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Consistent geometrical modelling of interlock fabrics

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ABSTRACT

The aim of this study is to simulate the deformations of dry fabrics during the first step of LCM (Liquid Closed Moulding) processes. Among the available numerical approaches, 3D finite elements simulation at the mesoscopic scale seems to lead to a good compromise between realism and complexity. At this scale, the fibrous reinforcement is modeled by an interlacement of yarns assumed to be homogeneous that have to be accurately represented. The paper therefore presents the creation of a, as realistic as possible, 3D geometrical model of the yarns of complex unit cells. It is achieved through the implementation of an iterative strategy based on two main properties. On the one hand, consistency, which ensures a good description of the contact between the yarns, that is to say, the model does not contain spurious spaces or interpenetrations at the contact area. On the other hand, the variation of the yarn section shape along its trajectory is accounted so that it enables to stick as much as possible to the evolutive shape of the yarn inside the reinforcement. Using this tool and a woven architecture freely implementable by the user, a representative model of any type of reinforcement (2D, interlock) can be obtained. The obtained CAD model is fully consistent so that it can be directly used for FE simulations at the meso-scale without any modifications or corrections. An example of equi-biaxial extension of a carbon interlock fabric is proposed.

1. Introduction

1.1. Context

The use of continuous fibre reinforced composites in various industries and especially in the transportation business is increasing because lighter, complex shaped parts can be manufactured. Among all the processes available for the manufacturing of such parts, the LCM (Liquid Composite Moulding) techniques seem to be the most promising. The first step of these processes consists in draping a dry mono or multi-layer preform before liquid resin is injected [1–3]. This preforming stage is a delicate phase since the physical mechanisms involved are complex and very different from those occurring during the stamping of metallic sheets. The dry fabric is able to undergo various strains (shear, tensile, bending, etc.) and loadings (binders, friction) in order to be draped on complex double curved dies [4–13]. The formability of a fabric is therefore in direct relation with the mechanical behaviour of the textile stack. Understanding, characterizing, identifying the mechanical behaviour of dry fabrics is consequently of primary importance in order to predict the feasibility of a given part with a given fabric, but also in order to optimize fabric choice or process parameters. Different approaches, experimental or numerical, can be used to achieve this crucial task. The experimental determination of the mechanical behaviour of fabrics has been intensively studied. A rich bibliography exists, among which [14–30] can be cited. However, many teams are still working on this topic in order to refine the knowledge of the composite community, since the mechanical behaviour of fibrous material is far from being understood. Although the experimental approach uses direct, accurate methods that have indeed helped understand and characterize the physical mechanisms involved during the deformation of fabrics ([31–32] for instance), many papers underline how difficult it is to get accurate repeatable results [19]. This approach also requires long and expensive experimental campaigns, and it can only deal with existing fabrics. It cannot be added in a loop of fabric creation, for instance. These difficulties contribute to raise the numerical approach as a necessary complement.

Numerical strategies are all the more interesting that, due to the weaving process, fabrics exhibit symmetries and periodicity that allow to consider a representative part that is named the unit cell. Among the numerical strategies, analytical methods are simple and efficient [15,33–36]. However, they do not deal well

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with all the complexity of fibrous reinforcements and especially the multi-scale nature of dry fabrics. This is especially the case for complex architectures, such as interlocks, which will be tackled in this paper. A fibrous composite reinforcement is constituted by the interlacement of yarns, themselves composed of thousands of fibres, the diameter of which is in the range of [37] a few microns. Three different scales can consequently be considered. At what is called the macro scale, the fabric is seen as a continuous membrane. This scale is classically used to simulate the forming step of the whole reinforcement, with a specific mechanical behaviour [38–48]. Nevertheless, it is not adapted to investigate the mechanical behaviour of the unit cell, since the latter does not explicitly appear in this kind of modelling. On the other hand, the micro scale tends to consider each individual fibre that constitutes the yarn. Each fibre is considered as a beam interacting with its neighbours. This scale is the finest one, but needs to account for thousands of contacts between the beams. The number of fibres considered therefore needs to be reduced to the range of a hundred, and even in this case, calculations are complex and require a huge amount of time [49]. At the moment, therefore, the optimal scale for the investigation for the mechanical behaviour of the unit-cell seems to be the intermediate meso-scale. Only the second level of heterogeneity, the meso level, is explicitly considered. As a consequence, the fabric is assumed to be the interlacement of continuous yarns. This scale enables to take into account the complex meso-architecture of fabrics without dealing with thousands of fibres. Coupled with 3D finite element simulations, it leads to reasonable calculation times and complexity. The fibres are modelled through a specific constitutive law, often obtained via simple tests and/or inverse identification, implemented in a finite element code [17,50–59]. Even if the meso modelling seems to be the best compromise between realism and complexity, such finite element simulations present the following difficulties:

- The yarn is modelled as a continuous material. Therefore, a specific behaviour law accounting for its fibrous nature has to be implemented. In particular, it requires to follow the fibre orientation during the unit-cell deformation using specific rotation tensors, since those implemented in standard codes such as Abaqus® cannot be used [60–63]. In this paper, the strategy presented in [61] will be used for the applications presented at the end.
- All the contacts between the yarns have to be taken into account, in the context of finite transformations. This results in complex simulations, all the more difficult that the number of yarns in the unit-cell is high.
- Above all, a 3D finite element simulation requires an accurate consistent 3D meshed geometry of the unit-cell. "Accurate" has to be understood here as modelling the real yarns geometry (yarn width, thickness, volume fraction, etc.) and all the real contacts between the yarns. "Consistent" means that the contact surfaces are accurately described, that is, no spurious voids or interpenetrations occur at the contact zones. Without both of these conditions, simulations cannot be considered as representative [64].

This paper aims at dealing with how to obtain this consistent accurate meshed model.

1.2. Interlock specificities—examples of application

Due to the large increase in the use of composites in structural parts for aeronautic and automotive applications, thicker parts have to be manufactured. This can be done via the stacking of multiple thin plies or using thick reinforcements, such as interlocks or 3D fabrics, in which several layers of weft yarns are linked by warp yarns. Depending on the weaving process capacities, very thick and large unit-cells can be obtained containing between ten and a hundred or so yarns. Fig. 1 presents the architecture of two interlock fabrics that will illustrate the proposed strategy. The first one is a "virtual" fabric (Fig. 1(a)) approximated from a real one used in [65], and has the following characteristics: the pitch distances between the neighbouring warps and wefts are 7 mm 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 2 mm and 0.3 mm. It is a very simple interlock with a low yarn density, which will be used to validate the basic functionalities of the software.

The second one is a woven interlock reinforcement used in aeronautics. It is denoted G1151® and constituted by an interlock weaving of 6 K carbon yarns (630 g/m², 7.5 yarns/cm) (Fig. 1(b)). 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 1.54 mm. The 6 K carbon yarn has an original width and thickness of about 0.34 mm. The fabric is manufactured by Hexcel Company and its mechanical characteristics (tensile test, picture frame tests, bending tests, etc.) have been studied [16,18,66] his second fabric gathers all the difficulties that can be encountered in this type of modelling, and will therefore help in showing the capability of the proposed strategy.

1.3. CAD modelling of unit-cells

The process to obtain a consistent meshed unit-cell can be broken down into two tasks: the CAD modelling and the meshing of the obtained CAD model. Various tools can be used to obtain the CAD model of a unit-cell. The most popular in the composites community are WiseTex [37] and TexGen [64]. Both are powerful and efficient software able to deal with any architecture of textile

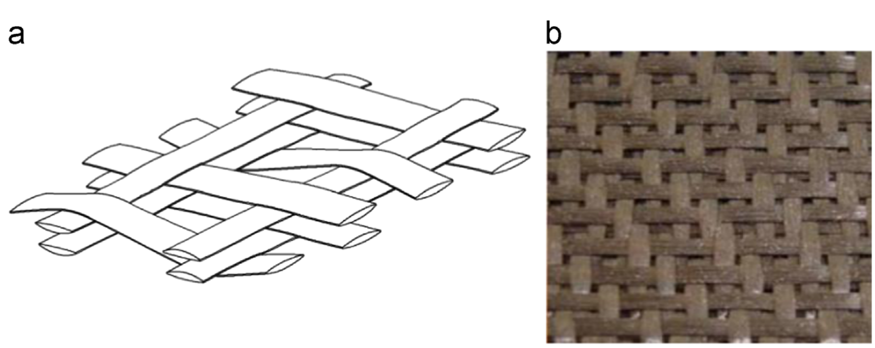

Fig. 1. Architecture of the studied interlock fabrics, (a) virtual interlock and (b) G1151® Interlock.