Analysis of defects during the preforming of a woven flax reinforcement

Pierre Ouagne, Damien Soulat, Gilles Hivet, Samir Allaoui, Davy Duriatti

Analysis of defects during the preforming of a woven flax reinforcement

P. Ouagne[a*], D. Soulat[a], G. Hivet[a], S. Allaoui[a], D. Duriatti[b]

[a]*Laboratoire PRISME, University of Orleans, 8 Rue Leonard de Vinci, 45072 Orleans, France*
[b]*Groupe Depestele - BP 21, 14540 Bourguebus - France*

**Corresponding author:*pierre.ouagne@univ-orleans.fr
Tel: +33 (0) 2 38 41 73 32 *Fax:* + 33 (0) 2 38 41 73 29

Abstract. This paper presents one of the first experimental investigations to analyze the formability of dry woven preform made of flax yarns. A defect analysis at the preform scale, such as wrinkling or buckling is conducted. This work indicates the mechanisms at the origin of these defects. To form complex shapes without generation of defects, the constitution and the architecture of the yarns constituting the woven fabric should be optimised.

Keywords: Composites, Preforming, flax fabric, Natural Fibres, RTM.

1. Introduction

Natural fibres have long been considered as potential reinforcing materials or fillers in thermoplastic or thermoset composites. Numerous studies deal with the subject [1-6]. Natural fibres are particularly interesting because they are renewable, have low density and exhibit high specific mechanical properties. They also show non-abrasiveness during processing, and more importantly biodegradability. A large amount of work has been devoted to identify the tensile behaviour of individual fibres or group of few fibres of different nature and origin [7-10]. However, few studies deal with the subject of the mechanical behaviour of fibre assemblies and particularly analyze the deformability of these structures.

To manufacture high performance composite parts, it is necessary to organise and to align the fibres. As a consequence, aligned fibres architectures such as unidirectional sheets, non-crimped fabrics and woven fabrics (bidirectional) are usually used as reinforcement.

In the Liquid Composite Moulding (LCM) family, the Resin Transfer Moulding, (RTM) process has received a large attention in the literature [11] and particularly the second stage of the process dealing with the injection of resin in preformed dry shapes and the permeability of the reinforcements [12-13]. The first stage of this process consists in forming dry reinforcements. In case of specific double curved shapes, woven fabrics are generally used to allow in plane strain necessary for forming without dissociation of the yarns.

The modification of the yarn orientation and local variations of fibre volume fraction have a significant impact on the resin impregnation step as the local permeabilities (in-plane and transverse) of the reinforcement may be affected [14-16]. In the most severe cases, the ply of fabric can wrinkle or lose contact with the mould, hence severely reducing the quality of the finished product [17]. Consequently the quality of the preform is of vital importance for the final properties of the composite part.

Several experimental devices have been set up to investigate the deformation modes and the possible occurrence of defects during forming of textile reinforcements. Hemispherical punch and die systems were particularly studied because the shape is rather simple, it is doubled curved and because it leads to large shear angles between the yarns [18-20]. In this paper, an experimental device is presented to form severe shapes. As an exemple, tetrahedron geometry is considered as it is much more difficult to form than hemispherical shapes especially if the radiuses of curvature are small.

This paper therefore proposes to investigate the feasibility of forming a complex shape such as a tetrahedron using a specific device from natural fibre based textile reinforcement. A discussion upon the possible appearance of defects during forming is also carried out.

2. Experimental set up

A device specifically designed to analyze the local strains during the forming of reinforcement fabrics [21] is presented on Figure 1.a. The mechanical part consists of a punch/open die couple and a classical blank holder system. The die is open to allow the measurement of the local strains during the process with the cameras associated to marks tracking technique. The motion of the punch is given by a piloted electric jack. Nine independent blank holders associated to pneumatic jacks can be activated under the woven flat fabric. Dimensions, positions, and specifically variable pressure on each of these blank holders can be easily changed to investigate their influence on the quality of the final preform. This device has been developed to preform different shapes. Severe double curved shapes containing faces, edges and triple points at the intersection of the edge are considered. The tetrahedron punch used in this work is presented on figure 1.b. The goal of the study is to analyze the possibilities of forming severe shapes with woven fabrics made of natural fibres.

3. Experimental results

3.1 Materials properties and preform analysis

The flax fabric (figure 1.c) used in this study is a plain weave fabric which areal weight is of about 625 g/m^2 manufactured by the Groupe Depestele (France). The fabric is not balanced. This fabric is constituted of continuous yarns (figure 1.d). Generally, when natural fibres are considered, twisted yarns are elaborated to increase its tensile properties. Indeed, as discussed by Goutianos *et al.* [22] sufficient tensile properties of the yarns are necessary for these ones to be considered for textile manufacturing or for processes such as pultrusion or filament winding. In this study, the flax yarns used to elaborate the plain weave fabric are un-twisted and exhibit a rectangular shape. The fibres or groups of fibres are slightly entangled to provide a minimum rigidity to the yarns. This geometry has been chosen as it generates low bending stiffness yarns, therefore limiting the crimp effect in the fabric and therefore limiting empty zones between yarns. It has also been chosen because fabric manufactured from highly twisted yarns exhibit low permeability preventing or partially preventing the use of processes from the LCM (Liquid Composite Moulding) family. Un-twisted yarns have also been chosen because manufactured composites display better mechanical properties than composites made with twisted yarns [23]. The tensile properties of the untwisted yarns used to constitute the fabric of this study are sufficient enough to sustain the loads applied during the fabric manufacturing, and it is expected that the tensile properties are good enough to sustain the loads taking place during forming.

An initial square specimen of the flax fabric is positioned with six blank holders placed on specific places around the tetrahedron punch. On each of them a pressure of one bar is applied. The maximum depth of the punch is 150 mm. At the end of the forming process, an epoxy resin spray is applied to the preform so that the shape is fixed in its deformed state. The preform in its final state is presented in Figure 2.a. At the scale of the preform the obtained shape is in good agreement with the expected tetrahedron punch. The fabric is not un-weaved on faces or edges. Some wrinkles appear (Fig.2.a) at the surrounding of the useful part of the preform. The position and the size of these wrinkles depend on the blank holder position and on the pressure they apply on the fabric. The process parameters (number and position of blank holders, choice of the punch, etc...) and the initial positioning of the fabric have a significant influence on the final shape. These aspects will be presented in future works. At the local scale, it is possible to analyse during the process the evolution of the shear angle between yarns and the longitudinal strain along the yarns. During the forming stage, the woven textile is submitted to biaxial tensile deformation, in plane shear deformation, transverse compaction and out-of-plane bending deformations. If all these components can be significant, the feasibility to obtain the expected shape is largely dependent on the in-plane shear behaviour. On the formed tetrahedron faces, values of the measured shear angle are relatively homogeneous [24]. These values do not reach the locking angle above which defects such as wrinkles appear. The link between the in-plane shear mechanical behaviour and the development of wrinkles has been studied in the literature especially for carbon woven reinforcement [21]. It has also been observed in this study that the yarns did not suffer any apparent failure on faces or edges. This means that the tensile strain reached in yarns during the process does not exceed the limit value.

3.2. Buckles defect analysis and discussion

At the preform scale, another type of defect denoted by buckles (Figure 2.b) appears on faces and on one edge of the formed tetrahedron shape. These buckles zones converge to the triple point (top of the tetrahedron) from the bottom of the shape (Figure 2.c). Due to this defect the thickness of the preform is not homogeneous. The height of some of the buckles can reach 3 mm near the triple point. Due to this thickness in-homogeneity generated by these buckles, the preform could not be accepted for composite part manufacturing.

At the fabric scale, the buckles are the consequence of out of plane bending of the yarns perpendicular to those passing by the triple point. The yarns passing by the triple point are particularly tight. On the contrary, the yarns perpendicular to the one passing by the triple point are not tight, and the size of the buckles depends on those yarns tension. In this zone, there is no homogeneity of the tensile deformation. This is illustrated by the orientation of the yarns perpendicular to the one passing by the triple point on both sides of the buckle zone (drawn figure 2.d). These yarns are curved instead of being straight, and this phenomenon is probably at the origin of the buckles.

Buckles have also been observed for a flax balanced woven fabric. This type of defect is therefore associated to the severe shape of the matrix and to the tensile state of the fabric. These tensions may be controlled by adjusting the blank holder pressure so that a more homogeneous tensile state in the fabric is observed, and the number of buckles decreases.

Some work investigating into depth the phenomena at the origin of buckles by producing these defects independently of the forming process is necessary. It is also expected that the geometry and the architecture of the yarns and of the fabric may affect the forming and the generation of defect.

4. Conclusions

In this work, a study investigating the possibilities of forming complex shapes from a woven fabric made of flax fibres has been presented. A specific device has been used to preform the given fabric with a complex tetrahedron shape. An analysis of the preform quality has been conducted. Globally, the complex shape with double curves and a triple point has been obtained. However, non acceptable defects called buckles are observed. This type of defect is therefore associated to the severe shape of the matrix and to the tensile state of the fabric. Depending on the tensile state of the fabric, in plane bending of some yarns perpendicular to the one passing by the top of the tetrahedron takes place. This mechanism has been identified as the mechanism at the origin of the buckles. The differential tensions in the different yarns could be controlled more accurately by adjusting the blank holder pressure. It is also important to work in collaboration with the textile manufacturer to optimize the constitution and the architecture of the yarns and the fabric with the goal to form complex shapes without defect.

References

1. La Mantia F.P., Morreale M. "Green composites: A brief review." *Composites Part A*, 42 (2011), 579-588.
2. Satyanarayana K. G. , Arizaga G. G.C., Wypych F. "Biodegradable composites based on lignocellulosic fibers—An overview" *Progress in Polymer Science*, 34 (2009), 982–1021
3. Biagiotti J., Puglia D., Kenny J. M. "A Review on Natural Fibre-Based Composites-Part I" *Journal of Natural Fibers*, 1: 2 (2004), 37 - 68.
4. Puglia, D. , Biagiotti, J. and Kenny, J. M. 'A Review on Natural Fibre-Based Composites—Part II', *Journal of Natural Fibers*, 1: 3 (2005), 23 - 65.
5. Pandey J. K., Ahn S. H., Lee C. S., Mohanty A. K., Misra M. "Recent Advances in the Application of Natural Fiber Based Composites" *Macromolecular Materials and Engineering*, 295 (2010), 975–989.
6. Ouagne P., Bizet L., Baley C., Bréard J. "Analysis of the Film-stacking Processing Parameters for PLLA/Flax Fiber Biocomposites". *Journal of Composite Materials*, 44 (2010), 1201-1215.
7. Baley C. "Analysis of the flax fibres tensile behaviour and analysis of the tensile increase" *Composites Part A,* 33 (2002), 2143-2145.
8. Bodros E., Baley C. "Study of the tensile properties of stinging nettle fibres" *Materials Letter*, 62 (2008), 2143-2145.
9. Alawar A., Hamed A.M., Al-Kaabi K.. "Characterization of treated data palm tree fiber as composite reinforcement" *Composites Part B*, 40 (2009), 601-606.
10. Kim J.T., Netravili A.N. "Mercerization of sisal fibers: Effects of tension on mechanical properties of sisal fibers and fiber-reinforced composites" *Composite Part A,* 41 (2010), 1245-1252.
11. Buntain M.J.,Bickerton S. "Modeling forces generated within rigid liquid composite moldings tools. Part A: Experimental study" *Composites Part A.*, 38 (2007), 1729-1741.

12. Lekakou C, Johari B, Norman D, Bader G. "Measurement techniques and effects on in-plane permeability of woven cloths in resin transfer molding" *Composites Part A*, 27 (1996) 401-408.

13. Ouagne P., Bréard J. "Continuous transverse permeability of fibrous media" *Composites Part A*, 41 (2010), 22-28.

14. Hammani A., Trochu F., Gauvin R., Wirth S. "Directional permeability measurement of deformed reinforcement" *Journal of reinforced plastics and composites*, 15 (1996), 552-562.

15. Bickerton S., Simacek, Guglielmi S.E., Advani S.G. "Investigation of draping and its effects on the mold filling process during manufacturing of a coumpound curved composite part" *Composites Part A*, 28 (1997) 801-816.

16. Loix F., Badel P., Orgeas L., Geindreau C. Boisse P. "Woven fabric permeability: from textile deformation to fluid flow mesoscale simulations" *Composites Science and Technology*, 68 (2008), 1624-1630.

17. Sharma S.B., Sutcliffe M.P.F., Chang S.H.. "Characterisation of material properties for draping of dry woven composite material" *Composites Part A*, 34 (2003), 1167-1175.

18. Molnar P., Ogale A., Lahr R., Mitschang P. "Influence of drapability by using thermoforming" *Composites Science and Technology*, 67 (2007), 3386-3393.

19. Li X., Bai S. "Sheet forming of the multy-layered biaxial weft knitted fabric reinforcement. Part 1: On hemispherical surfaces" *Composites Part A*, 40 (2009), 766-777.

20. Vanclooster K., Lomov S.V., Verpoest I. "Experimental validation of forming simulations on fabric reinforced polymers using an unsymmetrical mould configuration. *Composites Part A*, 40 (2009), 530-539.

21. Soulat D., Allaoui S., Chatel S. "Experimental device for the ptimizati step of the RTM process". *International Journal of Material Forming*, 2 (2009), 181–184.

22. Goutianos S., Peijs T. "The optimization of flax fibre yarns for the development of high-performance natural fibre composites" *Advanced Composite Letters*, 12 (2003) 237-241.

23. Goutianos S., Peijs T., Nystrom B. Skrifvars M. "Development of flax based textile reinforcements for composite applications" *Applied Composites Materials*,13 (2006), 199–215.

24. Ouagne P., Soulat D., Allaoui S., Hivet G. "Mechanical properties and forming possibilities of a new generation of flax woven fabrics". Proceeding of the 10th international conference on textile Composite (Texcomp). 26-28 October 2010, Lille, France.

Captions to figure

Figure 1: (a) Description of the device. (b) Tetrahedron punch. (c) Flax fabric (d) Flax yarn.

Figure 2. (a) Preform and Wrinkles. (b) Zoom on buckles. (c) Position of buckles. (d) yarns orientation

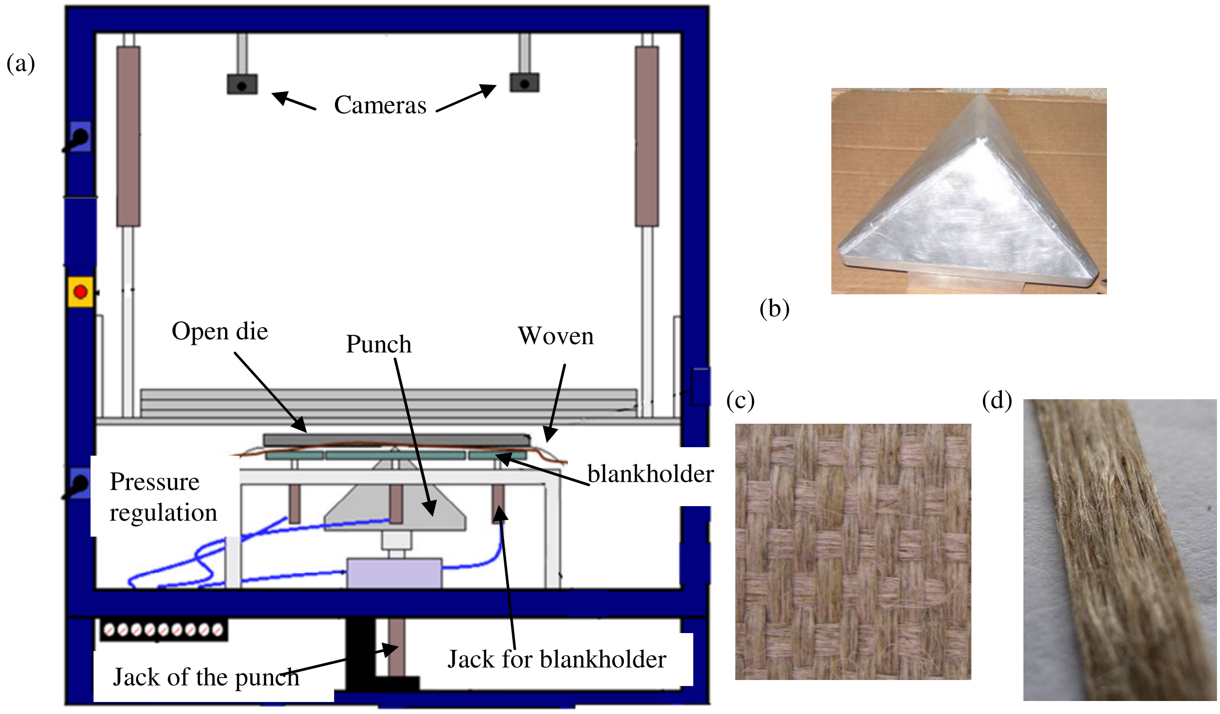

Figure 1: (a) Description of the device. (b) Tetrahedron punch. (c) Flax fabric (d) Flax yarn.

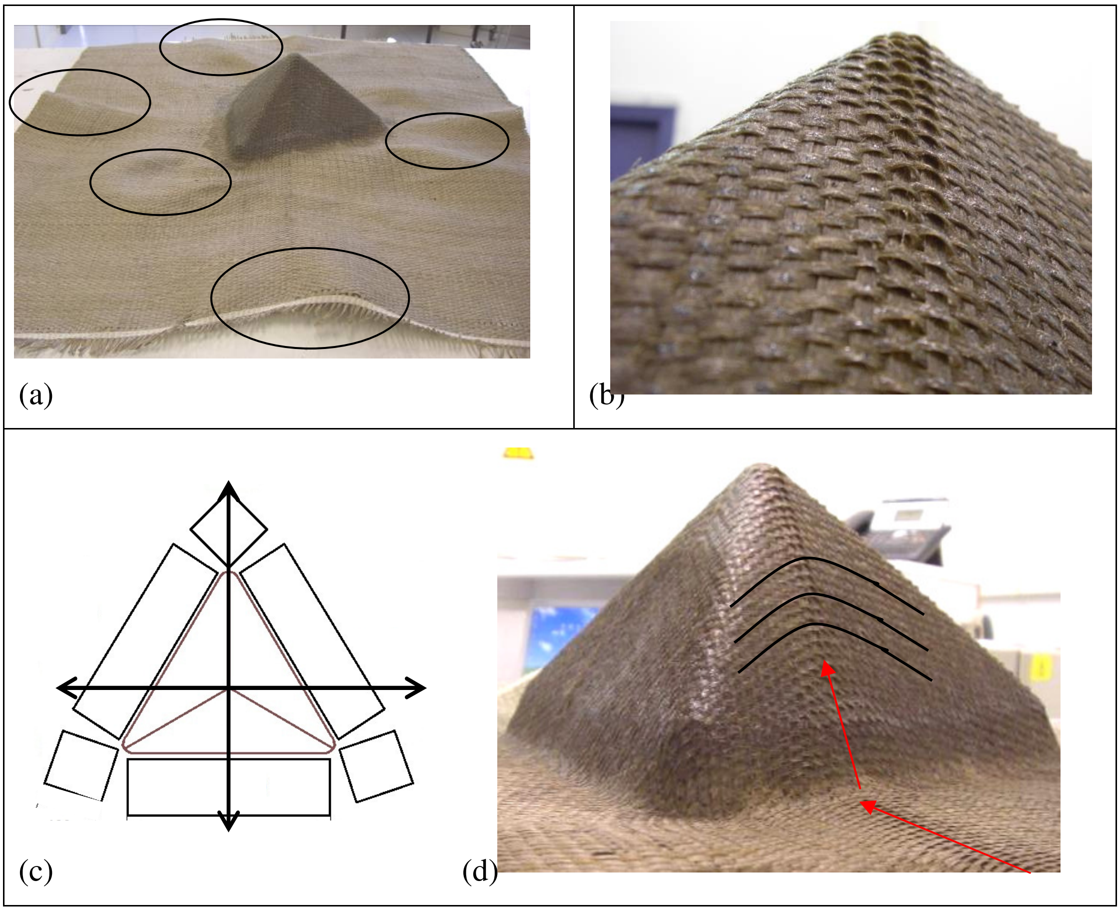

Figure 2: (a) Preform and Wrinkles. (b) Zoom on buckles. (c) Position of buckles. (d) yarns orientation