Numerical approach of the weaving process for textile composite

J. Vilfayeau$^{1,2}$, D. Crepin$^{1,3}$, F. Boussu$^{1,3*}$, D. Soulat$^{1,3}$, P. Boisse$^{2}$

$^1$ Ensait, Gemtex, F-59100 Roubaix, France,
$^2$LAMCOS, UMR CNRS 5514, INSA de Lyon, F-69621 Villeurbanne, France,
$^3$Univ. Lille Nord de France, F-59000 Lille, France

*francois.boussu@ensait.fr

Keywords: Numerical modelling, 3D weaving process, textiles composites, composite materials.

1 General Introduction
The complexity of fibrous architectures (especially for 3D woven or braided structures), used as reinforcements for composites in structural applications (mainly in aeronautics), leads to perform simulations at elementary cell level (the so-called VER) [1-4; 6-9]. Many studies have shown significant differences (up to 30%) between the stiffness obtained by the VER behaviour resulting from models and experiments [10-12].

Such differences are mainly due to wrong geometrical descriptions of these elementary cells from which finite element meshing are performed [13]. These geometrical parameters include, in a non-exhaustive manner, the interlacing path of strands and the choice of cross sections (shape, ratio aspect) [14-15]. A special attention must be paid to a bad description of reinforcements orientation as it affects material directions and therefore the material basis used to described the orthotropic behaviour [5, 7].

Moreover, penetrations between the strands is a common problem experienced in software packages devoted to the generation of elementary cells [20, 21]. The software package WiseTex [16-18] contains a textile pre-processor that utilises the principle of minimum energy to calculate strand trajectories and strand cross section shapes. The strand cross section shape is assumed to be constant, although its size is allowed to vary.

In TexGen, the yarn trajectories are defined by splines through sets of master nodes. Sherburn et. al [19] proposed a method to generate spatial textile models in TexGen together with a commercial FE software, using an energy approach. However the method utilises a procedure where the architecture is projected onto a single plane. It is therefore not applicable for textiles with crimped out-of-plane yarns, as in the case of 3D-weave [13].

To refine geometrical description of their models, many authors rely only on the cross sections based on tomographic picture performed on resin coated reinforcements [4, 13, 21]. Some studies describe more precisely strands in unit cell of woven reinforcements by 3D Beam element taking into account transverse deformations in compaction [22].

All of these approaches disclose the fibrous structure complexity, once the weaving process achieved. However, strands are subject to significant load during the process which modify their positions, orientations but also their transversal properties due to contacts with mechanical parts of the loom and friction with others strands. Unlike studies conducted in braiding [23] or knitting [24] few numerical tools focus on simulating the weaving process. The objective of the present study, which is part of the NUMTISS research program, is to develop a simulation tool that mimics the weaving process to obtain more realistic textile samples.

2 Basic kinematic motions of the weaving process
To understand the mechanics of the weaving process on an industrial weaving loom, the tracking of parts motion of some strategic elements on the industrial weaving loom (reed, heddles, rapier ...) have been carried out. The tracking obtained from the video of the high speed camera will help us to check the kinematic of the numerical model.

The weaving of two orthogonal yarns, respectively the warp and weft yarns, occurs in a precise area of the loom, allowing the shed motion, the filling insertion and the reed beat up.

The kinematic of the fabric forming zone (see Fig. 1(a)) can be described by these three main steps:

Step 1: Selection of each heddles involving the motion of warp yarns into two positions (up or down) (see Fig. 1 (b)). The obtained angle between these two warp yarns plans gives the shed value.
Step 2: Pick-in of the weft yarn (filling) inside the shed (see Fig. 1 (c)).
Step 3: Beat up of the weft yarn on the fabric by the use of the weaving reed (see Fig. 1 (d)).

The proposed simulation tool tends to reproduce all these main production steps in order to simulate the complete behaviour of warp and weft yarns during the weaving process.

3 Numerical simulation of a plain weave fabric (FEM)

3.1 General remarks

As the process is a time depend problem, simulations are conducted with an explicit solver in the industrial software Radioss [25]. One of the objective of the intended numerical tool is to simulate the strands interlacing at some steps. To control computation time, only the reed is modelled by a rigid body. The heddles motions are transcribed via kinematic constraints imposed to strands.

3.2 Numerical model description

Yarns setting-up: Yarns are considered deformable with a transverse isotropic elastic law; this material law is the one of E-glass yarn (see Table 1). For meshing parts, 8-nodes hexahedra solid elements were used (see Fig. 2 (c)). Strands friction is described by a Coulomb's law with a friction coefficient equal to 0.3. The yarn has a circular cross section before the weaving process (Figure 2(c)), due to the given initial twist.

Reed setting up: Reed was modelled by a steel plate composed of 4 quadrilateral elements, in which an horizontal displacement has been imposed (see Fig. 2(b)).

Contact setting up: Contacts between warp and weft yarns were represented like contacts between deformable surface, and contact between the reed and the weft yarns as a contact between a master surface (reed) and slave nodes (weft) [25].

Boundary conditions:
The warp yarns displacement is set by simulating the heddles vertical motion (see Fig. 2 (a)). Afterwards, the weft yarns are constrained to a free horizontal motion. Weft yarns tension that occurred during weaving is modelled by fixing weft yarns at edges. Then, the warp and weft interlacing yarns zone is modelled by a rigid plate that can stop weft yarn when the reed is beating.

It was decided to perform an acceleration of the weaving kinematic to decrease computation time. The weaving cycle which lasts 600 ms for a weaving speed of 100 RPM on an industrial loom, was accelerated to 1.6 ms for our model. Being at high speed is not a problem for the moment, as we choose to not take into account strain rates in the material’s behaviour law. The computing time required was approximately 24 hours with 16 CPUs, for modelling the production of a weave fabric compounds of 8 warps and 4 wefts yarns.

3.2 Simulation results for E-glass plain weave fabric

Fig. 3 (a) depicts the numerical simulation of a plain weave elementary cell including 8 warp and 4 weft yarns. Modelling with 8 warp yarns was a good compromise between a reasonable CPU time and a good representation of the edge effects occurring during the reed beating.

Fig. 4 and Fig. 5 show a good agreement between images of E-glass plain weave fabric cross section produced experimentally and cross section images of the numerical model of plain weave fabric. Comparison has been made in different planes cut in warp and weft directions (0.5 mm interval between each plane cut). For instance, Fig. 5 (a) and (e) represent a cross section that goes through the weft yarn center, and figure 5 (b) and (f) a cut that goes through between two weft yarns. Images from Fig. 5 shows a realistic warp yarn cross section deformation, which was initially circular (see Fig. 2 (c)). We can notice that this deformation is more important for warp yarns than for weft yarns in the numerical model, with a gap of 0.1 mm (See Fig. 4 and Fig. 5). This difference can be explained by weft yarns which are only blocked on their extremities and then, can't be subjected to initial tensile stress; while warp yarns are blocked into the weave forming zone and are subjected to a light tensile stress due to Z-node displacement, resulting from heddles motion imposed to warp yarns. Besides, it will be interesting to add more weft yarns in the model, due to the fact that the first inserted weft yarns help to create the fabric structure and then can't be blocked into the weave forming zone.
Fig. 1. (a) Scheme of the fabric forming zone on a simplified weaving loom; (b) Shed motion; (c) Insertion of the weft yarn; (d) Beat up of the weft yarn.

<table>
<thead>
<tr>
<th>E11 (Mpa)</th>
<th>E22, E33 (Mpa)</th>
<th>G23, G31 (Mpa)</th>
<th>G12 (Mpa)</th>
<th>v12, v13</th>
<th>v23</th>
</tr>
</thead>
<tbody>
<tr>
<td>52500 [4]</td>
<td>0.6</td>
<td>250</td>
<td>200</td>
<td>0 [26]</td>
<td>0.99</td>
</tr>
</tbody>
</table>

Table 1. E-glass material law used in the simulation of the plain weave fabric.
Fig. 2. (a) Configuration of kinematic conditions to produce a 2D plain weave fabric; (b) Configuration of the warp and weft interlacing yarns zone; (c) Meshing of yarn section with solid elements.

Fig. 3. (a) Numerical model of a glass plain weave fabric (300 Tex); (b) Picture of a glass plain weave fabric (300 Tex).
Fig. 4. (a), (b), (c), (d) Warp cut of a real plain weave fabric, respectively cut plane A-A, plan A-A + 0.5 mm, plan A-A + 1 mm, plan A-A + 1.5 mm; (e), (f), (g), (h) Warp cut of a numerical plain weave, respectively cut plane A-A, plan A-A + 0.5 mm, plan A-A + 1 mm, plan A-A + 1.5 mm.
Fig. 5. (a), (b), (c), (d) Weft cut of a real plain weave fabric, respectively cut plane A-A, plan A-A + 0.5 mm, plan A-A + 1 mm, plan A-A + 1.5 mm; (e), (f), (g), (h) Weft cut of a numerical plain weave, respectively cut plane A-A, plan A-A + 0.5 mm, plan A-A + 1 mm, plan A-A + 1.5 mm.
Conclusion
A numerical model (FEM) was performed to describe strain phenomena of yarns when we produce E-glass plain weave fabric, with 300 Tex yarns. Weaving simulation results with an isotropic transverse behaviour's law from glass strand has been introduced, and compare with pictures of warp and weft cross sections coming from coated samples. A good correlation, in different cut plane, has been established between coated sample pictures and numerical model pictures. Results for simulation of satin 8 and 2-2 twill E-glass fabrics will be presented soon, as well as for interlock structures. Then, tomographies from 2D and 3D E-glass structures produced, will enable us to perform a comparison more precise with numerically simulated weaved fabric.

Acknowledgements
This study received support from the French National Agency of Research (ANR) bearing the NUMTISS reference, ANR-09-MAPR-0018

References