A CONSISTENT WOVEN FABRIC UNIT CELL AND PREPROCESSOR FOR MESO ANALYSES OF DEFORMATION AND PERMEABILITY

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ABSTRACT: Analyses of mechanical behaviour and resin flow at the mesoscopic scale, need accurate geometrical model and mesh of woven composite reinforcement unit cells. From experimental observations of yarn geometry for different cases of yarn structure and weave patterns a 3D model of the woven yarn shape is defined. From this yarn model, a consistent 3D geometrical model of fabrics is presented. This model ensures an accurate contact between yarns. It is called consistent because penetrations and spurious voids between warp and weft yarns are avoided. The yarn section shape varies along the trajectory, so that the influence of contact between yarns on their cross-section shape can be taken into account. A meshing preprocessor based on this geometrical model is then developed. Its consistency is important for analyses of the unit cell deformation and resin flow simulations within this strained woven cell.

KEYWORDS: Fabric, Unit cell, Geometrical model, Mesoscopical model, Meshing pre-processor, Geometrical consistency.

INTRODUCTION

In the LCM processes (RTM for example), the first step consists in forming the dry fabric before the resin is injected in a second step. Simulations of these processes (forming of the reinforcement and resin flow) are very interesting tools in order to predict the conditions for the feasibility of a composite part without expensive prototypes. Nevertheless, to perform these simulations, fabric mechanical properties and permeability properties have to be known. Experimental analyses may allow the obtaining of both mechanical properties and permeability [1][2][3][4][5]. These experiments are often expensive, time consuming and moreover don't enable to obtain results on non-existing fabrics. Thus, simulation is a possible alternative to obtain fabric properties. Since most of the fabrics are periodic material, it is possible to define an elementary cell from which the fabric can be constructed. The fabric behaviour (stiffness and permeability) is then deduced from the analysis of the elementary cell. Finite element analysis is an efficient method to perform these computations, but it needs an accurate meshing of the unit cell [6][7]. The multi-scale nature of the fabric (macro-scale), composed of yarns (meso-scale), themselves composed of fibres (micro-scale) leads to a complicated geometry that is difficult to model. A simplified geometrical model has to be used to obtain the mesh of the elementary cell. Numerous models exist [8][9][10][11]. Nevertheless, meshes obtained with these models are not really well adapted to finite element analysis of the unit cell since contact surfaces between yarns are not described precisely enough. Interpenetration between yarns, likewise the existence of unreal voids (due to the modelling) significantly affects finite element results. The goal of this study is to present a tool for the definition of a consistent 3D geometrical model of fabric (i.e. that avoids interpenetration and spurious voids) and its application to a meshing pre-processor [12]. These meshes are applied to mesoscopic finite element simulations of fabric deformation [6] and injection simulation on the deformed reinforcement [13].

GEOMETRICAL MODELS OF THE WOVEN UNIT CELL

Experimental observations

Models have been developed to be able to give a description of fabric geometry at the initial state.

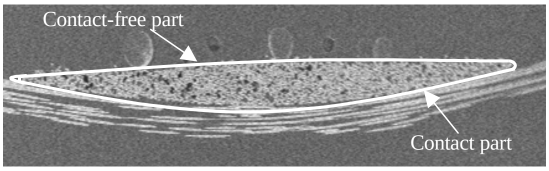

Fig.1 Transverse cut of a glass plain weave. Definition of yarn section

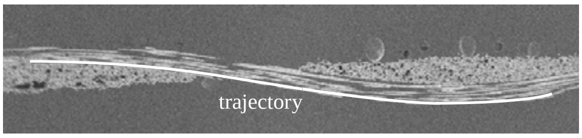

Fig 2 Transverse cut of a glass plain weave. Definition of the trajectory

There are two types of mesoscopic models. For the first type, yarns are assumed to be a composition of hinge rods. These rods can be deformable [8] or rigidities can be introduced by springs. The Kawabatta model is simple, but it is not 3D consistent. No 3D model can be made without interpenetration between the yarns of the two directions. Thus, coefficients identified concerning transverse crushing behavior are not physically consistent [6]. In the second type of model, the fabric is assumed to be the composition of 3D yarns that are supposed to be homogenous [14][15]. Their purpose is to give a better description of fabric geometry at the initial state. Most of them are based on the principle of a constant section with curvilinear trajectory. Curves used to represent elements can be sinusoids, splines, circles, or polynomials with elliptic section. Nevertheless, in general, consistency is not ensured. Some interpenetration can be noticed at the contact zone between warp and weft yarns. A main reason is that the constant section is not possible without interpenetration. The proposed geometrical model for fabrics will be consistent (no interpenetration and no spurious void). It is based on experimental observations. Then its application to a meshing preprocessor will be shown. Finally, we will apply the model to perform 3D finite element simulations on the elementary cell, in order to identify mechanical properties and permeabilities.

Different experimental methods can be used to observe the cross section and the trajectory. For many fabrics, the cohesion between fibers is not sufficient to ensure the conservation of the cross section with contact. Thus, contact methods are not useable to identify dry fabrics geometry. Two other types of methods can be carried out. The first one is based on optical measures. These techniques enable to perform precise 3D geometrical measurements but only the visible parts can be obtained. The second one consists in coating a dry fabric sample with a resin to keep the original shape and then cut the sample. But the resin penetrates inside the yarn, between the fibers, and can modify its shape. None of these techniques is perfect but allowed us to obtain interesting information on the yarn section shape for a dry fabric at the initial state. Different materials and different weavings have been tested, some of them due to collaborations with University of Massachusetts Lowell (Fig. 1 to 5). It can be seen from these observations that the reorganization of the fibers in the yarn appears to be a very important phenomenon. The cross section is dissymmetric due to the contact, and it changes depending on boundary conditions on the fabric (Fig 1 to 5). Thus, the cross section has to change along the trajectory. It is clear that the assumption of a constant section is not correct.

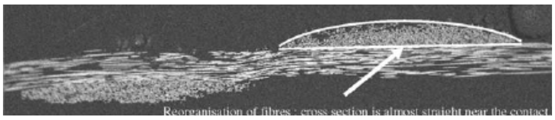

Fig. 3 Yarn cross section when the fabric is stretched in the opposite direction

Fig 4 Transverse cut of a glass plain weave, contact free zone

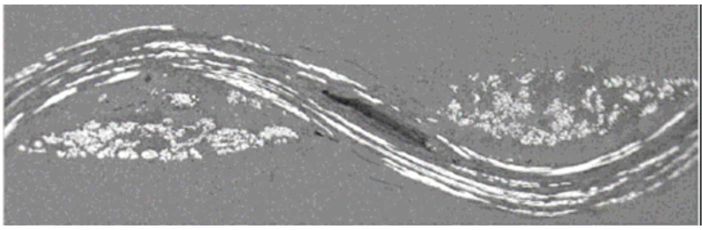

Fig 5 Transverse cut of a Twintex fabric

The second series of tests have been performed with optical measures. Some of the results are presented Fig. 6 for a carbon twill and a glass plain weave. The specificity of these two fabrics is that the carbon yarns are coated and the glass yarns are twisted. The consequence is higher cohesion between the fibers in the yarn. Here again, the cross section is dissymmetric. The contact zone between the yarns is large and the contact mainly influences the cross section shape. But the reorganization of fibers is not sufficient to get to the lenticular shape previously observed. There are lateral zones between the contact and contact-free sides.

Consistent 3D model of the geometry

The conclusion of all these experiments is that three different zones can be differentiated for the cross section: a contact zone, a contact-free zone, and a lateral zone that can be limited to only two points in case of a weak cohesion of fibers (Fig. 7). In the general case, these three zones can be approached through four conic curves for instance (parabolas, circles). Values chosen for the lateral conics parameters will make these vary from straight line to dot. Thus, all types of yarns observed can be represented using this model. For plain weave fabrics, the symmetry according to the vertical plane leads to a simplified form of the cross section.

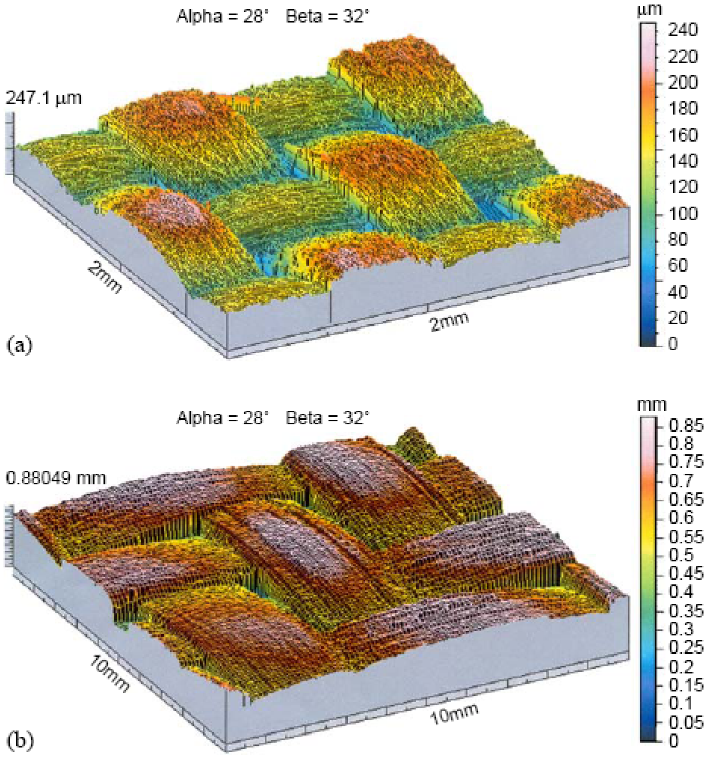

Fig 6. 3D optical measure of dry fabrics at the initial state
(a) unbalanced glass plain weave (b) carbon twill 2 ∗ 2..

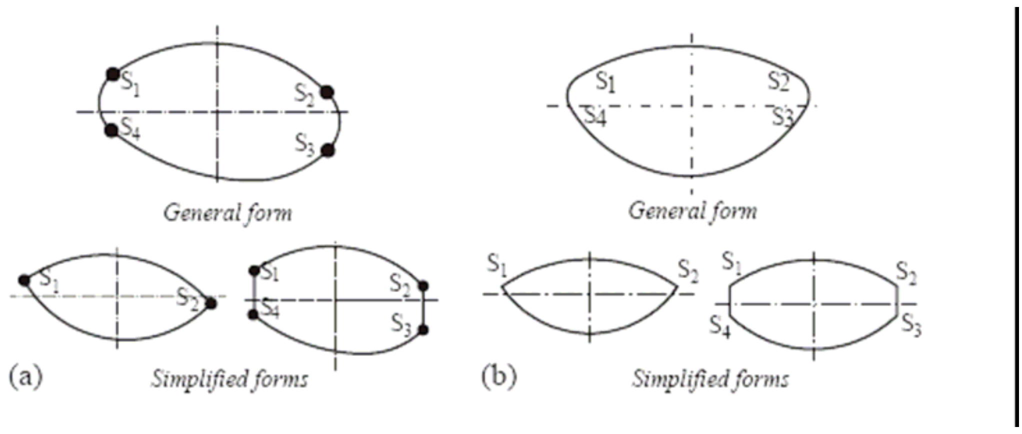

Fig 7. Models for the cross section of a 2D fabric: (a) generic (b) plain weave.

The trajectory is constrained by the necessary 3D consistency of the fabric model. For plain weaves, the contact zone will consist in the same conic as that of the cross section (Fig 1.). In the contact-free zone, no lateral load is applied to the yarn. Given that the bending rigidity of yarns is very weak, the contact-free part of the trajectory should be straight (Fig. 4). So, the trajectory is composed of conics and straight segments. Tangency conditions between conics and segments must be ensured.

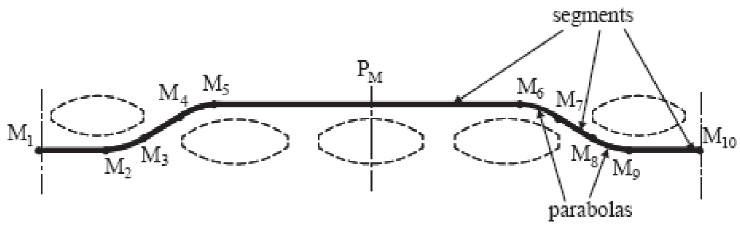

Fig. 8 Model of a trajectory for twill 3 *2.

For twills, the problem is a little bit more complex.A yarn passes over m and under n transverse yarns. When this yarn passes over the m transverse yarns, two cases may be considered:

• The yarn follows the original curvature of the transverse yarn cross sections. In this case, the yarn is curved when contact occurs.

• The transverse cross section flattens and the yarn keeps almost straight.

The second assumption is much more consistent with our previous observations. Moreover, when the fabric is deformed, tension in the fibers will make this second model more suitable. The trajectory obtained for any twill (or satin) is then very simple, which is a good point for model identification. This is presented in Fig. 8. Variations of section shape along the yarn are taken into account using control sections at control points (Fig. 9)[12].

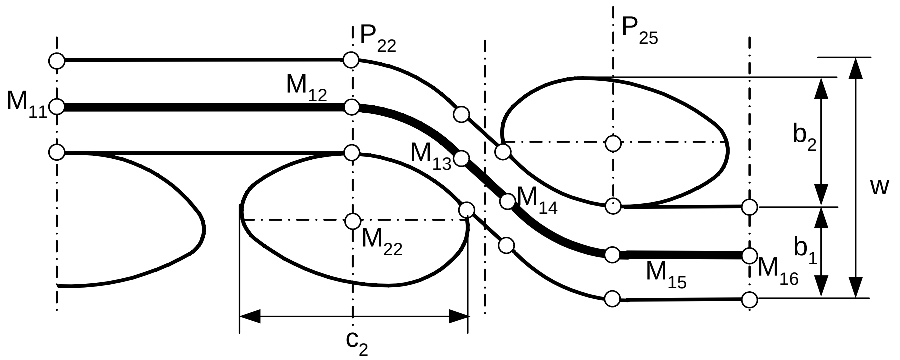

Fig. 9. Transverse cut in the direction 1 of the simplified model for a twill m*n.

The complete 3D model of the yarn is obtained through a smooth interpolation between the control sections, which respects the imposed trajectory. The interpolation is obtained using CAD software, such as PROEngineer®, which includes a “swept blend” feature that is able to build volumes using control sections and trajectories. The elementary cell of fabric is obtained by assembling m+n yarns. Figure 10 and 11 present the obtained geometry in the case of a 3*2 twill and of a 4*3 twill. Sections shapes at the beginning and the end of the contact are prescribed to ensure consistency. The model is said to be “consistent” because it guarantees there is no penetration between warp and weft yarns, and it imposes that contact happens where it should take place.

APPLICATIONS TO MECHANICAL AND PERMEABILITY PROPERTIES DETERMINATION

A meshing software such as Patran® can be used to obtain a finite element mesh from geometries obtained using the consistent 3D model. A PCL routine enables to generate automatically a hexahedral mesh of the elementary cell. In that way, a 3D geometrical

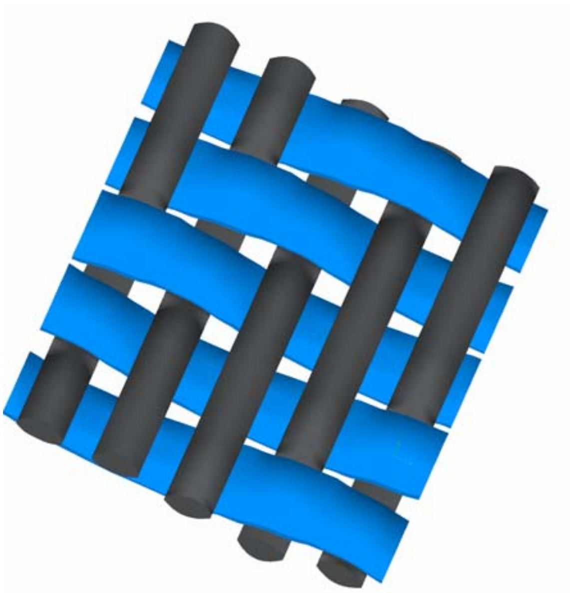

Fig. 10 3D model of a carbon twill 3*2

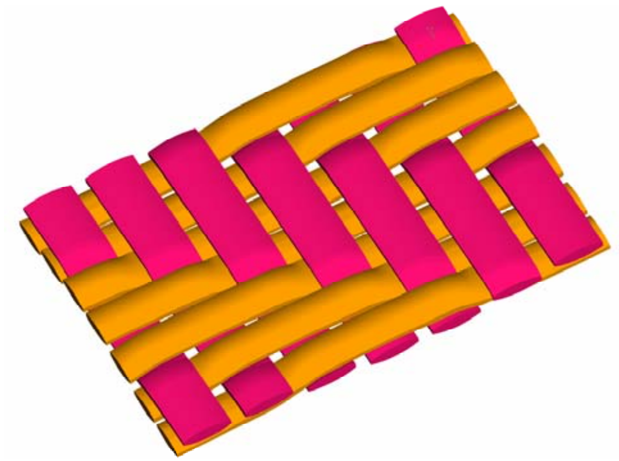

Fig 11 3D model of a carbon twill 4*3

meshing pre-processor of woven unit cells is defined. The mesh obtained in the case of a plain weave is presented figure 12. These meshes permit to perform virtual tests in order to obtain the mechanical behaviour of the fabric from finite element simulations [6]. These analyses permit to investigate the influence of different parameters. They also allow analysing fabrics before their manufacturing. An example of the shear deformation of twill 2*2 is presented figure 13.

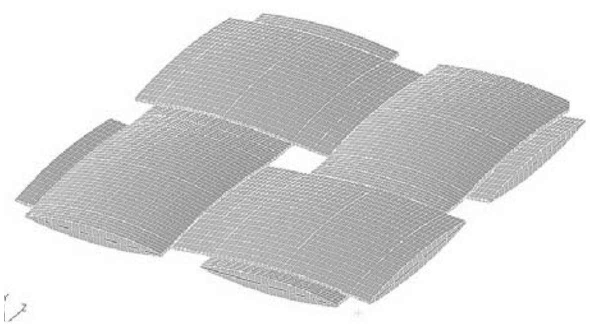

Fig. 12 3D mesh for a plain weave fabric

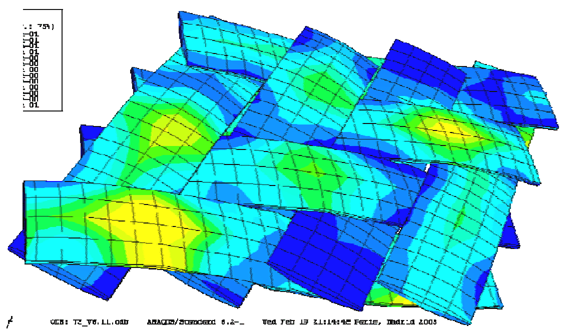

Fig 13 Finite element simulation of the shear deformation of a twill 2*2

The 3D preprocessor is also used for the generation of the channel network geometry that is the complementary volume of the reinforcement. The obtained mesh (Fig. 12) permits to simulate the resin flow (Fig. 13) and to deduce the permeability matrix [13].

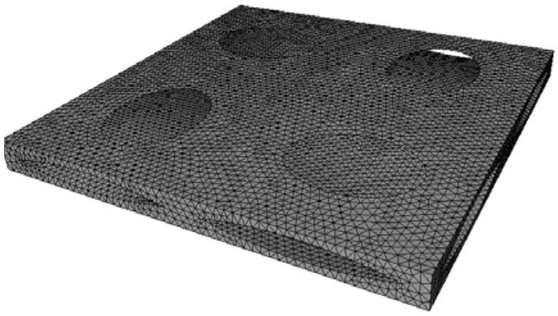

Fig. 14 Mesh of the complementary part of a plain weave

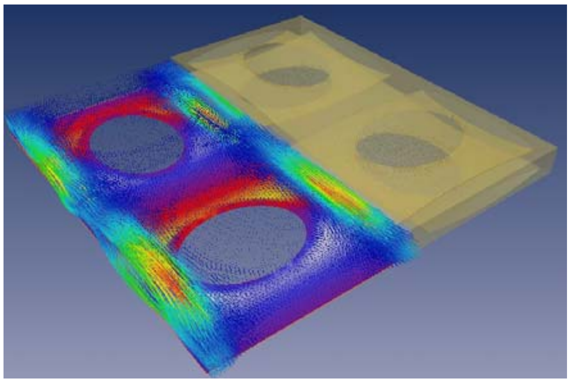

Fig. 15 Resin flow in a glass plain weave

CONCLUSION

A consistent 3D geometrical model for woven fabrics has been defined. It is adapted to most weavings. It insures no penetrations and no spurious voids in the contact zone between warp and weft yarns. It is the first stage of a 3D geometrical meshing preprocessor of the unit woven cells. Using PROEngineer® and Patran®, hexahedral meshing of the fabric geometrical model can be obtained. This permits 3D finite element analyses of elementary cells in order to determine the mechanical behaviour properties by virtuel tests. It can also be used to simulate resin flow in the complementary volume of the yarns and in that way calculate the permeability parameters. Future developments will concern more complex types of fabrics, such as 2.5D or 3D fabric.

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