CONSISTENT GEOMETRICAL MODELING OF INTERLOCK AND 3D FABRICS

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Abstract

Numerical approaches at the elementary cell level represent a promising method to determine fabrics mechanical properties and permeability for example. But, these simulations are associated to a lot of difficulties linked to the multi-scale nature of the fabric and the large strains. A key point for meso 3D finite element simulation is the obtaining of an accurate 3D geometry of the unit cell. The present paper presents a powerful method that enables to generate consistent unit cells of interlock or 3D fabrics using the standard CAD software Catia V5 and user routines. The unit cells are said to be consistent since the contacts between the yarns are accurately described (no voids or interpenetration).

1 Introduction

Numerical simulations at the part scale represent a powerful tool to predict the feasibility of a composite part using a LCM process with given fabric and resin [1, 2]. Difficulties generated by this type of calculation are numerous, but among them one of the main issue is to dispose of accurate models of the mechanical behaviour and permeability of the dry fabrics. Experimental methods are efficient [3] to identify these properties but since, they are difficult, time consuming and expensive to perform, when dealing with composites materials they need to be complemented with numerical approaches [4]. In addition, experimental techniques cannot be used to investigate the design of new fabrics. Other approaches have consequently to be considered to identify the fabric properties: among them, one of the most promising is undoubtedly the 3D finite element analysis at the meso scale, that is at the scale of the unit cell. Indeed, it enables to ensure a good compromise between accuracy and complexity, dealing with the interlacement of the yarns without explicitly modelling the thousands of fibres. However, the difficulties induced by this type of calculation are numerous: large strains and displacements, important number of contacts, specific homogeneized behaviour law for the yarns, meshing [5,6]. But before dealing with the implementation of the material behaviour and limit conditions of the finite element calculation, one needs the 3D geometrical model of the unit-cell. Since the specific fabric properties are mainly due to the interlacement architecture, it has to be represented with a high accuracy. Representing sharply the contact zone between the yarns is a difficult and key point at different levels. First, the local crushing at contact zones between the yarns plays a crucial role concerning the mechanical behaviour (non-linear part of bi-axial extension for example). Secondly, as far as permeability is concerned, the contact description is very important since it is responsible for the definition of local micro and macro pores and then has a significant influence on the resin flow. Thirdly, the section shape evolution during the fabric deformation is significantly affected by its description at the initial state. Finally, interpenetrations between the yarns don't authorize the convergence of the finite element calculation, thus, if they appear complex strategies have to be used to overcome this problem.

Different tools exist so as to obtain the CAD model of a unit-cell, the most well known in the composites community are WiseTex [7] and TexGen [8] , both of them of powerful and efficient software that enables to deal with any architecture of textile reinforcements from UD to NCF and 3D. . Many other techniques can be found in the literature based on the same principle, that is considering independently the different networks only dealing a posteriori with internal contacts networks [9-14]. Because it is so important oft finite element simulations, the strategy proposed in this paper is to make the consistency a natural property of the model.

For 2D fabrics, consistent 3D CAD modelers have been developed over the last years [6]. They enable to obtain consistent, accurate unit-cells but are restricted to standard 2D fabrics (plain, twill, satin weaves). Due to the complexity of the weaving targeted, the 2D approach cannot be directly adapted but has to be fundamentally revised. The goal of this paper is to present this new approach that leads to the obtaining of consistent unit-cells of complex (interlock, 3D fabrics).

2 Model properties

The present model has four main characteristics. First, the model is said to be consistent, i.e. a surface contact is imposed between the transverse yarns at the interlacements. Therefore, no voids or interpenetrations can occur. This property will be obtained imposing that the contact zones of the warp and weft yarns are represented by the same surface.

Secondly, the yarn section shape changes along the trajectory. Thus, the yarn profile is a variable section sweep along a curvilinear trajectory.

Thirdly, the geometrical model is build using standard CAD softwares so that one can benefit of their powerful geometrical features.

Fourthly, any type of weaving can be dealt with, that is, the user can implement any architecture.

2.1 Contact types

4 types of contacts can be differentiated, according to their nature in interlocks (**Erreur ! Source du renvoi introuvable.**)

- "Weaving contacts": the weaving process is the interlacement of two yarns network, the contacts due to the interlacement process will be defined as weaving contacts.
- "Intermediate contacts" between transverse yarns: since the spacing between the yarns is lower than their width a yarn that could be supposed to be straight (for 2D fabrics for example) between two weaving contacts can encounter other transverse yarns.
- "Lateral contacts" between yarns of the same network: the weaving process is supposed to impose to the yarns of the same network to be parallel and separate; this property is verified for fabrics with low yarn density. But as far as dense interlock fabrics such as G1151 are concerned, lateral contacts between yarns of the same network occurs, because the spacing between 2 yarns can be taken inferior as the width of the yarns.

- "Longitudinal contacts" : bottom/up contacts between yarns of the same network

These 4 types of contacts can have three different consequences:

- a modification of the yarn trajectory and section which is responsible for the yarn crimp,
- a modification of the yarn section without any change in the yarn trajectory, which is a kind of "indentation" ([publi Lomov]).
- Modifications on the yarn trajectory and section can be neglected (publi Lomov)

The challenge is obviously to account as accurately as possible for all these types of contacts and their consequences on the unit cell.

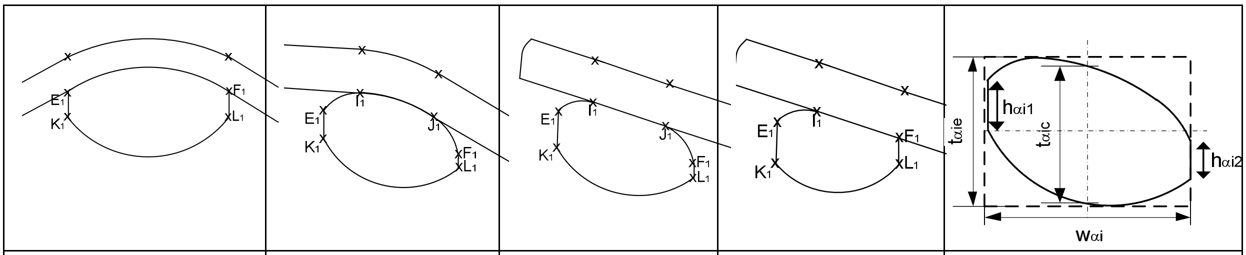
2.2 trajectory

The trajectory is plane and is composed of a succession of straight segments and parabolas, linked with each other by tangency conditions. Parabolas model contacts implying a crimp on the yarn, straight segments model contacts that lead to no modification of the trajectory. Between two contacts (of any type), since no loads except residual tensions can occurs the yarn is supposed to be straight. Straight segments therefore model the free parts of the yarns.

2.3 Section

For 2D fabrics, since the model is mainly dedicated to finite element simulation of technical fabrics, any section shape was very efficiently modelled by two parabolas and two segments [**Erreur ! Source du renvoi introuvable.**, Figure .a]. Concerning interlock fabrics, an extension of this shape is proposed so as to take into account the higher variety and complexity of the contacts. Indeed contacts may occur at different locations around the yarn section and can be modelled by a parabolas or a straight segment (see 1.4.1). One to three curves linked by tangency conditions therefore model the contact face of the yarn, the cases being automatically selected by the software (Figure). The yarn section at each control point is consequently defined using 4 parameters: section width, right and left flange, thickness (Figure).

Obviously the consistency is explicitly respected due to the use of the same geometrical entities at the contact interface for the two yarns. Any other section shapes could be easily implemented but since we intend to mesh the CAD model with hexahedral elements this section shape is well adapted to the need and is able to approach efficiently any section shape (lenticular, elliptic, champs de course,...).



a/ 4 elements section (2D and interlock fabrics)

b/ three conics contact face/ parabolic contact (crimp)

c/ three conics contact face/ straight contact (no crimp)

d/ two conics contact face/ straight contact (no crimp)

/ section parameters

Figure 1: models of yarn section shape.

3 Dealing with contacts

3.1 Weaving and intermediate contacts

As it has been detailed before, intermediate and weaving contacts, that is, contacts between yarns of transverse networks are ensured through the equation system. Composed of straight curves and parabolas, the yarn trajectory leads to 2 types of geometrical constraints have to be considered (Figure 2):

- 2 tangency conditions par parabola (left and right side).
- 2 periodicity condition (continuity and tangency).
- Contact parabola is the same for the trajectory and the section.

In order to obtain a well conditioned system, some unknowns have to be measured or imposed. Even though any unknown could be chosen, the $x_{\alpha ij}$ are selected because they are among the easiest to identify on a real fabric and, in addition, this will lead to an easier manipulation of the model. The yarn crimp is a predominant value for the fabric mechanical properties; therefore, characterizing the undulation of the yarn is a key point to obtain an accurate model. Heights between the summits of the contact and the extremities will be measured experimentally. The trajectory in this case is completely identified solving the previous equation system.

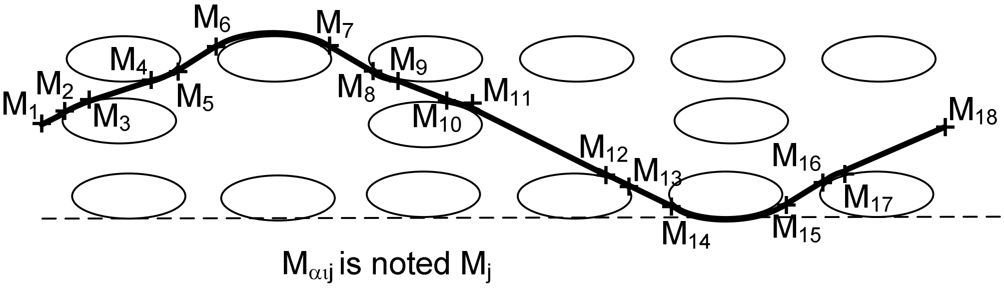


Figure 2: Example of yarn trajectory, Mij are the extremities of the geometrical entities (segments and parabolas).

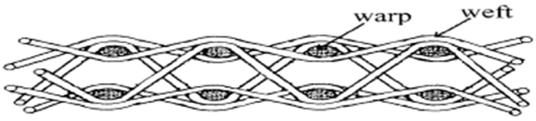
3.2 Lateral contacts

Since the width and the trajectory of each yarn are known, these contacts are automatically detected. The crossing points C_{ri} and C_{ri+1} between two neighboring yarns for which the spacing is smaller than half the sum of the two initial yarn widths w_{i0} and the interference i_{lc} are computed by the software. A control section is then added on each yarn at these points. In order to get the consistency, the user has to predefine a repartition coefficient $r_{lc} \in [0,1]$ that controls the ratio between the transverse crushing and the yarn shift. This ratio depends on the yarn constitution and especially the fibers organization that makes the transverse crushing more or less easy.

4 Applications

Figure 3 presents the architecture of two interlock fabrics that will illustrate the proposed strategy. The first is a virtual fabric derived from a real one used in [15] and has the following characteristics: the pitch distances between the neighboring warps and wefts are 7 and 4 mm, respectively. The thickness of the unit-cell is 1.5 mm. The overall fibre volume fraction was measured to be 0.25, of which 0.07 and 0.18 were lying respectively in the warp and weft directions. Width and thickness of the yarn are assumed to be respectively: 2mm and 0.3mm It is a very simple interlock with a low yarn density for which very few difficulties are encountered.

The second one is a woven reinforcement used in aeronautics. It is denoted G1151® and constituted by an interlock weaving of 6K carbon yarns (630g/m², 7.5 yarns/cm) (Figure 5). The G1151 unit cell consists in 6 warp yarns and 15 weft yarns, the weft yarns being distributed on 3 levels. The ply thickness is 1.54mm. The 6K carbon yarn has an original width and thickness of about 0.34mm. On the contrary this second fabric gathers all the difficulties that can be encountered in this type of modeling and will therefore enable show the potentiality of the proposed strategy.



(a) Schematic of three-layer interlock woven structure

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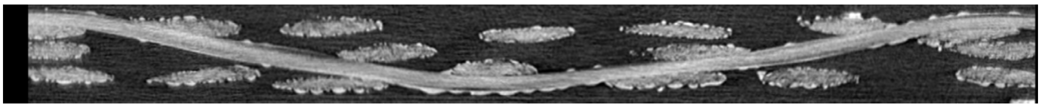

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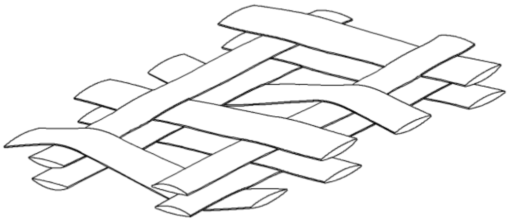
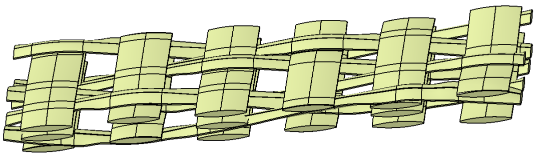
Figure 3: Architecture of the two interlock fabrics

5 Results and conclusion

The CAD model obtained with the previously described inputs for the two interlocks is presented on Figure 4. It can be noticed on the transverse cut that the model is fully consistent, thus no interpenetration or spurious void exist at the yarn crossing. Few minutes are needed to input the data, the computation is immediate on a standard laptop. 5 minutes or so are then needed for the Catia V5 features creation especially because the program has not been optimized to save creation time but in order to enable an easy access to the user for the model modification. Every geometrical feature and parameter can be modified directly in Catia V5 if a local refinement of the unit-cell is needed. In addition, since it is fully automated, it doesn't need any participation of the user.





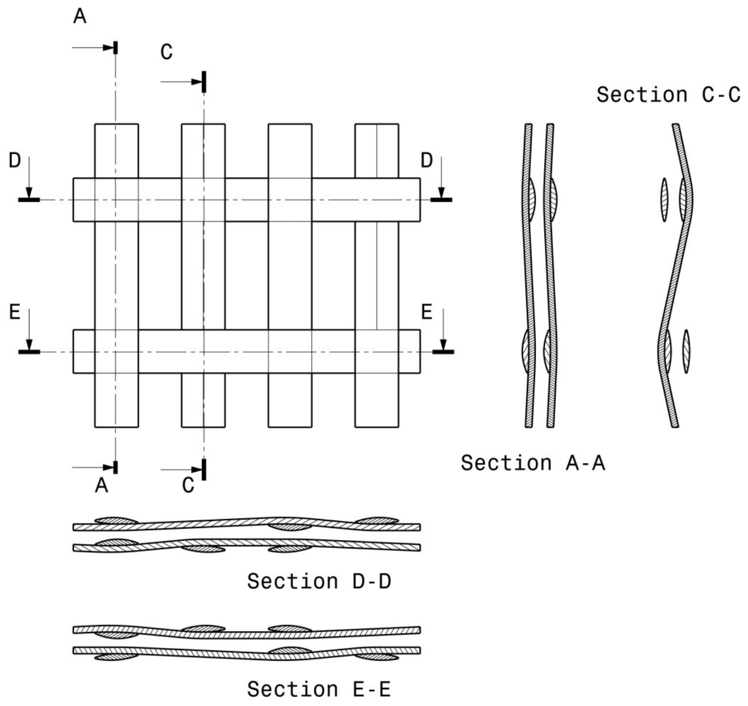


Figure 4: CAD model and consistency.

An innovative modeling strategy for interlock and 3D fabrics has been proposed. It enables to obtain automatically the CAD model of a unit cell with the respect of two main properties:

- the consistency that ensures no penetrations and no spurious voids in the contact zone between warp and weft yarns.
- the evolution of the section shape along the trajectory.

Due to theses two properties the unit-cell obtained can be directly meshed and used to perform finite element simulations.

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