Numerical simulation of reinforcements forming: the missing link for the improvement of composite parts virtual prototyping

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ABSTRACT: *Composites draping simulation is introduced. There are basically two methods: the geometric approach and the mechanical approach. The possible results that can be obtained using these methods are illustrated by an example. This type of simulation can be used not only to optimize the fabrication process but also to improve the mechanical performance calculations and more generally speaking the composite parts design. For example, the influence of the preforming operation on resin injection for processes like resin Transfer Molding (RTM) is demonstrated on a numerical example.*

RÉSUMÉ: *La simulation de drapement de composites est présentée. Il y a essentiellement deux classes de méthode : approche géométrique et approche mécanique. On rapporte un exemple illustrant les différences possibles entre les résultats fournis par les deux méthodes. Ce type de simulation peut-être utilisé pour optimiser le procédé de fabrication mais aussi pour améliorer les calculs de performances mécanique et plus généralement la conception des pièces composites. Comme exemple, l'influence du préformage sur l'injection de résine pour des procédés de type Resin Transfer Molding (RTM) est mise en évidence numériquement.*

KEY WORDS: *numerical simulation, composites, RTM, draping*

MOTS-CLÉS: *simulation numérique, composites, RTM, drapement*

1. Introduction

Numerical simulation is nowadays fully integrated into industrial design processes for metallic parts. In spite of the progress made in modelling, this level of maturity has not been reached so far for composite parts. One of the identified reasons is that the strong effects of manufacturing on the mechanical performance could not be taken into account.

One reports here the status of forming simulation operations that have been developed over the last ten years (section 2). These methods are useful to assist the process engineer in the optimisation of the fabrication and even more importantly provides information to subsequent analysis. As an example, the use of the draping results to improve the injection in resin transfer molding process is reported in section 3. This is presented as a first step towards the development of a full numerical tool that will enable to perform mechanical performance analyses based on a description of the composite part as it is built.

2. Reinforcement Forming Simulation

There are two main numerical methods available for simulating the forming operations: the geometric method and the mechanical method. Each of these methods is described hereafter.

The geometric method uses only geometrical information namely the part geometry. The numerical method used is known as the 'fisher-net algorithm' (Rudd *et al.*, 1997) . This method is very quick, the simulation time being approximately one second. The results are made of the shear angle and possibly of the flat pattern. Because only the geometry of the part is used in a simulation, the reinforcement architecture is not taken into account, nor the process or the process variant used. The common use of this method is to identify the areas with large shear and to compare the results with the maximum shear angle that can sustain the fabrics ('the locking angle'). That allows for a rough estimation of the part feasibility.

The second method is the mechanical approach and leads to the use of the finite element method. Most of the examples reported as today are based on an explicit time integration. This method is very popular for dynamic problems like car crash simulations and was extended successfully to forming problems (Pickett, 1995). This method can handle easily the various non linearities encountered in forming simulations: large displacements, rotations and strains, non linear mechanical behaviour and non linearities induced by extensive contact.

For unidirectional reinforcement or for woven fabrics, non linear elastic behaviour is assumed. A special treatment is done regarding the modelling of the yarns bending and shearing (Cartwright, 1999); this is dictated by the discrete nature of the reinforcement, as opposed to a continuum medium. If the reinforcement is not dry but pre-impregnated, a viscous modelling of the matrix is introduced. In this case it is also necessary to use a mixed dry and viscous modelling of the sliding. When relevant, thermal modelling is included in the analysis; the temperature modifies the viscosity of the resin and the friction coefficients. Additional details can be found in (Pickett *et al.*, 1996). As can be deduced from this short description, significant material characterization is necessary before conducting a simulation (Clifford *et al.*, 2001).

Thanks to this accurate modelling, all the details of the process like blankholder forces, tools and laminate temperatures, holding systems can be considered (de Luca *et al.*, 1998). Also, different materials give different results. This method is clearly a tool to optimize a forming process.

One reports here an example where the geometric method fails and the mechanical method reproduces successfully the reality. The part is a section of a prototype helicopter blade. An unidirectional prepreg is draped by hand over a tool. Irrespective of the way in which it is draped, a wrinkle consistently appears at the same constant location and a lack of adherence is noticed on a part of a radius.Figure 1 depicts a view of a ply after draping as computed by the finite element method. A wrinkle is clearly visible on the right hand side. Figure 2 shows sections along the length of the tool. One can see the tool sections (red lines) and the ply sections (green lines). There is a zone with a lack of adherence that is shown by the calculation that is visible exactly at the location where it happens in reality.

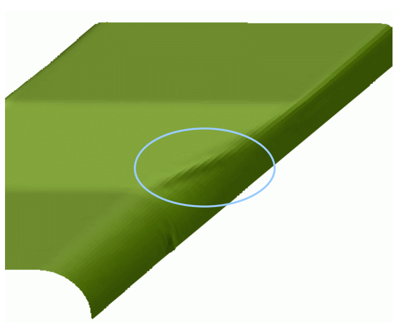

Figure 1. *Prototype blade Helicopter: Wrinkling.*

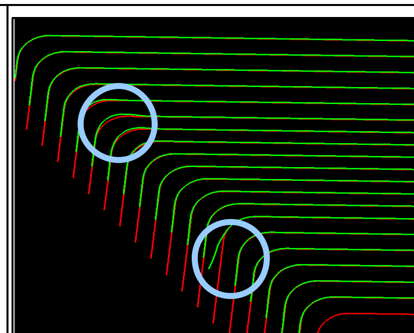

Figure 2. *Sections view. Wrinkling and lack of adherence.*

The hand lay-up process is modelled using a static pressure with a value comparable to the pressure that can be exerted by the hands of a worker. Other examples have been reported elsewhere for a wide range of processes: matched metal tools, diaphragm forming, rubber pad forming and roll forming.

To be exhaustive on this topic, one has to mention the development of intermediate method that combine a geometric approach and a mechanical approach through the minimization of the deformation energy (Long *et al*., 2001). This term usually includes only a limited number of terms (for instance only shear energy). This is useful to take into account the nature of the reinforcement but the process is still not taken into account.

3. Use of forming results in RTM injection simulations

Briefly the RTM (Resin Transfer Molding) unfolds in two steps. In a first step, a preform is placed in a mold which is closed. Then, resin is injected and flows through the reinforcement. After curing, the composite part is obtained.

Work on the simulation of the RTM injection simulation started about the same time as the development of the preforming simulation (Trochu *et al.*, 1993), which ave have reached now a good level of maturity. The critical material parameters that drives the filling of the mold is the so-called permeability K that appears in the Darcy’s law which is used to model the flow through the reinforcement.

$$V = [K]\ \text{Grad. } P / m \qquad [1]$$

where P is the hydraulic pressure, m is the fluid viscosity, and V is the velocity field. To perform a simulation, an experimental measure of the reinforcement permeability is necessary. Most of the time the permeability values used are for undeformed reinforcement. Though it is known that deformation modifies significantly the permeability, not only the numerical values but also the principal directions of the permeability tensors as observed by (Louis *et al.*, 2001). This calls for calculation of the permeability field prior the beginning of an injection simulation. One reports thereafter an example of such an influence.

The geometry studied is a bath tube (figure 3). The filling time contour using a constant permeability can be seen on figure 4. To study the effects of the draping, a filling simulation is done using a permeability field based on a preliminary geometric calculation of the fiber reorientation that occurs during the draping (figures 5 and 6). The shearing angle reaches 52°. The permeability is computed using the Kozeny-Carman model (Rudd *et al*., 1997). The results are shown on figure 6: the shape of the flow front is different. From a practical point of view, it means that the vents should be located at different points. Other examples dealing with a bonnet geometry shows a variation of the filling time of 20% (de Luca *et al.*, 2002).

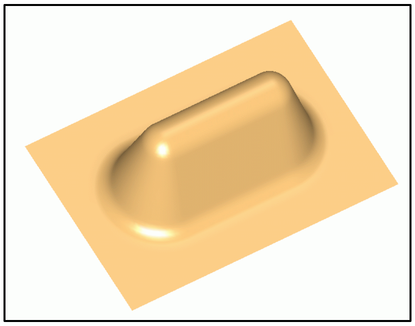

Figure 3. *Bath tube geometry*

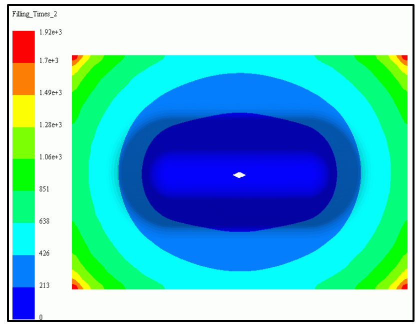

Figure 4. *Filling time contour*

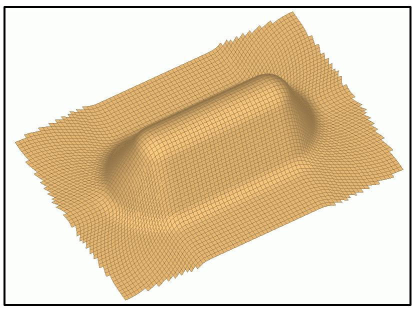

Figure 5 *Fiber reorientation*

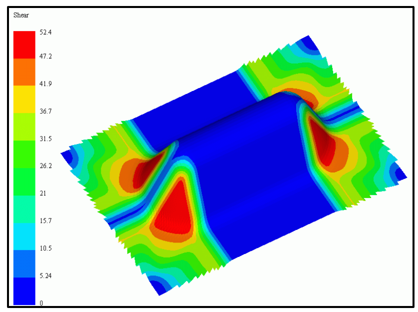

Figure 6. *Shear angle*

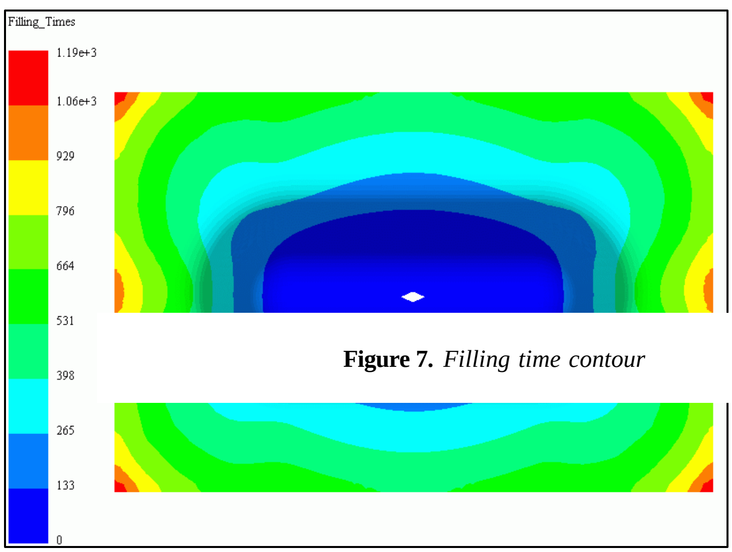

Figure 7. *Filling time contour*

4. Conclusion and perspectives

A state-of –the-art of the numerical simulation for reinforcements of composite parts was presented. These new types of numerical tools enable not only to optimize the draping process but also make available manufacturing information (fiber reorientation) for further analysis. An example regarding the influence of draping on RTM injection was reported.

The current research tackles the modelling of new types of reinforcement architectures: multi-axial fabrics, knitted and braided reinforcements. To take full advantage of the draping results, it is necessary to develop appropriate permeability models for all of these reinforcements both in undeformed and deformed states.

Finally, this work in the RTM field is only the first step of the development of comprehensive simulation tools for the design of a composite parts. The next steps include using draping information in mechanical analysis and in impact or crashworthiness studies.

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