Numeric simulation tool of the weaving process

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Abstract - *This project is directly attached to the challenge in the aerospace industry to meet the new environmental requirements as the Kyoto Protocol [1]. One of the potential axis being explored through various national and European programs is the global reduction of the structure's mass when economic conditions are met. One of the mass reduction's solution can be provided by the introduction of composite materials. To achieve substantial gains in the design of new materials based fibrous reinforcements, it is necessary to have numerical models of textile structures accurate and reliable. Currently, this modeling process is time consuming, random and can be costly.*

To answer this, the NUMTISS project proposes to model the main weaving motions during the manufacturing to obtain the geometry of the textile structure while incorporating its damage effect occurring during the production. Modeling and numerical simulation of the manufacturing process coupled with the understanding of the laws materials at different scales lead to an accurate answer of the actual geometry of the textile structure. This approach has been applied both on the modeling and simulation of 2D E-glass fabrics.

Keywords: Visualization tools and systems for simulation and modeling, Multi-level modeling, Simulation in industry, Finite element methods, Tools and applications

1 Introduction

The used modeling process to obtain a precise geometrical model for a 2D textile dry structure, to be implemented into a numerical computation system in order to predict its mechanical behavior, can be resumed in main four steps: the geometrical modeling of the textile structure, its real production, a geometrical characterization and an homogenization step. This current modeling process is time consuming and leads to several problems, as described in Figure 1.

The first problem is linked to the un-accurate geometry of the 2D textile structure provided by the different existing softwares which lead to broad assumptions on the yarn structure and, sometimes, don't manage the contact between yarns in the two directions which lead to interpenetration of material.

The second problem is linked to the weaving process of the 2D textile structure which takes a long time of preparation and induces many defects on the final structure due to the important uncertainty of the weaving production process. Most of the time, yarns damages occurring during the weaving process are not measured and thus can't be integrated as a key parameter of the predicted mechanical behavior of the final structure.

The third problem is due to the 3D tomography process which requires to fit the scale level of the textile structure representation while keeping the accuracy of the fibrous geometry. Additionally, the identification and selection of the representative unit cell may lead to a long time process of interpretations and discussions.

The fourth problem is mainly oriented on the images analysis process which needs to use a powerful data processing method in order to avoid huge time of human interpretations and decisions.

By the end, the last problem lies in the difficult integration of the accurate geometric modeling highlighting the residual mechanical properties of the 2D textile structure. No understanding of the internal stress caused by the weaving process which mainly influence the internal properties of the composite material is done.

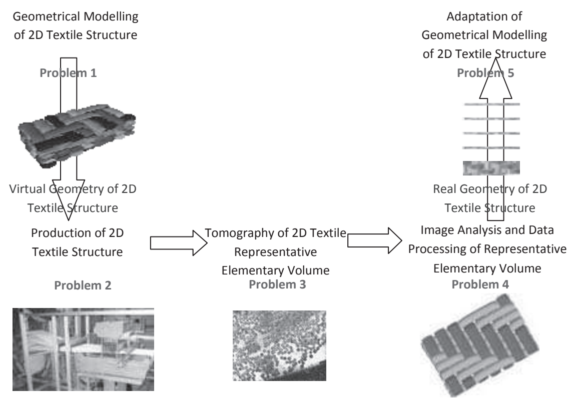

Figure 1. Existing problems linked with the 2D textile structure modeling

The complexity of 2D textile structures, especially for 3D warp interlock fabric, used as fibrous reinforcements for composites in structural applications, pushes us to simulate only the representative elementary cell (noted REC) [2][3][4][5][6][7]. Several specific studies have revealed significant difference (up to 30%) between the stiffness obtained by the REC behavior resulting from models and real experiments [8][9][10].

Such differences are mainly due to un-precised geometrical descriptions of these elementary cells from which a finite element meshing is performed [11]. These geometrical parameters include, in a non-exhaustive manner, the interlacing path of yarns and the choice of cross sections (shape, ratio aspect) [12]. 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 behavior [13][14].

To refine geometrical description of models, many authors use the cross sections of yarns extracted from tomographic images performed on resin coated reinforcements [15][16][17]. Some studies describe more precisely the yarn geometry used inside woven reinforcements using 3D beam elements taking into account transverse deformations under compaction [18].

However, yarns are subjected to significant load during the weaving process which modify their positions inside the fabric, but also their transversal properties due to contacts with mechanical parts of the weaving loom and friction with other yarns. Contrary to studies conducted in braiding [19] or knitting [20] structures, so few numerical tools are focusing on simulating the weaving process. The objective of the present study is then to develop a simulation tool that mimics the weaving process to obtain more realistic textile samples. The proposed software architecture needs several input data, both geometric parameters of the textile fabrics and weaving process parameters, in order to provide a more realistic geometric modeling as described in Figure 2.

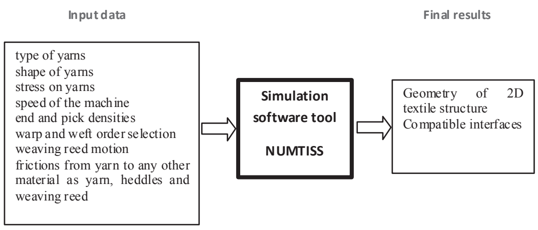

Figure 2. Proposed architecture of the NUMTISS simulation software tool.

In order to take into account the kinematic motions of the different weaving loom parts, a description of the step by step weaving process is briefly exposed in Figure 3.

2 Basic kinematic motions of the weaving process

The weaving of two orthogonal yarns, respectively warp and weft, 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 Figure 3 (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 Figure 3(b)). The obtained angle between these two warp yarns plans gives the shed value.

- Step 2 : Insertion of the weft yarn (filling) between the two warp yarns plans (see Figure 3(c)).

- Step 3 : Beat up of the weft yarn on the fabric by the use of the weaving reed (see Figure 3(d)).

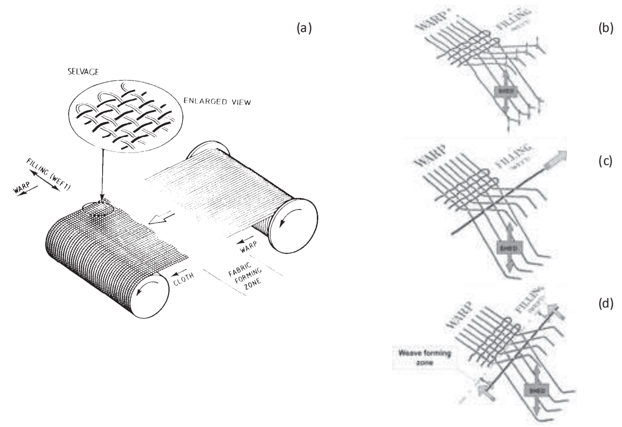

Figure 3. (a) Scheme of the fabric forming zone on a simplified weaving loom ; (b) Shed motion ; (c) Insertion of the weft yarn ; (d) Beat up of the weft yarn.

Taking into account these three main steps of the shed motion of the weaving process, a wider view of the weaving loom helps to locate the different parts in motion or in contact with the warp and weft yarns. The proposed simulation tool tends to reproduce all these main production steps in order to simulate the complete behavior of warp and weft yarns during the weaving process.

3 Simulation software tool of the weaving process

As the process is a time dependant problem, simulations are conducted with an explicit solver Radioss [25]. One of the objective of the intended numerical tool is to simulate warp yarns interlacing with few weft yarns. In order to control the computation time of simulation, the weaving reed is modeled as a rigid body. The heddles motions are transcribed via kinematic stresses imposed to yarns.

3.1 Description of the numerical model

Separately, yarns and their in-contact moving weaving components have been differently modeled with respect to their raw material characteristics. Yarns are considered deformable with a transverse isotropic elastic law. For the meshing, 8-nodes of hexahedra solid elements are used (see Figure 4 (c)). Existing and checked material law of para-aramid yarn has been used. Yarn to yarn friction is given by a coulomb's law with a coefficient equal to 0.3.

The weaving reed has been modeled by a steel plate composed of 4 quadrilateral elements for which an horizontal displacement has been imposed (see Figure 4 (b))

Contacts between warp and weft yarns have been represented like contacts between deformable surface, and contact between the weaving reed and the weft yarns as a contact between a master surface (weaving reed) and slave nodes (weft yarns) [21].

3.2 Boundary conditions

The displacement of warp yarns is set by simulating the heddles vertical motion (see Figure 4 (a)). The weft yarns are constrained to a free horizontal motion. Tension applied on weft yarns is modeled by fixing weft yarns at edges.

The interlacing zone of warp and weft yarns is modeled by a rigid plate that can stop weft yarns when the weaving reed is on a beating-up position.

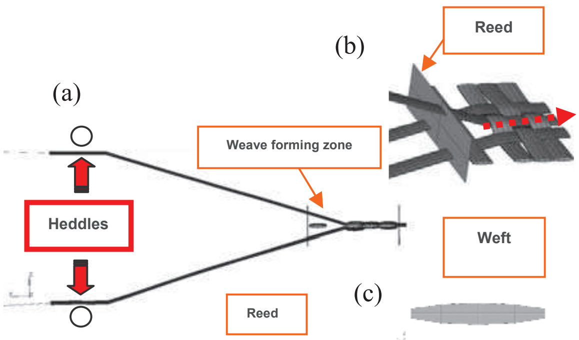

Figure 3. (a) Configuration of the kinematic conditions to produce a 2D plain weave fabric; (b) Configuration of the interlacing zone of warp and weft yarns; (c) the meshing of yarn section with solid elements.

In order to decrease the computation time, an acceleration of the weaving kinematic has been applied. The weaving cycle which lasts 600 ms for a weaving speed of 100 rounds per meter has been accelerated to 1.6 ms for our model where the material behavior's law is independent of strain rates. The required computing time was approximately 4 hours (on Personal computer equipped with 4 CPUs) to model the production of a 2D plain weave fabric made with 3 warp yarns and 4 weft yarns.

4 2D plain weave fabric simulation results

The Figure 5 (a) depicts the results of numerical simulation of a plain weave elementary cell including 8 warp yarns and 4 weft yarns. The modeling with 8 warp yarns was a good compromise between a reasonable computation time and a good representation of the edge effects occurring during the beating-up of the weaving reed. Numerical model from Figure 5 (a-c-e) reveals a good correlation with the experimental results of the para-aramid fabric produced on the weaving loom (Figure 5 (b-d-f)). Indeed, first numerical results have provided more realistic geometries than existing softwares, particularly concerning the warp and weft interlacing and the yarn deformations close to the contact zones of warp and weft yarns.

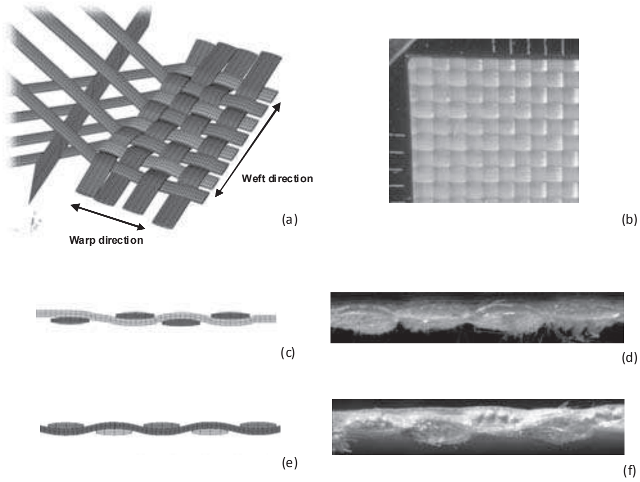

Figure 4. (a) Numerical model of a para-aramid plain weave fabric; (b) Front view of a para-aramid plain weave fabric; (c) Warp cross section view of the simulated plain weave fabric; (d) Warp cross section view of the corresponding para-aramid plain weave fabric; (e) Weft cross section view of the simulated plain weave fabric; (f) Weft cross section view of the corresponding para-aramid plain weave fabric

5 Conclusions

A numerical model has been designed to integrate weaving process conditions to act on the final geometric model of the 3D textile structure. The sequencing of the weaving process has been optimized in the model to fit with the weaving process of an industrial loom. By comparing the real and simulated geometries of the 2D plain weave fabric, a good correlation has been revealed which highlights the interest of introducing both weaving and geometrical parameters in the numerical model.

In the work in progress, the current model will be refined soon taking into account the circular geometry of an E-glass cross section yarn and real mechanical parameters obtained on yarns directly picked on the warps plan of the weaving loom.

6 Acknowledgement

This study has received support from the French National Agency of Research (ANR) with the project reference: ANR-09-MAPR-0018.

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