FINITE ELEMENT ANALYSIS OF THE THERMO-FORMING PROCESS OF THERMOPLASTIC COMPOSITE PARTS

F. Pascon, M. Bruyneel (LMS Samtech, Belgium);
M. Schultz, C. Brauner (Faser Institute, University of Bremen, Germany);
H. Hasselbruch (IWT Institute, University of Bremen, Germany);
H. Krieger, T. Gries (Institut für Textiltechnik (ITA) of RWTH Aachen University, Germany);
K. Jalta (ISMANS, France).

Dr. Ir. Michaël Bruyneel, R&D Team Manager

THEME

Composite manufacturing simulation

SUMMARY

In this paper, the numerical solution for the simulation of a manufacturing process for thermoplastic reinforced materials is presented, built in the SAMCEF finite element code. In a first step the depositing /draping of the layup is simulated. This can be done based on a kinematic or a finite element approach and will be compared in this study. In a second step a thermal analysis is conducted, in order to determine the history of the temperatures during the cooling of the composite part. This temperature history is then used for computing the relative degree of crystallisation. During the thermoforming process the relative degree of crystallisation can be introduced as a state variable to identify the solidification point. At this point the matrix material behaves nearly solid and thermal loads can induce process induced distortions. Therefore, at this stage, specific crystallisation based material laws are used. The paper discusses the assumptions made in the analysis chain, the relevance of the different draping methods and the material parameters of the crystallisation laws. Applications demonstrate the ability of the computational chain to identify the final distortion of the composite part, as well as the residual stresses resulting from the manufacturing process.

KEYWORDS

Composites, manufacturing simulation, thermoplastics, crystallisation.

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1: Introduction

In this paper, the results of the research project PROTON (ZIM, Germany), which addresses the simulation of the thermoforming process of composites, are presented. As illustrated in Figure 1, the thermoforming process includes several steps. First, the thermoplastic pre-preg made of woven fabric is heated. It is then draped onto the mould. The compaction is carried out in the closed mould and the subsequent cooling allows the matrix to crystallise and consequently to reach the solid state. The part is then removed from the mould. At that stage, distortion might appear in the resulting composite part due to thermal contraction and chemical shrinkage.

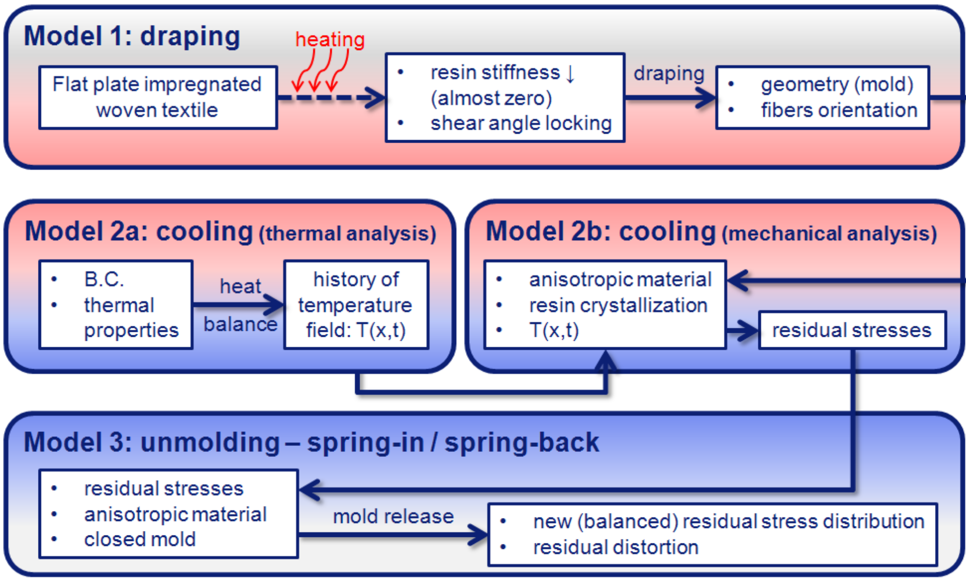


Figure 1: Steps of the thermo-forming process (simulation)

The numerical solution for the simulation of the whole process built with the SAMCEF finite element code is presented. The draping is first simulated. This can be done based on a kinematic or a finite element approach. Then, the thermal analysis is conducted, in order to determine the history of the temperatures during the cooling of the composite part. This temperature history is then used for the modelling of the crystallisation. At this stage, specific material laws are used. The paper discusses the assumptions made in the analysis chain, the relevance of the different draping methods and of the material parameters of the crystallisation laws. Applications demonstrate the ability of the computational chain to identify the final distortion of the composite part, as well as the residual stresses resulting from the manufacturing process.

2: The draping process

The draping process can be addressed in two ways. The first one is based on the solution of the elastic problem with the finite element method [1]. In that case, not only the mould on which the fabric is to be draped must be modelled, but also the full punch system, with the correct boundary conditions (Figure 2).

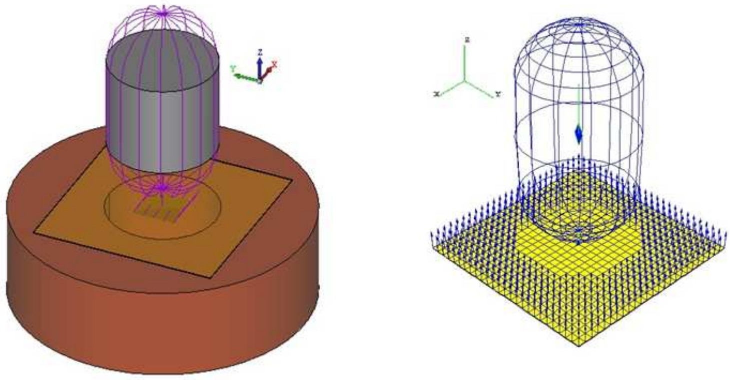


Figure 2: Finite element model of the draping process

A solution obtained with the SAMCEF finite element code is illustrated in Figure 2, and is compared to a solution from the literature [1].

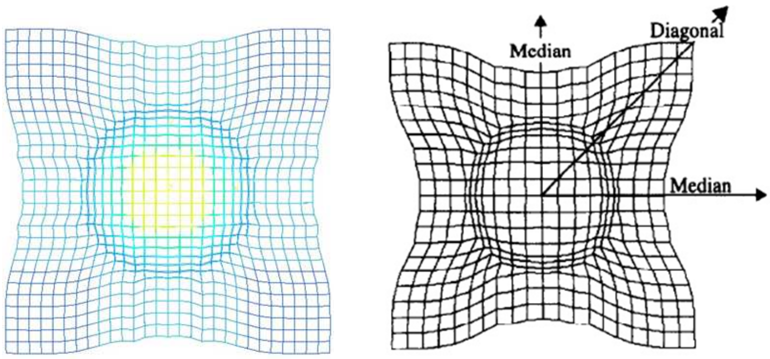


Figure 3: FE solution of the draping simulation

The second way to address the draping simulation is to use a kinematic approach [2]. Here the method developed in [3] for the definition of the course trajectories in the Automated Fibre Placement (AFP) process is used. In this method, a reference fibre is defined on the mesh of the structure. This reference fibre is then propagated to the whole structure, as is an initial front with the Fast Marching Method (FMM) which is used in several fields of the Physics [4]. Since the travel time of each point on the front is the same, the method provides a network of equidistant curves (defined on the mesh, in a level-set fashion). This network can be seen as courses of an AFP process. Since the curves are equidistant, the method avoids the presence of gaps and overlaps.

When two reference fibres, perpendicular at the seed point, are used, the method can be seen as a way to define the draping of fabrics. FEM and FMM solutions are compared in Figure 4. The advantage of the FMM is that it provides a very quick solution, because the computational effort is less. The inconvenient is that this scheme is independent of any fabric pattern. However, even if approximated, a solution is always obtained, what is not the case with the FEM approach as convergence problems in the non-linear solution can appear.

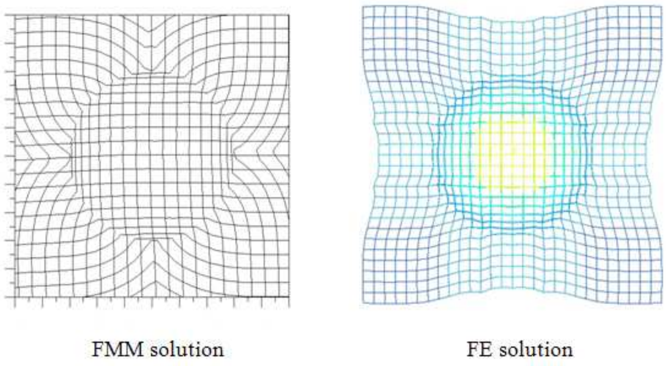


Figure 4: Kinematic approach based on FMM for the draping simulation

Furthermore the textile is draped on another non-developable surface. Therefore the Drapeability-Test [5] with an elongated hemisphere is used at the Institut für Textiltechnik (ITA) of RWTH Aachen University, Germany. In Figure 5 the experimental test setup is shown. A draping ring, filled with lead, functions as a die. After draping the textile on the surface the deformation of the textile is measured optically. The optical measurement system ARGUS (GOM - Gesellschaft für Optische Messtechnik mbH, Braunschweig, Germany) is used. The results of the optical deformation measurement can be used to generate a full field comparison between experimental and simulation results. [5]

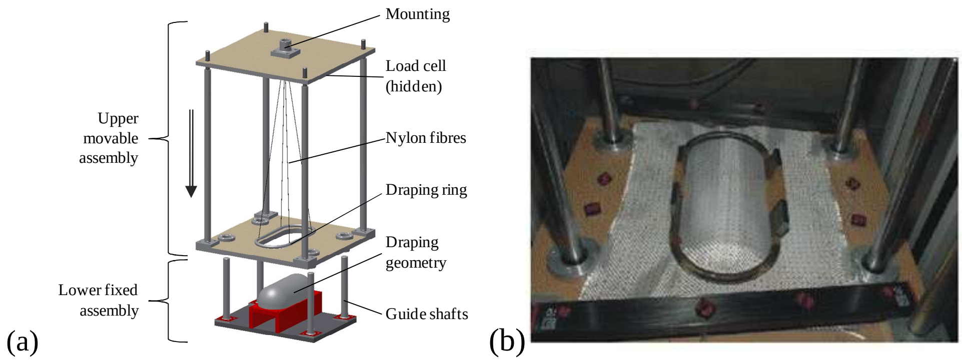


Figure 5: Drapeability-Test : (a) Principle. (b) Textile draped on an elongated hemisphere [5]

In Figure 6 the numerical results obtained for a textile draped on the elongated hemisphere in the Drapeability-Test are presented. The finite element model is set up in order to reproduce the sequence that forces the textile on the surface, and the use of the draping ring.

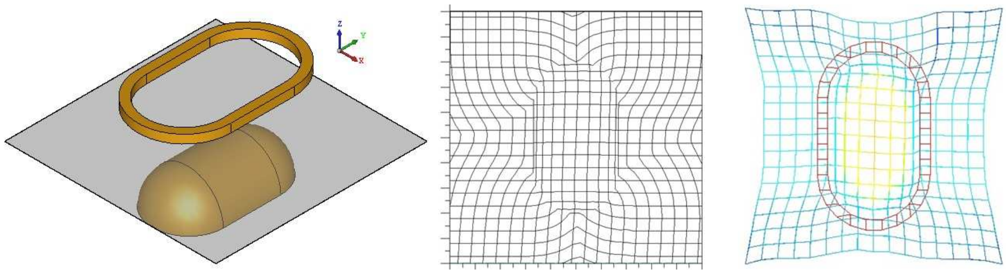


Figure 6: Kinematic approach based on FMM for the draping simulation

3: The thermal analysis and the crystallisation

While the thermoplastic material cools down, its structure changes from a liquid state to the solid state. With the crystallisation kinetic model developed in [6,7], it is possible to determine the relative degree of crystallisation $\theta(T)$, which is a function of the temperature T and of the cooling rate (see Figure 7).

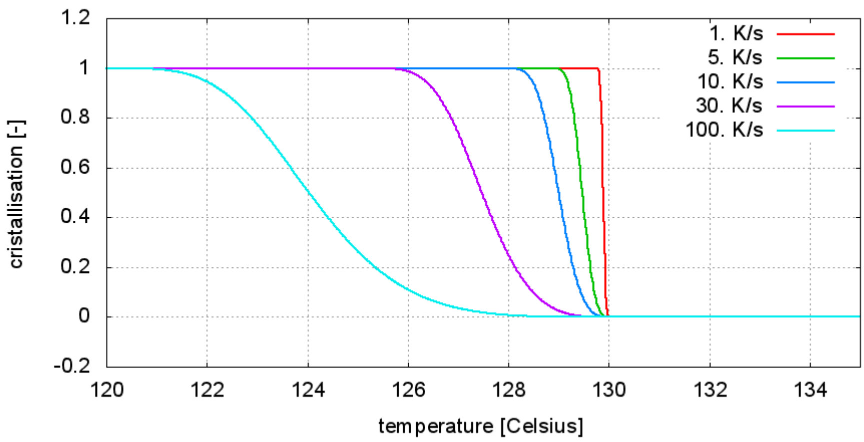
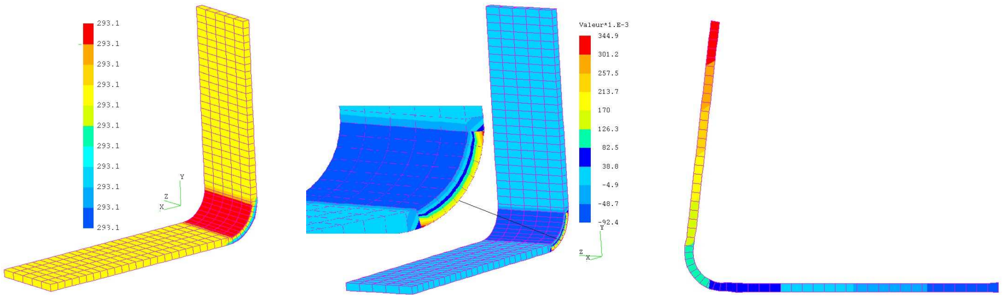


Figure 7: Relative crystallisation degree wrt temperature and cooling rates

It is assumed that as long as the relative degree of crystallisation is lower than 50%, the mechanical properties of the matrix are very close to zero. Above this rate, solid mechanical properties appear, and thermal loads can induce deformations and residual stresses.

4: Illustration

The case of an L-shaped beam is studied here. In that case, the draping of the textile is trivial and skipped from the results. In Figure 8, the results of the thermal analysis are given. It reflects the cooling of the structure. The temperature history will be used as an input for the crystallisation model.



Temperatures Crystallisation Shape distorsion

Figure 8: The full analysis process applied to a L-shaped beam

5: Conclusions

A first solution obtained with the SAMCEF finite element code for the simulation of the thermo-forming of thermoplastic composites was presented. The draping simulation was studied with the finite element method and with a new kinematic approach. The process simulation, including the crystallisation of the matrix, was able to identify the distortion resulting from the manufacturing process. A comparison with experimental results is planned in order to validate the approach.

6: Acknowledgements

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