SIMULATION OF THE PREFORMING STEP FOR FLAX DRY WOVEN FABRICS

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Abstract

The preforming of dry reinforcements is the first step of the Resin Transfer Moulding process. To validate the feasibility to obtain a given shape, a simple model built from elastic isotropic shells coupled to axial connectors is proposed in this paper for the preforming of flax woven fabric. The mechanical behaviours of flax based fabrics characterized by strong non linearites in tension and in-plane shear are implemented in the simulation code and comparisons with experimental tests realized on a hemispheric shape show the importance of taking into account the non-linear behaviour in tension.

1. Introduction

Natural fibres, of animal or vegetable origins, are the object of numerous studies as for their potential as reinforcement for composite applications [1, 2]. This growing interest is due to their environmental properties, their low density compared to glass and carbon fibres, but also their tensile mechanical properties [3]. Consequently numerous publications dealt with the identification of their mechanical characteristics [4-6]. These works, at different scales investigate the influence of several parameters (nature of fibers, density; length, section, etc...) on the mechanical behavior [7]. This study concerns the manufacturing process of composite material from flax reinforcement and specifically the preforming stage, first step of the RTM process. During this stage several defects can qualify this step as successful or unsuccessful drape. At the scale of the preform, it is possible to investigate if the preform shape is well obtained (if the preform fits to the tool in the case of sheet forming process), if wrinkles appear [8-11], if there is non-homogeneity of the fibre density in tows, or if a discontinuity of the preform due to sliding of tows takes place. All these defects have a strong influence on the resin flow impregnation and specifically on the in-plane and through-the thickness permeability components [12, 13]. They consequently impact the performance of the composite part [14, 15]. A lot of parameters should be taken into account during this preforming step. Consequently a lot of papers describe experimental studies [9, 16-17] on the influence of process or material parameters on the feasibility to realize without defects this preforming step. Associated to these works, several numerical approaches, based on finite element method, have been extensively developped to investigate the draping behaviour of fabric on specific tools [18,19], but few numerical works concern the simulation of the preforming step of flax woven reinforcements. After the presentation of the flax fabric used, we will describe in this paper the in-plane mechanical characterization to identify the reinforcement behaviour. This law is used for a simplified [20] developed in Abaqus Software for the simulation of the preforming step. Comparisons with experimental tests realized on hemispheric shape show the importance of taking into account the non-linear behaviour in tension.

2. Mechanical behaviour of the flax reinforcement

2.1. Material

The reinforcement used in this study is made by the Groupe Depestele (France) [21]. The characteristics of this reinforcement are detailed in Table 1.

Reinforcement composition	100% flax	
Made by	Groupe Depestele (France) [22]	
Reinforcement structure	Plain weave	
Yarn structure	Roving	
Linear mass [g/m]	Warp : 468.2 ± 34.78	Weft : 537.7 ± 44.36
Density [g/m²]	373.2	
Average width [mm]	Warp : 2.12 ± 0.35	Weft : 2.46 ± 0.28

Table 1. Reinforcement characteristics

Due to different linear masses in weft and warp directions, the flax woven fabric (Figure 1.a) is not balanced and is constituted of flat untwisted yarns.

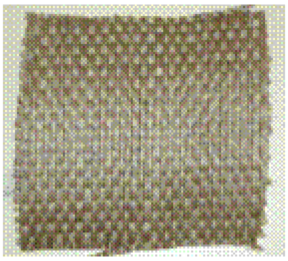

Figure 1. Flax woven (a). Bias-test (b)

The mechanical behaviour of woven reinforcement during the preforming step is classically characterized by in-plane properties and especially by uniaxial tensile and shear tests [22, 23]. In our study, for the shear behaviour the bias-test was used (Figure 1.b). Experiments have been conducted on 200x100 mm sample size with a traction speed of 2 mm/min.

2.2. Uniaxial tensile test

Uniaxial tensile test have been realized in warp and weft directions of the reinforcement, on 150x70 mm sample size with a traction speed of 2 mm/min. Evolutions of the load as a function of the applied displacement show that the behaviour is not balanced for the reinforcement studied (Figure 2). Otherwise a significant non-linearity at the beginning of the test is present and is due to the loss of the yarn undulation. This non-linearity must be taken into account within the framework of the stamping simulation.

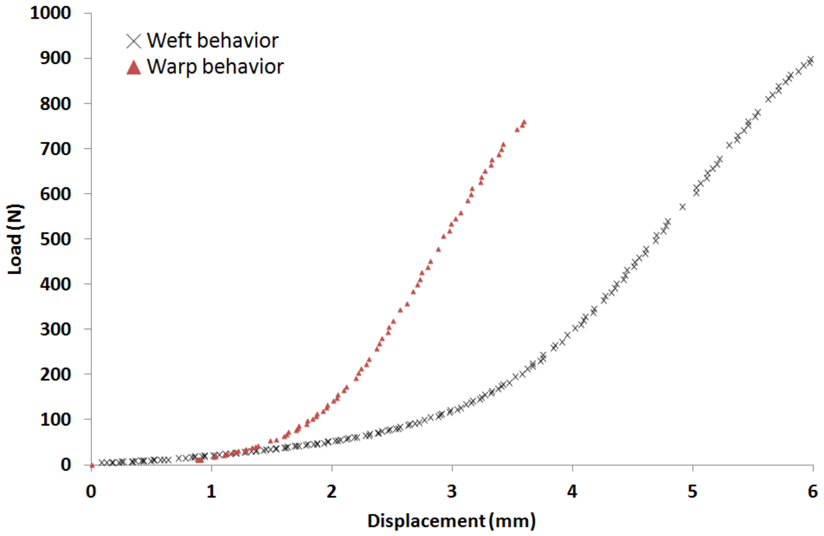

Figure 2. Strengh/displacement responses in warp and weft directions

3. Finite elements model

3.1. Model presentation

On the Contrary to geometrical approaches, based on fishnet algorithms [24], finite element methods can take into account the mechanical behaviour of the textile reinforcement and the effect of the tools (i.e. the punch, die and blank holder) during forming. Several methods for the finite element modeling of woven reinforcements have been proposed. It is possible to consider the fabric as a continuum material obtained either by homogenization techniques (anisotropic behaviour) or with a non-orthogonal constitutive modelling method [25], or with an anisotropic hypo-elastic continuous behaviour [26]. Discrete or semi-dicretes approaches have also been proposed [27]. In this application a simple model constituted by a discrete approach to model the tensile behaviour of the yarns and a continuum approach to take into account the specific shear behaviour and contact with the tools is used [20].The model is based on the description of a unit cell built with shell elements and specific connectors (Figure 3).

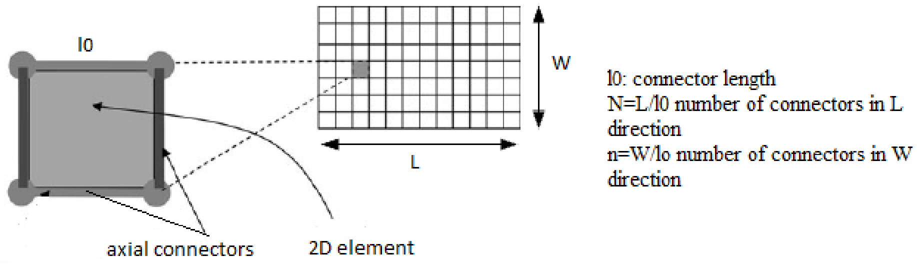

Figure 3. Discret modelling principle

The tensile behaviour is modelled by axial connectors managed with a load/displacement function. These connectors may describe elastic linear connections, managed by a constant rigidity K, and also non-linear connections. The in-plane shear behaviour is expressed by shell or membrane finite elements. A load of 650N applied on blank holder and 25 mm punch displacement are considered. The friction coefficient between flax woven reinforcement and tools has been chosen to 0.3. S4R shell elements and connectors for the behaviour in tension complete the definition of this finite element model in ABAQUS software.

3.2. Tensile identification

For the tensile parameters, two formulations can be considered. The first one is a linear formulation, represented by a constant rigidity identified from of load/displacement curves of uniaxal tensile tests (Figure 4).

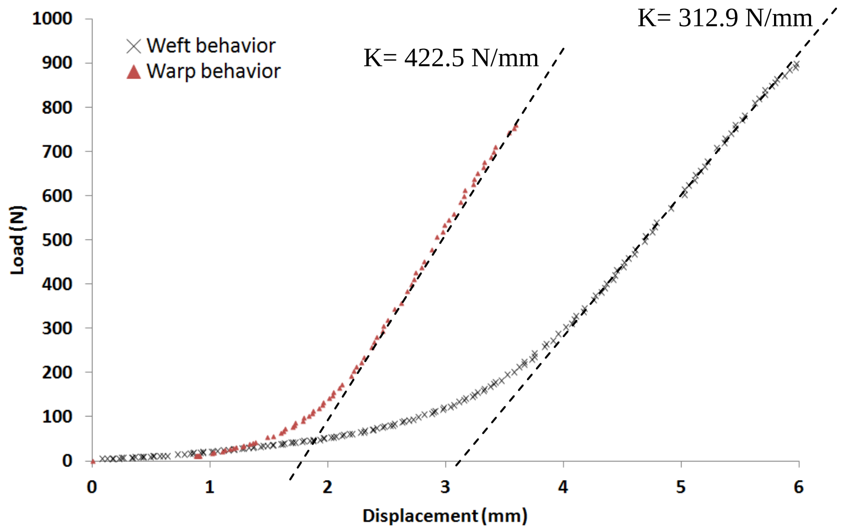

Figure 4. Linear formulation of tensile behavior

The local behaviour associated to each connector, and denoted K_0, (Figure 3) is deduced from the global behaviour, and the parameters of the mesh size (N, n, W, L and l_0 defined in Figure 3), according to the following relation:

$$K_0 = K\left(\frac{N}{n+1}\right) = K\left(\frac{L/l_0}{W/l_0+1}\right) \tag{1}$$

For the reinforcement used, the tensile parameters in the weft and warp directions are:

$K_{0\ weft} = 661.1$ N/mm and $K_{0\ warp} = 892.7$ N/mm

For the non-linear law, the approach consists in modelling the behaviour with a polynomial function followed by a linear equation. The local behaviour of each cell is established (2), from the global behaviour as a function of the mesh size, where a_n denoted coefficients of polynomial and linear relations and d_{conn} the displacement of each connector.
Polynomial behaviour ($0 < dconn < d/N$) and linear behavior ($dconn > d/N$):

$$F_{conn} = \frac{a_1}{n}(N \times d_{conn})^3 + \frac{a_2}{n}(N \times d_{conn})^2 + \frac{a_3}{n}(N \times d_{conn})$$
$$F_{conn} = \frac{a_4}{n}(N \times d_{conn}) + \frac{a_5}{n} \tag{2}$$

Tensile tests have been numerically reproduced with the linear and non-linear behaviours and compared to experimental load/displacement curves. Results (Figure 5) obtained show that the numerical approach used reproduces faithfully the experimental behaviour in tension.

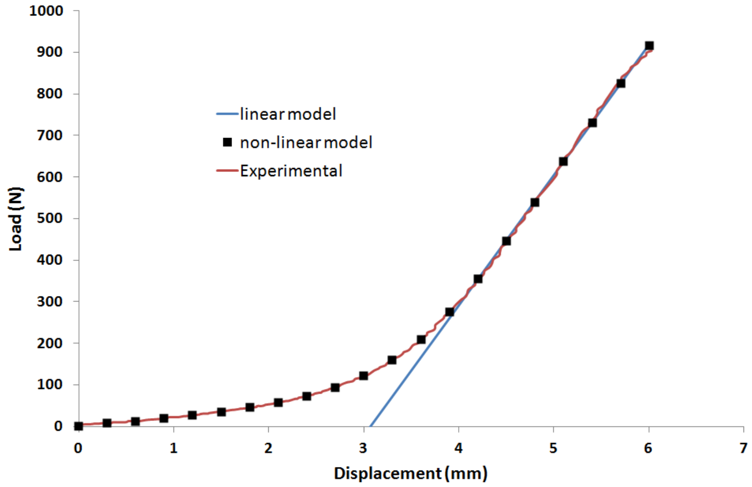

Figure 5. Tensile correlation between numerical formulations and experimental results for weft direction.

The linear approach, in the case of the flax woven fabric used in this work omits a consequent part of the behaviour and this may have an influence on the quality of the performing simulation especifically for weak loads.

3.3. Shear identification

The shear behaviour of the flax woven reinforcement is during the simulation is controlled by the shell element, and specifically the Young modulus, the Poisson's ratio and the thickness (*E*, *v*, *e*). These parameters are identified from the experimental curve obtained by performing a bias extensiontest (Figure 6).

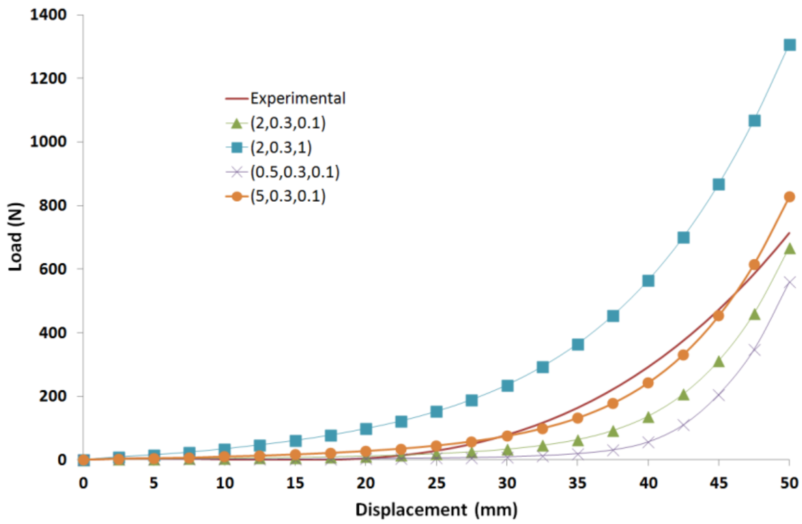

Figure 6. Approach of experimental shear response for different *(E, v, e)* with linear formulation

4. Hemisphere stampings

4.1. Experimental bench

The sheet forming device used in this work was developed at GEMTEX laboratory [20]. For this study a hemispheric punch of 50 mm diameter (Figure 7), with an open die and the associated blank holder have been used. Experimental tests have been realized on square (160*160 mm²) samples constituted of the flax woven reinforcement presented before. Experimental results in terms of shear angle and maximum displacements will be compared to numerical results.

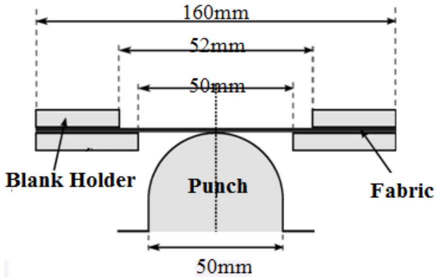

Figure 7. Geometry of the tools

4.2. Results

The shape obtained is not symmetrical because the fabric is not balanced. The displacement is consequently more important in the warp direction because the fabric is more rigid in this direction. Moreover, this displacement is higher in the linear formulation case. Compared to the experimental measurements, numerical results obtained with non-linear model are closer, especially in the weft direction (Table 2).

	Experimental values	**Numerical values with linear model**	**Numerical values with non-linear model**
Warp	9.30 mm	9.20 mm	9.22 mm
Weft	8.50 mm	9.12 mm	8.31 mm

Table 2. Maximum displacement measurements in warp and weft directions for a 625N loading

The influence of the choice of the tensile behaviour is numerically studied as a function of the load applied to the blank-holder (Table 3). For weak loads it’s necessary to take into account the non-linearity of the behaviour in tension as this one has an influence on the displacement and consequently on the shape obtained.

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		125N	**425N**	**625N**	**825N**
Linear Model	Warp	11.24 mm	10.04 mm	9.20 mm	8.39 mm
	Weft	11.17 mm	9.92 mm	9.12 mm	8.14 mm
Non-Linear Model	Warp	10.65 mm	9.99 mm	9.22 mm	8.91 mm
	Weft	9.93 mm	8.78 mm	8.31 mm	7.76 mm

Table 3. Influence of the Blank-holder load on the maximum displacement in warp and weft direction

The influence of this choice is also studied on the shear angle measured experimentally in 6 areas, as described in Figure 8.a. We report in Table 4 comparisons on the shear computed and measured for a 625N applied load.

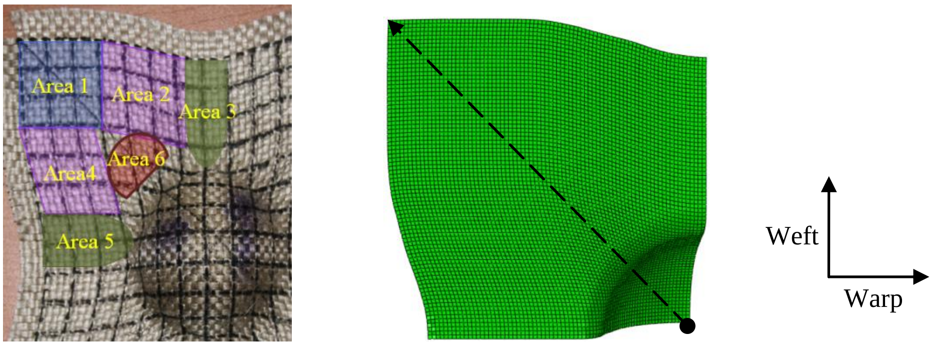

Figure 8. Experimental area (a) and numerical line (b) of shear angle measurements

	Area1	Area2	Area3	Area 4	Area5	Area6
Experimental	2.5°	14.5°	4.0°	14.0°	6.0°	26.3°
Linear model	0.3°	17.7°	4.5°	17.2°	4.1°	25.7°
Non-linear model	0.4°	18.3°	5.5°	18.2°	6.0°	26.1°

Table 4. Average shear angle measurements for a 625N loading

Both models estimate reasonably experimental shear angles. The influence of the load effect on the shear behaviour computed along a defined line (Figure 8.b) is shown on Figure 9. Results show that loads on the blank-holder have an influence on the shear behaviour, especially for the maximum values of the shear angles. Results obtained with both models show a coupling between the tensile behaviour and the shear behaviour. The linear model is more sensitive to the load modification but the non-linear model gives a smoothest approach of the shear behaviour.

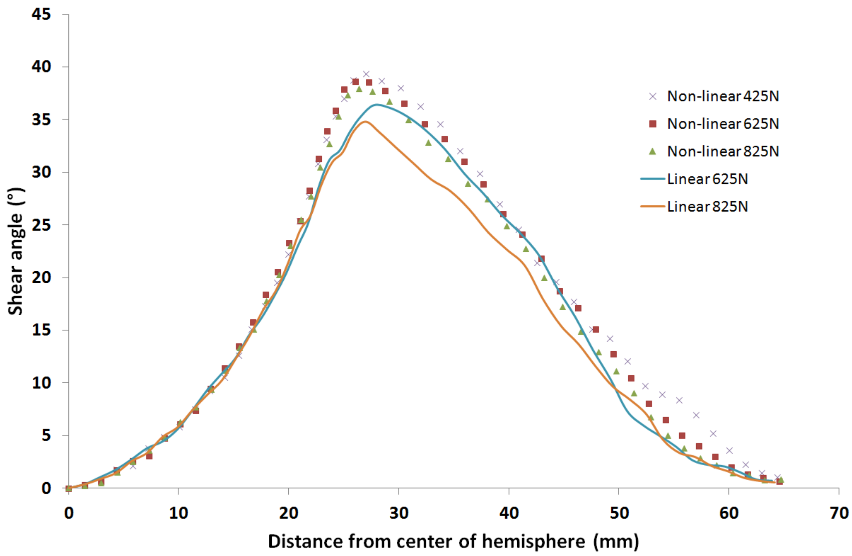

Figure 9. Evolution of shear angle along the defined line in Figure 10

Associated to experimental characterization on a flax woven, a finite element model has been used. On simple shape, the influence of the non-linear behaviour in tension has been proved relatively to the load applied during the preforming step of the RTM Process.

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