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MODELING OF ROBOT DRAPING SEQUENCES WITH PREPREG PLIES

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Summary. The draping of woven prepreg fabric onto a double curved mold is currently done manually but a robot system under development will enable to automate the process. This automation relies on modeling of the fabric during manipulation such that satisfactory layups can be achieved. The present study presents a Virtual Draping Environment (VDE) that can aid in the generation of robot sequences as well as simulate the process off-line as a verification. Amongst other things, the VDE consists of a nonlinear transient Finite Element (FE) model based upon experimental data obtained at different strain rates. The numerical results illustrate that the model can predict the final configuration with the fabric on the mold, but that the robot sequences should be chosen carefully in order to avoid defects such as wrinkles.

1 INTRODUCTION

Woven carbon fiber plies which are pre-impregnated with resin, so-called prepregs, find considerable application in the aerospace industry due to the favorable mechanical properties. In the production process of carbon fiber parts, a substantial number of plies are draped onto a double curved mold prior to curing. This process is manual which not only is costly but also prone to variations in the final product quality. An automatic robot draping system which can handle entire prepreg plies is therefore under development as part of the research project FlexDraper. It features a specially designed tool with an array of actuated grippers for manipulation of the ply. Current automatic solutions are restricted to unidirectional plies[1].

The ideal draped configuration implies that the ply follows the mold surface within tight tolerances and that the fiber angles match prescribed angles. While the ideal end configuration is straightforward to calculate, it is not trivial how to reach it with the robot. That is, the grippers can move in infinitely many ways but some draping sequences will result in wrinkles and air pockets. Such flaws will deteriorate the mechanical properties of the final part and cannot be tolerated. One of the major tasks associated with development of the robot system is thus to generate feasible draping sequences. To this end,

off-line simulation is very convenient during the development process.

The modeling of fabric dates back to 1956 with the kinematic pin-jointed net model proposed by Mack and Taylor[2]. More recently the Finite Element (FE) method has yielded more accurate modeling of reinforcement fabric e.g. for simulating preforming as part of the Resin Transfer Molding (RTM) process. In the work by Peng et al.[3] a hyperelastic material model with test data input was presented. Hamila et al.[4] developed a special purpose finite element for the simulation of woven fabric. Common for all models is, that they must account for the changing fiber angles, i.e. shearing or trellising, which is a result of the transformation from a flat to a double curved mold surface. Experimental characterization is also a well visited field, see e.g. Cao et al.[5].

This study will combine a kinematic mapping algorithm and a nonlinear FE model to investigate robot draping sequences with emphasis on the path taken to the draped configuration.

2   THE VIRTUAL DRAPING ENVIRONMENT

The system under consideration consists of the mold, the ply and the grid of actuated grippers. During draping, the grippers will move the ply down to the mold. In order to generate and assess draping sequences a Virtual Draping Environment (VDE) has been developed, see Fig. 1. It consists of a module that can predict the ideal draped configuration on the mold and generate draping sequences by means of various interpolation schemes. The second module it a nonlinear transient Finite Element (FE) model used to assess the draping sequence by including the physics of the prepreg material. In the following, the mapping algorithm and the transient FE model is elaborated.
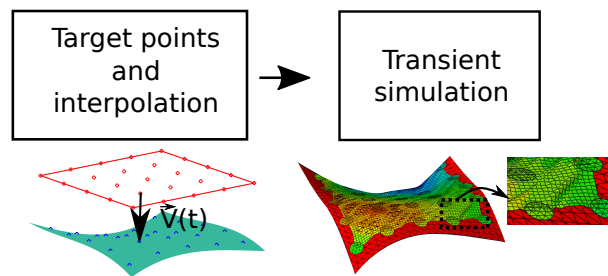

Figure 1: The virtual draping environment.

2.1   Kinematic Mapping Algorithm and Interpolation

The kinematic mapping algorithm[6] assumes that the fibers do not extend while the ply is allowed to shear infinitely. The mapping of the ply from the flat configuration in $\mathbf{R^2}$ onto the mold in $\mathbf{R^3}$ is then uniquely determined by a starting point with known fiber angles. From the mapped ply it is possible to extract target points for the actuated grippers. That is, the points that the grippers should move to in the final configuration.

Next, an interpolation from the gripper points in the initial configuration to the gripper points in the final configuration is carried out. Here, a linear interpolation in time is employed.

2.2 Nonlinear Transient Finite Element Model

The nonlinear transient Finite Element (FE) model is built using Abaqus Explicit and linear shell elements. The mold and the grippers are modeled as rigid with the latter represented by the lower contact surface. The ply is modeled as nonlinear rate-dependent, which is accomplished by the intrinsic phenomenological material model *fabric* which is indeed suitable for fabric material with two initially orthogonal structural directions. While the fibers are stiff in tension, relative fiber motion within the yarns results in a low bending stiffness. In order to capture this phenomenon with shell elements based on lamination theory, the compressive stiffness is lowered effectively causing the Young's modulus to be asymmetric. The material model uses test data as input, i.e. nominal stress and strain for fiber direction 1, direction 2 and for shear. These data are obtained by material characterization at different strain rates, i.e. tensile tests, bias-extension tests and cantilever bending tests. The latter is used to determine the compressive stiffness of the fibers. The grippers are fixed to the ply, such that no slipping is possible. The contact formulation between the mold and the ply uses a Coulomb friction model in the tangential direction with an experimentally determined coefficient of friction equal to 1.5.

3 NUMERICAL RESULTS

The ply is mapped onto the mold and the linear interpolation is done for all 25 grippers. The draping sequence is then simulated using the FE model and the results are depicted in Fig. 2. As is evident from the figure the draped configuration has large diagonal wrinkles
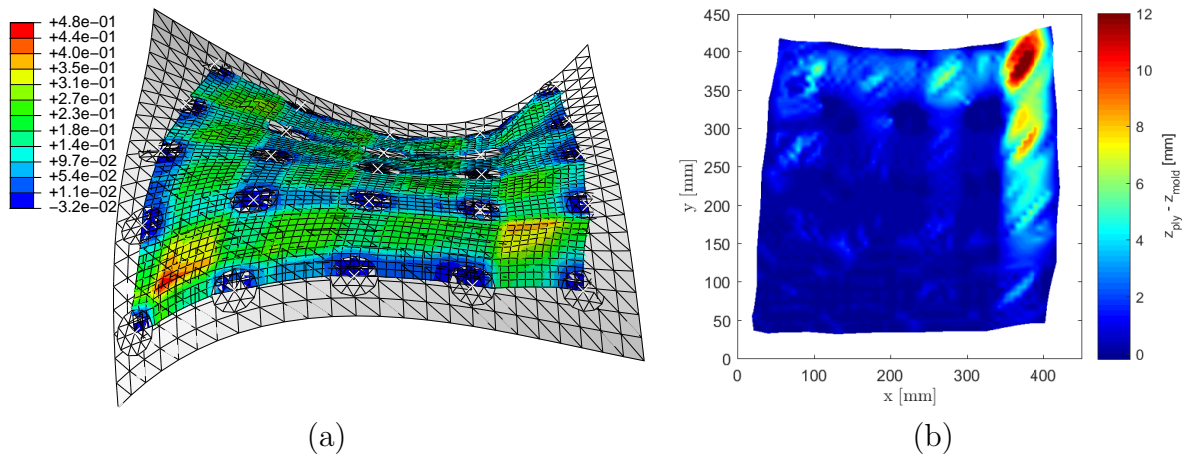

(a)   (b)

Figure 2: Simulation of linear interpolation draping sequence. (a) The ply in the draped configuration on the mold. Contours: shear strain. (b) The height (z) difference between the ply and the mold.

or shear buckles, mostly in the concave areas. They can in part be attributed to the no-slip condition between the grippers and the ply which over-constrains the material but more importantly to the simple draping sequence employed. So while the model is capable of simulating the process, more work should be put into developing feasible draping sequences.

4 CONCLUSIONS

This study has presented a Virtual Draping Environment (VDE) and demonstrated its applicability in the development of automatic robot draping sequences. The kinematic mapping algorithm can easily predict the ideal draped configuration, but it doesn't include information about how it is reached. This is the reason why the transient Finite Element (FE) model is employed. The simulation with the simple linear interpolation draping sequence predicted wrinkles in the draped configuration. Thus, the conclusion is that feasible draping sequences are path dependent and non-trivial to generate. The problem will be addressed in a future study.

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