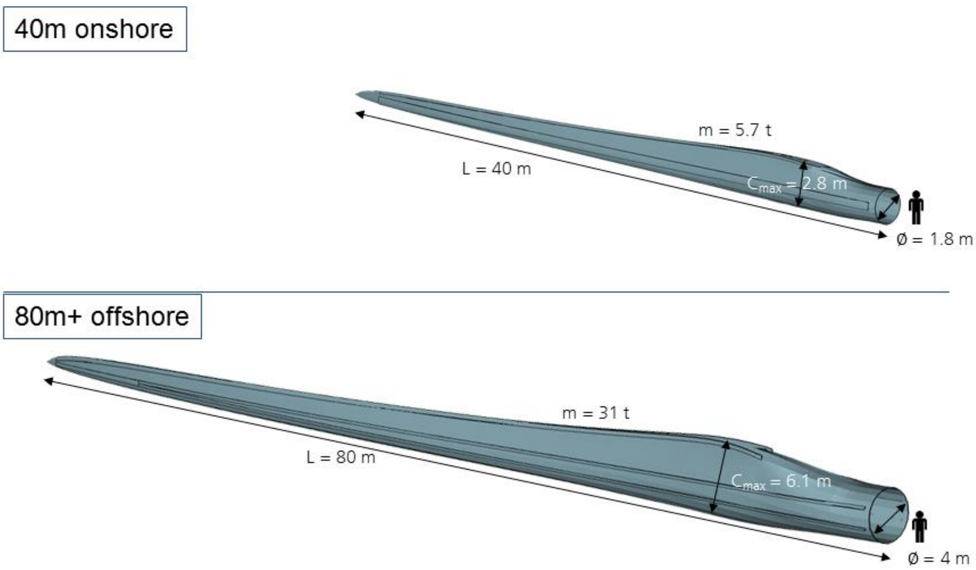

Figure 1: Typical dimensions of current and upcoming wind turbine rotor blades

Industrialized manufacturing will not only ease the production of large wind turbine blades, it also promises significant improvements leading to higher reliability, higher blade value and ultimately lower cost-of-energy for the entire turbine.

2 STATE OF THE ART: MANUFACTURING PROCESSES AND COST DISTRIBUTION OF WIND TURBINE BLADES

3.1 Materials and Processes

Composite materials for high performance applications like rotor blades are made from roving or textiles like woven or non-crimp fibers. Non-crimp fibers, NCF, are currently widely used for the manufacturing of blades. The NCF integrates different layers of roving direction in one fabric. This leads to significant higher area weights and therefor to higher throughputs by manual application.

The root section of a blade has to transfer the complete loads from the blade into the blade bearing by additional bolts assembled or integrated at the root end. The bending and torsion loads and the additional high pressure on the bolt area require high composite thicknesses. The composite design for this section is made of up to 140 layers of textiles. Typical dimensions on a 40m-blade are approximately 1.50m length and 2m diameter (Figure 1). The blade length will still increase in the next years, in the same way the challenges for manual manufacturing will become more and more.

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For the production of the root section different manufacturing scenarios have been set up in the blade industry. The simple way of manufacturing is stacking the layers directly in the main mold. For the hardening of the blade the complete textile lay-up of shell and root will be done in one shot. This leads to a longer usage time of the mold for the different process and for a single blade.

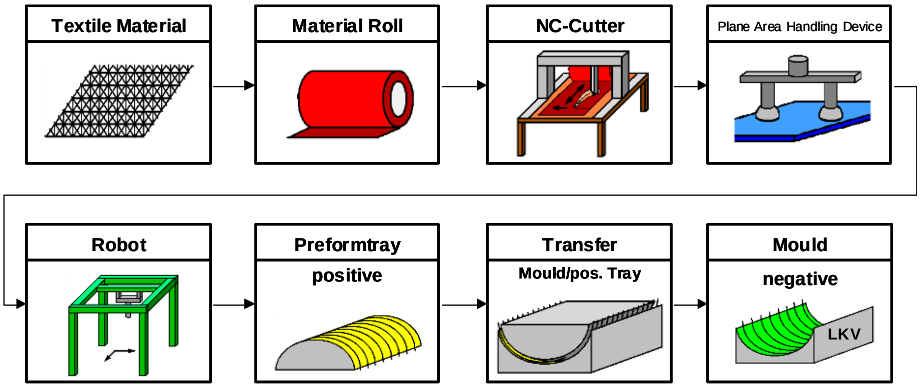

Figure 2: Exemplary Process Chain with pre-cut part-manufacturing by NC-Cutter [8]

For the reduction of molding times the root is manufactured by Preforming in a parallel process (Figure 2). Basic process is the cutting, handling, lay-up of the textile cut-offs. This process is widely automated for the cutting process, some manufacturers are supplied with cut-offs directly from the NCF-manufacturer. The handling and lay-up is done manually. By increasing the production numbers or by increased dimension of blades this manual stacking process will be limited in time and in the handling of the cut-offs with the required quality. The NCFs show a great variety in their mechanical properties. Additionally these kinds of textiles are very sensitive against mechanical loads. For the basic requirements of industrialized blade production both the key factors – molding times and constant quality – will be achieved by an automated solution for root section manufacturing.

3.3 Industrialized Textile handling

For a process with industrialized textile handling, a system is required which is able to pick and place the dry non-crimp fabrics reproducibly. After the cutting of material on the cutting table it is required to pick up the material and either place it in the mold directly or on a storage table first and then picking it up again and placing in the mold. The second option reduces the cutting table occupation time. Fraunhofer IWES intends to conduct this process with the help of a gantry robot with an application head mounted on it. The application head will have vacuum grippers for picking up the fabric material. The aforementioned application head needs to ensure that the non-crimp fabrics are not damaged during the handling process. Damages can occur in the following forms: gaps, deformations, distortions, deflections of the fiber orientation and buckling of fibers. All of these damages can influence the mechanical properties of the resulting composite material. Another aspect which has to be analyzed is the accuracy of the placement process and in this case the definition of the required number of vacuum grippers.

3.4 Development of industrialized Pick&Place for large fabrics

For the development of the handling and application head which will be integrated in a robotic solution Fraunhofer IWES has developed a test booth called Pick & Place, shown in action in Figure 3. This test booth will used for the evaluation of single gripping technologies but also for the evaluation of the handling simulation.

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Figure 3: Pick & Place test booth in operation

Based on the required gripping technology, for example low pressure gripping units, the loads for a safe gripping and the deflection for the different types of fabric will be evaluated by a FE-method. Based on this data the intended handling solution will be designed and tested in an exemplary application environment.

3.2 Tools for simulation of textile handling process

The handling of textiles can be realized by different handling operations. The project BladeMaker is researching the manufacturing of thick composite structures by automated pick & place-process. In the last years there a lot of different technologies for the handling of textiles have been developed. Especially handling technologies for grabbing the complete surface of the cuttings have been preferred [2, 3, 8, 10]. For flexible manufacturing solutions single gripper like needle gripper or vacuum gripper can be integrated more easy.

In a first application a limited numbers of special suction grippers will be used for the pick & place of fabric cut-offs. This will lead to different deflection of the cut-offs made by varying fabrics or textiles. The handling process has to be executed with minimized mechanical impact on the textiles. The textiles show a low bending rigidity with orthotropic structure which can be measured with a special tool (Figure 4).

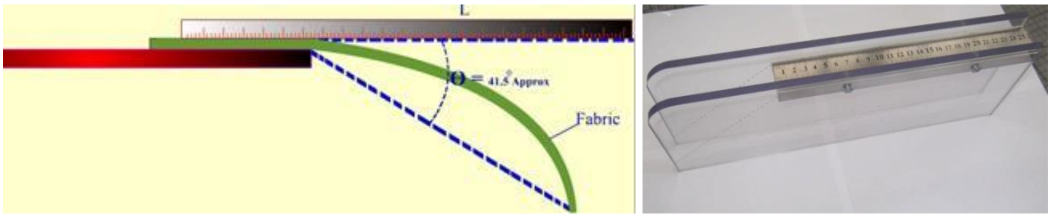

Figure 4: Principle of the cantilever test for measuring bending stiffness of textiles [13]

Because of the different fabrics and textiles used for blade manufacturing the automation equipment has to be able to adapt to the varying properties during the running process. The bending stiffness depends on the textile structure, e.g. the layer design of the NCF, the fibres and roving diameters.

Based on work at the University of Bremen and applied University of Bremen [5, 10, 11] a method for acquiring the material data and set up the FE-Model has been developed.

With these measured propoerties of the textiles plus the weight, the thickness and the geometry it is possible to set up a geometrical-nonlinear FE-Model for large deflections. For this purpose the existing FE-Model based on nonlinear, orthtropic shell-Elements by ANSYS will be enhanced by an optimisation algorithm as shown in Figure 6.

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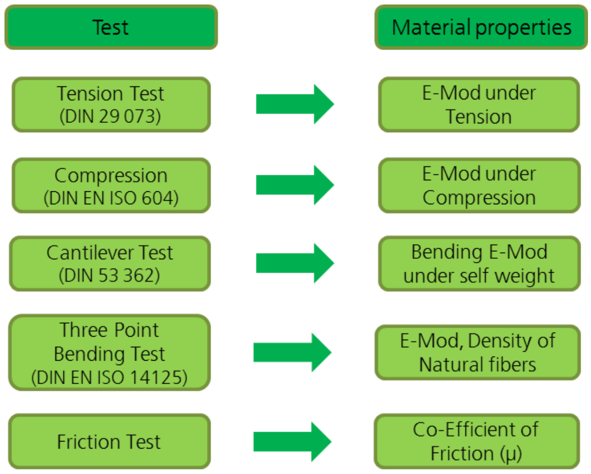

Figure 5: Typical data of of technical textiles aquired for FE-Analysis [13]

The existing methodologies are based on Element having the same E-Moduli under both Tension and Bending Conditions.However, the handeling requires consideration of bending with different E-Moduli from Tension (Membrane effect).

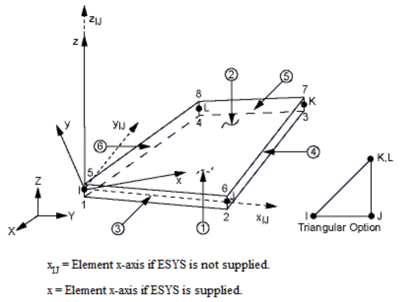

Figure 6: 8-node Ansys-Element used for the simulation of the handling process [12]

The simulation results have been evaluated by practical trials. For this purpose a gripper using low differential pressure by high flow volume, built at IWES, was used (Figure 3). The cut-offs of different NCF’s were tested and their deflection was measured at several points. Exemplary Figure 8 shows the result for an NCF made of glass. The length of he specimen was 1000mm, the width 500mm. The first model, red line, was adapted to different boundary conditions, resulting in the new model, blue line,which shows good results for the intended aim integral design of handling devices.

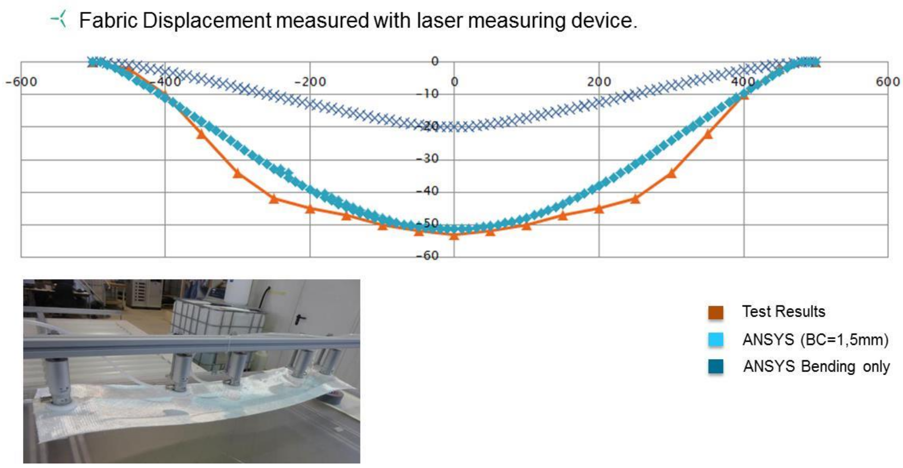

Figure 7: Comparison of real and simulated textile deflection for glass fibre NCF [13]

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As a result of this work the FE-Model was integrated into a MATLAB-tool to calculate the optimized gripping setup for given materials, cutting geometries and number of grippers (Figure 8). The gripper position on the fabric surface is usually not straight forward and needs experience with the particular fabric material. As a next step of this task, the optimization of these pickup locations is done using the inbuilt optimization function FMINCON .This is amultivariable optimization function which call the ANSYS program for various positions of the gripper. Since the design variables are the Gripper Positions(X, Y), the optimization leads to complex multi variable random minimization and takes significant time to complete the optimization.

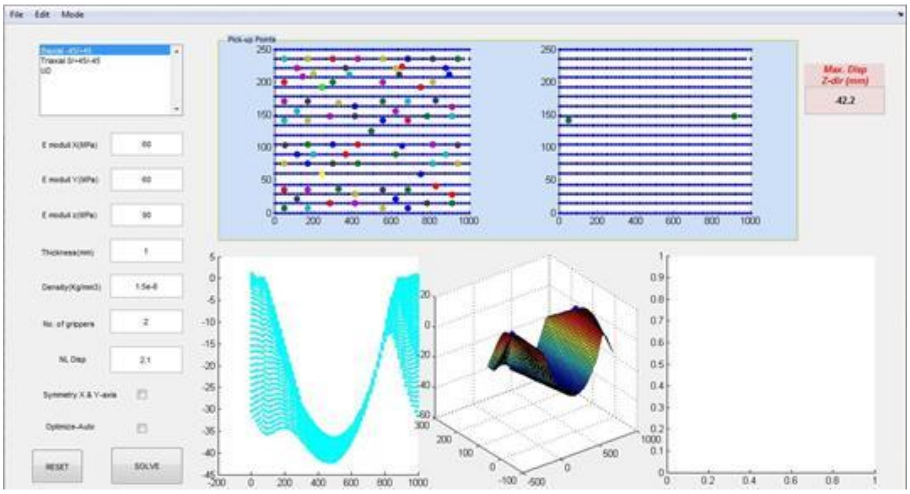

Figure 8: Matlab-integrated Tool for the calculation of optimized set-up of pick-up locations [13]

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