INVERSE CHARACTERIZATION METHOD FOR DRAPING SIMULATION BASED ON AUTOMATIC MEASUREMENT OF FIBER ORIENTATION

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Abstract

FibreMap project aims at the development of an automatic quality control and feedback mechanism to improve draping of carbon fibers on complex parts. There is a strong need in the automotive industry for automatic systems that perform quality control and improve draping processes in order to allow high production volumes. From the simulation point of view, the FibreMap projects aims to develop inverse method allowing material characterization from measured fiber orientation. Indeed, material parameters are key inputs for draping simulation software but they are difficult and somehow expensive to identify. This situation can lead to poor quality of simulation results due to bad material parameters. FibreMap project proposes to overtake this issue by developing a unique optimization loop. Simulation results are compared to experiment results through projection of measured fiber orientation on the finite element mesh. Then PAM-OPT™ capabilities and comparison tool developed by INSA-Lyon are used to modify the simulation input (material parameters) in order to improve simulation results accuracy. Finally, the convergence of simulation results towards measured fiber orientation leads to a better knowledge of the material to be draped.

1. Introduction

Greenhouse gas emission reduction policies sign the advent of composite in the automotive industry. Indeed, one of the levers developed by the automotive industry to produce cleaner cars is overall weight reduction as a 10% mass reduction can give between 6% and 7% fuel consumption reduction[1]. In this context an increasing number of structural parts are produced in so-called "structural" composites. However, very high rates of fabrication required by the automotive industry implies a strong need for improvements of composite manufacturing processes.

Facing the very high costs of trial and error methods in the framework of composite parts manufacturing, simulation becomes a mandatory tool to accelerate and reduce cost of process set-up. A key step of manufacturing processes (LCM or prepreg) is the forming or draping of the reinforcement which controls the fiber orientations and thus the functionality of the final part. However, the accuracy of simulation tools such as ESI Group PAM-FORM™ or INSA PLASFIB™ software is strongly linked to the good

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knowledge of material parameters which identification can be difficult through regular individual test such as the “bias-extension” test[2].

FibreMap project proposes to overtake this issue by developing a unique optimization loop (see figure 1) in order to perform inverse characterization of material properties. Initial simulation results are compared to experiment results through projection of measured fiber orientation on the finite element mesh. Then PAM-OPT^{TM} capabilities and comparison tool developed by INSA-Lyon are used to modify the simulation input (material parameters) in order to improve simulation results accuracy. Finally, the convergence of simulation results towards measured fiber orientation leads to a better knowledge of the material to be draped.

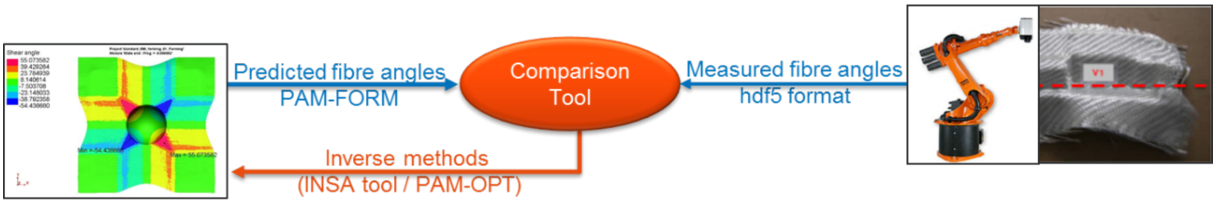

Figure 1. FibreMap inverse material characterization loop

The current paper focuses on an extensive presentation of the tools and methods currently developed in the project in order to perform inverse material characterization for draping simulation.

2. Draping Simulation Software

Draping simulation consists in anticipating the deformed architecture of a fabric due to the forming process. To achieve this, two kinds of methods exist. On one hand, kinematic approaches are fast and easy to use but perform pure geometric analysis and therefore do not account for physics. On the other hand, finite element software based on physical behavior of the plies are more accurate but require more CPU time and above all necessitate material parameters characterization. In FibreMap project, two pieces of finite element software are considered ESI Group PAM-FORM^{TM} and INSA PLASFIB^{TM}.

2.1. ESI Group PAM-FORM^{TM}

PAM-FORM^{TM} is a finite element software used to simulate the preforming process of dry textiles or the thermoforming of prepregs materials made of thermoset or thermoplastic resins. It predicts final fiber orientations, thickness distribution, optimum initial flat pattern, bridging, wrinkling, etc. All of these results are available at the ply level and not just at laminate level allowing, for instance, the prediction of internal wrinkles. The numerical method used is finite elements with explicit time integrations accounting for large displacements, large rotations and large strains. Each ply is modeled with an anisotropic material behavior [3].

2.2. INSA PLASFIB^{TM}

PlasFib is finite element software developed at INSA to simulate draping and forming of dry or prepreg fabrics. This piece of software is based on a semi-discrete approach. In this approach that is intermediate between stadard finite element and discrete methods, the textile composite reinforcement is considered as a set of a discrete number of unit woven cells submitted to membrane loadings, i.e., biaxial tension, in-plane shear and bending moments which are directly those given by the experimental tests and are specific to textile composite reinforcement[4].

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3. Fibre Orientation Measurements

Fiber Angle measurement uses a specific patented sensor technology that is able to acquire a dense mapping of fiber angles from images acquired from a carbon fiber surface. The sensor technology is made of two main sub components, a ring of LED and a gray scale camera looking perpendicular to the surface of the part to be scanned (see figure 2(a)). As explained by Palfinger et al. in [5], it is possible to measure fiber orientations with the system by comparing multiple images created by the reflection of the light from several LED groups on the carbon fibers captured by the camera.

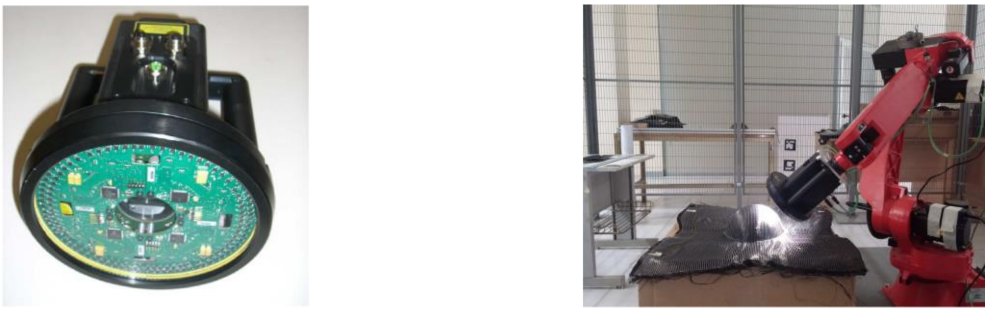
(a) (b)

Figure 2. (a) Sensor courtesy of PROFACTOR. (b) Automatic fiber orietation measuring system (robot + sensor) courtesy of IT+ROBOTICS and University of Padova

This sensor is mounted on a robot that will scan the whole part by following an automatically generated path covering all relevant surface areas on the part (see figure 2(b)). Using accurate calibration and synchronization mechanisms. The measured fiber angles are then projected on the 3D model of the part leading to a set of vector coordinates (x, y, z, u, v, w). This technology provides results at the yarn scale, i.e., one direction vector per measuring point corresponding to the orientation of the individual yarn located under the measuring point (see figure 3).

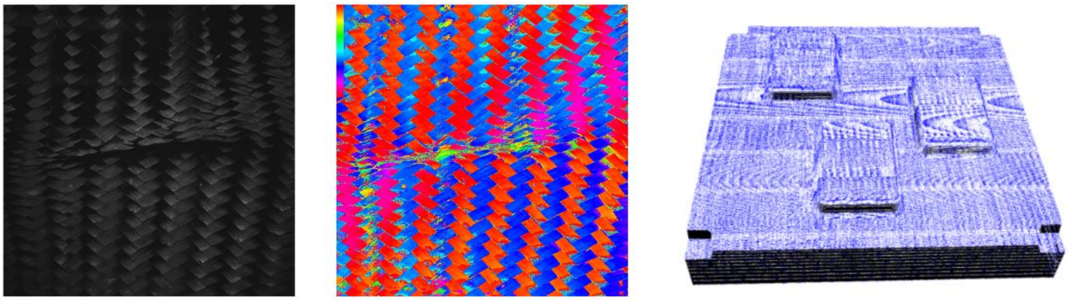
(a) (b) (c)

Figure 3. Fibre Orientation results: (a) Raw image from the sensor, (b) Color coded orientations, (c) Set of vectors projected on 3D CAD

4. Comparison Tool

The comparison tool is a set of MatLab^{TM} files which compare the experimental fiber orientation measurements and the results of finite element draping simulations. The schematic presentation of the com-

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parison tool is shown in figure 4. It is made of two main scripts, “Fiber Direction Script” (FD Script) and the “Comparison Script”.

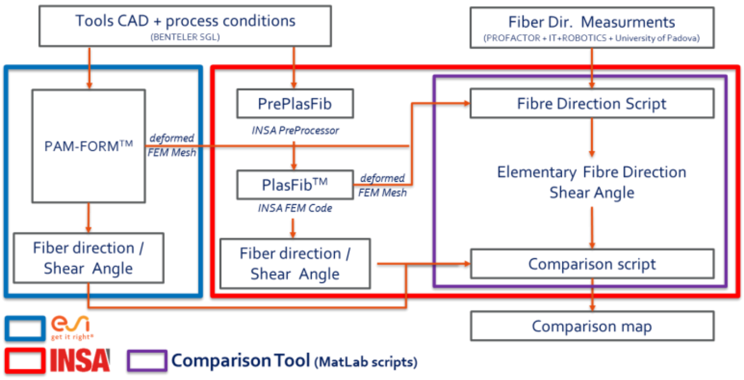

Figure 4. Comparison tool schematic presentation

The FD Script reads data from the fiber orientation measurement system and converts it into a discrete element-wise field of fiber directions. Indeed, the very high resolution of the data provided by the measuring system (few million vectors for a 0.16m^2 preform) and the fact that this data consist in one vector per measuring point don’t allow a direct comparison with finite element results which provide warp and weft directions for each finite element. So the FD scripts, consists in projecting experiment data onto the deformed finite element mesh (result of simulation) and then for each element averaging individual yarn directions into two vectors (warp and weft direction) at element level. Figure 5 illustrates the orientation re-scaling by showing the superposition of typical experiment data and output of the FD Script.

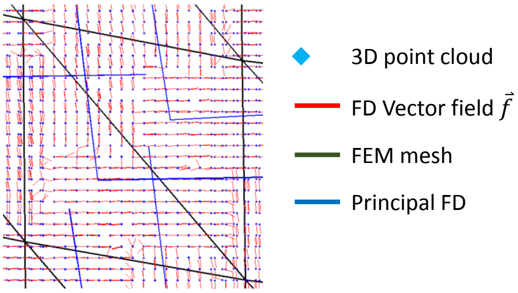

Figure 5. Comparison tool schematic presentation

“The Comparison Script” consists mainly in graphical post-processing of data obtained from draping software and FD Script. After FD Script, experimental shear angle is directly deduced from fiber direction elementary field, thus it can be compared easily with simulation results for each element of the FEM mesh. All results are interpolated to obtain nodal values.

5. Inverse Characterization Method

The objective of the inverse characterization method is to identify (or calibrate) the material parameters to input into draping simulation software from a simple draping experiment rather than from dedicated characterization experiments. The overall objective is to optimize material parameters in order to minimize the difference between the simulation results and the experimental reference. In this paper, we will focus on the shearing behavior of the reinforcement which is usually the trickiest to identify based

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on experimental tests. This parameter represents the ability of the yarns to rotate with respect to each other in order to allow the reinforcement to conform to complex shapes such as double curvatures. The following will present the developed work-flow to identify this input from a reference experiment.

The optimization loop, illustrated on figure 1, is constituted of three main pieces of software. An optimization engine (PAM-OPT^{TM}), the comparison tool and a finite element software dedicated to draping simulation (PAM-FORM^{TM} or PLASFIB^{TM}).

5.1. PAM-OPT^{TM}

PAM-OPT^{TM} is a software package from ESI Group which organizes repeat process calls to an executable program, such as PAM-FORM^{TM}. Each process call computes points in a parametric solution space. PAM-OPT^{TM} organizes the parameter set for the repeat process calls, controls the execution of the chosen solver with these parameters on a single computer or distributed network, then manages the results in the output space, as shown schematically in Figure 6. PAM-OPT^{TM} was developed to solve optimization problems using a variety of techniques.

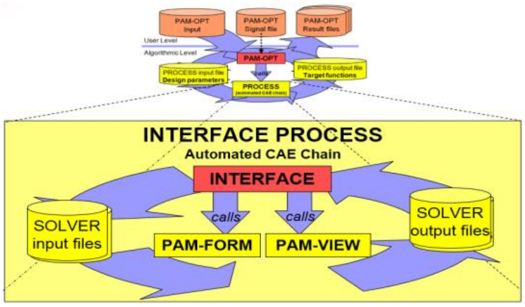

Figure 6. PAM-OPT^{TM} flow chart

PAM-OPT^{TM} is used here to control the optimization loop, it will handle solver input generation, solver and comparison tool calls and analysis of comparison output.

5.2. Optimization loop

In order to calibrate the shearing behavior of the fabric, a simple forming experiment was considered. The so called “three hills” geometry consists in three boxes in the middle of a 300x300 mm^2 rectangle as described in figure 7. The manufactured preform is made of 4 fabric plies conformed to the die geometry. The preform is then automatically scanned with the fibre orientation measurement system. The resulting file is used as a reference in the optimization loop. The manufacturing process is then modeled in PAM-FORM^{TM}. Finally, PAM-OPT^{TM} generates input files modifying the shear behavior, calls PAM-FORM^{TM} solver to run simulations and calls comparison tool to compare simulation results with measured fiber orientations. This loop is repeated until convergence which is reached when experimental and simulation fiber directions difference is smaller than a defined threshold.

In this research, two optimization algorithms are used, genetic algorithm and “ESI adaptive RSM” algorithm. On one side, genetic algorithm can handled highly non-linear problems avoiding convergence toward local minima but requires a lot of solver calls (high use of computing resources). On the other side, “Adaptive RSM” is an ESI special implementation of the RSM methods. It requires a small amounts

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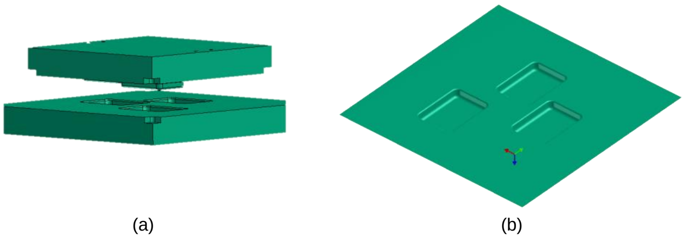
(a) (b)

Figure 7. Three hills geometry: (a) CAD of punch and die, (b) overview of die top surface

of solver calls (small use of computing resources) but is limited to problem with a small number of local minima. Those two approaches are implemented in PAM-OPT$^{\text{TM}}$ and can be used to perform the optimization analysis.

6. Conclusion and future work

We presented an innovative approach aiming to identify shearing behavior of dry fabric in order to perform more accurate draping/forming simulations. Instead of performing a standard "picture frame" or "bias-extension" tests which are not simple to handle, it is proposed to consider a simple draping experiment. Preform resulting the experiment is automatically scanned with FibreMap fiber orientation system. Then, the fiber angles resulting the scanning are used as a reference results in an optimization loop which modify simulation input until material dataset is representative of reinforcement behavior. This method is currently under validation and additional results will come.

As future work, it will be necessary to investigate further the approach in order to identify if it is possible to calibrate several parameters, bending and shearing stiffness for instance, with a single experiment. Especially, additional sets of geometries and process parameters will have to be tested.

Acknowledgments

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