OPTIMISATION OF THE PROCESS PARAMETERS TO PREVENT THE APPEARANCE OF DEFECTS DURING THE COMPLEX SHAPE FORMING OF FLAX BASED REINFORCEMENTS COMPLEX SHAPE

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Abstract

Solutions to preform complex shapes such as a tetrahedron without any defect from flax based woven fabrics are investigated in this work. The first way to prevent the appearance of defects such as tow buckles consists in designing specific woven architecture fabrics. However, even if this solution was shown to be effective on the tetrahedron shape, solutions based on the optimisation of the process parameters to prevent the appearance of buckles from commercial fabrics were also investigated with success.

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 tows. However, when considering complex shape forming, defects such as tow buckling, [14-15] may appear and cannot be predicted yet by using a numerical approach. As a consequence, an experimental approach needs to be used. To prevent the appearance of this particular defect, specifically designed fabric architectures can be used. A complex tetrahedron shape was formed without any defect [16]. However, in the case of forming necessitating very high shear deformations, this reinforcement would probably not be suitable, and this is why it would be very much interesting to investigate the possibility of forming complex shapes without any buckle appearance with woven fabric of the market and particularly with the ones showing good shear abilities. To reach this goal, it is important to study and optimise the process parameters. Particularly, the design of the blank holders used in our previous studies was probably not adapted to minimise tow buckles [16] as well as too high strain in several tows [17]. As a consequence, this work suggests to optimise the process parameters controlling the sheet forming process to avoid the appearance of defects occurring during complex geometry forming of natural based fabrics such as tow buckling and too high tow tensile strains. Particularly, the goal of the process optimisation consists in applying locally the right blank holder pressure using a specifically designed blank holder set.

2 Experimental setup

2.1 Global design of the forming device

A device specifically designed to analyze the local strains during the forming of reinforcement fabrics [18] is presented on Figure 1.a.

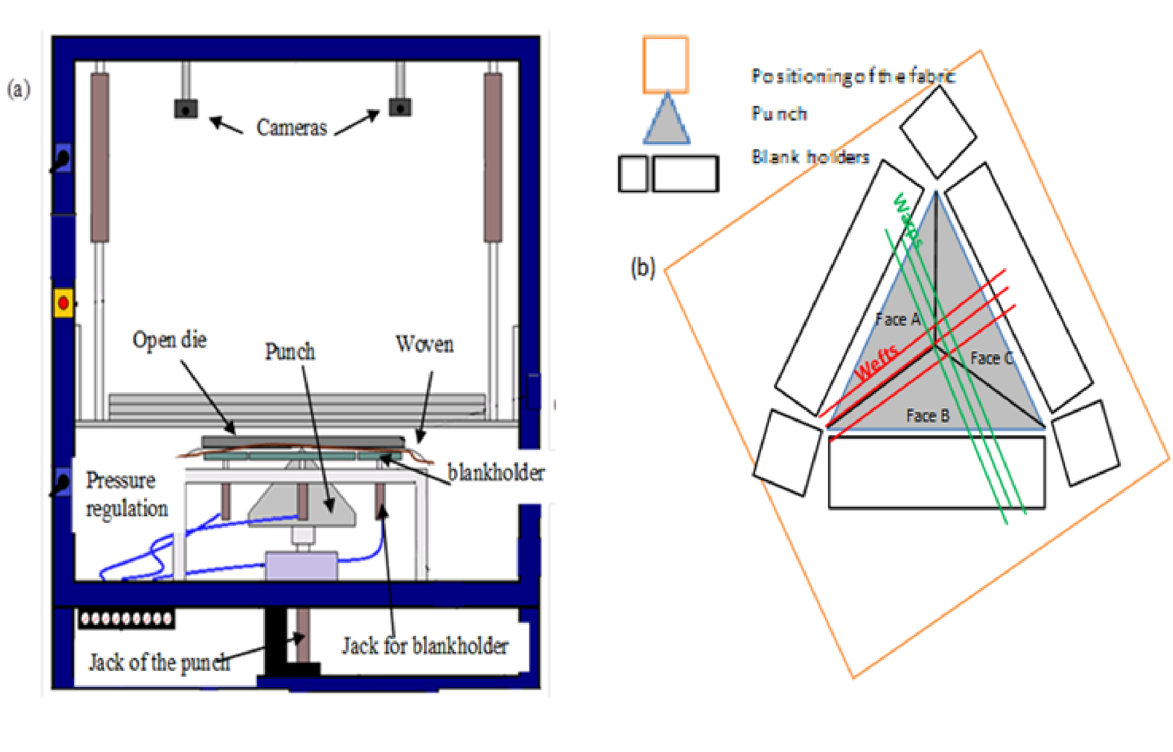

Figure 1: (a) Description of the device. (b) Tetrahedron punch. (c) Flax fabric (d) Flax tow.

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.

2.2 Blank holders designs

Both the tow buckles and the excessive tensile strain in tows are localised in zones close to the tows passing by the top of the tetrahedron as indicated in Figure 2.a by the black arrows [19]. In this zone, the vertical tows passing by the triple point are too tight in the three faces and on the edge opposed to Face C. The perpendicular tows may show the presence of tow buckles partly resulting of the bending in their plane of tows and also probably because of a too low tension of these tows. In Figure 2.b the buckles are localised on Face C of the tetrahedron and on the opposite edge. No buckles are observed on Faces A and B. This is linked to the un-balanced architecture of the fabric used [16]. The basis of the new blank holder generation therefore consists in reducing pressure in the vertical tows and to increase the tension of the horizontal ones. A schematic diagram of the blank holder is presented in Figure 3. Instead of the 6 initial blank holders (Figure 2.a), the new blank holder generation consist of 4 blank holders with specific geometries. The blank holders impose tensions to the membrane and particularly to the bent tows exhibiting tow buckles. Between the 4 blank holders, empty zones have been left to release the tension of the tows showing too high tensile strains. It can be noted that small blank holders could be used to fill up the spaces and impose a local pressure to this zone if necessary.

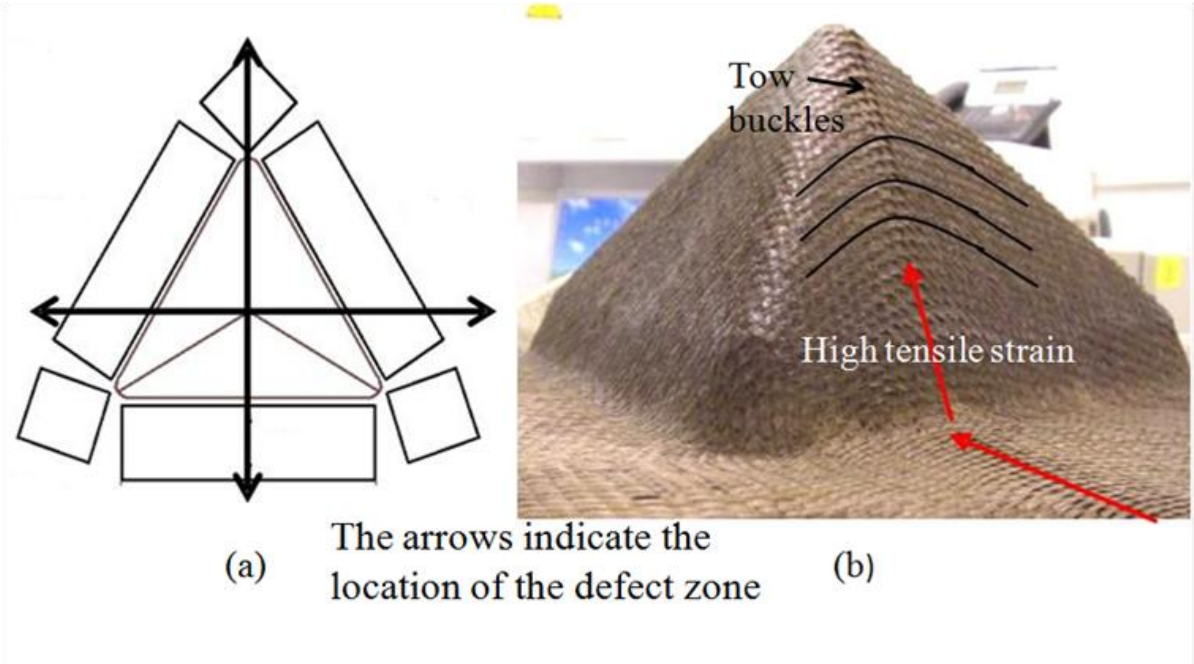

Figure 2: (a) First blank holder generation; position of the defect zones (a and b)

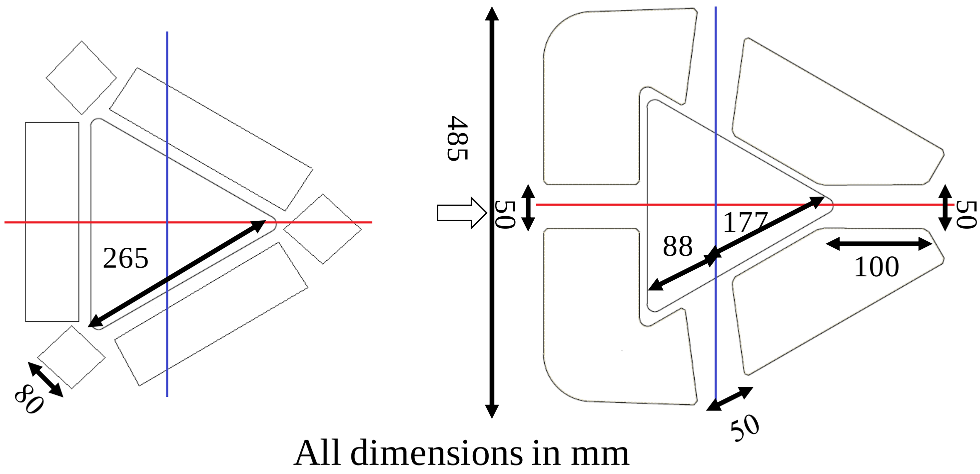

Figure 3: Evolution of the blank holder design

3 Results

It is proposed in this Section to analyse the interest of using the especially designed blank holder set on the appearance of the tow buckling defect and too high strains in the tows passing by the triple point for the two fabrics considered in this study.

Figure 5 shows views of Face C and Edge 1 in the case of forming with the specially designed blank holder set for the plain weave fabric. It shows that no apparent defects such as wrinkles tow sliding or tow buckling appears. This first visual result needs to be compared to the observations carried out on the shape formed using the original blank holder set (Fig 2) and on the results presented and developed in [15] that indicate it was not possible to prevent the appearance of this particular defect using the original blank holder set.

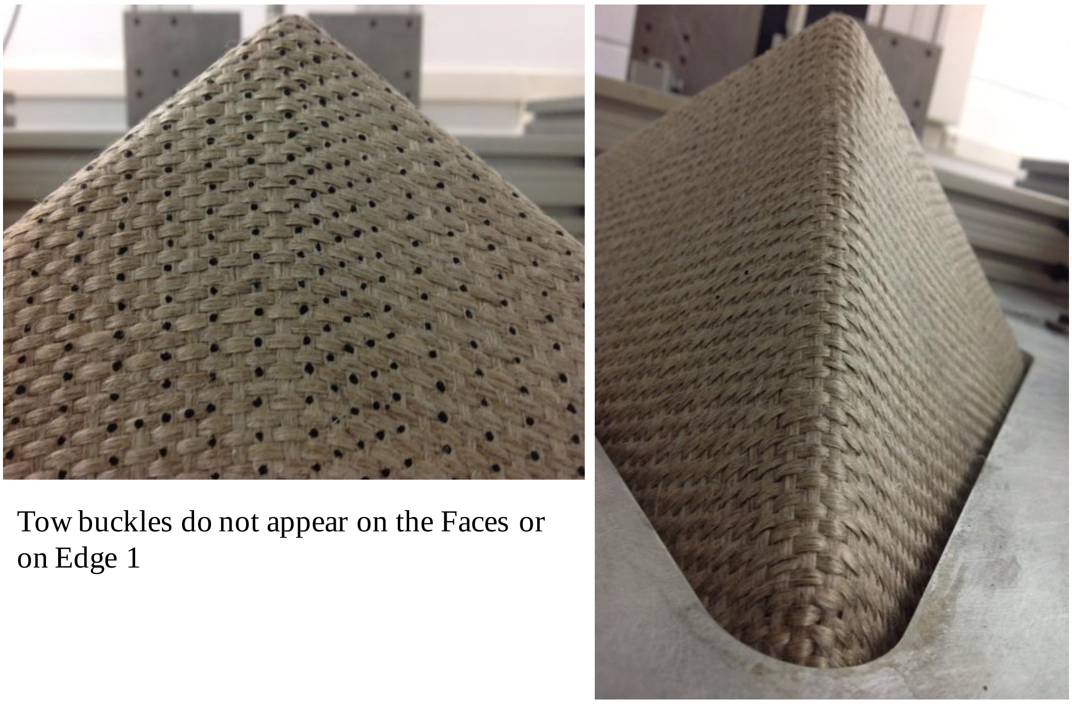

Figure 5: Plain weave fabric: Face C and Edge 1 using the specially designed blank holder set

While looking at Figure 5, it appears that the use of the new blank holder set contributes to an important progress as no apparent defects are visible. Particularly, the use of the new blank holder set design prevents the appearance of tow buckles on the faces and on edge 1.
If no apparent defects are observed on the faces and on the edges of the tetrahedron formed using the new blank holder geometry, it is still necessary to investigate if the tensile strains of the tows passing by the triple point (top of the pyramid) are higher than the strain at which local failure may happen. Figure 6 shows a comparison of the tensile strains measured using both set of blank holder for the plain weave fabric and at the same location on the preform (on the weft tow passing by the triple point of Face C using 2 bar of blank holder pressure).

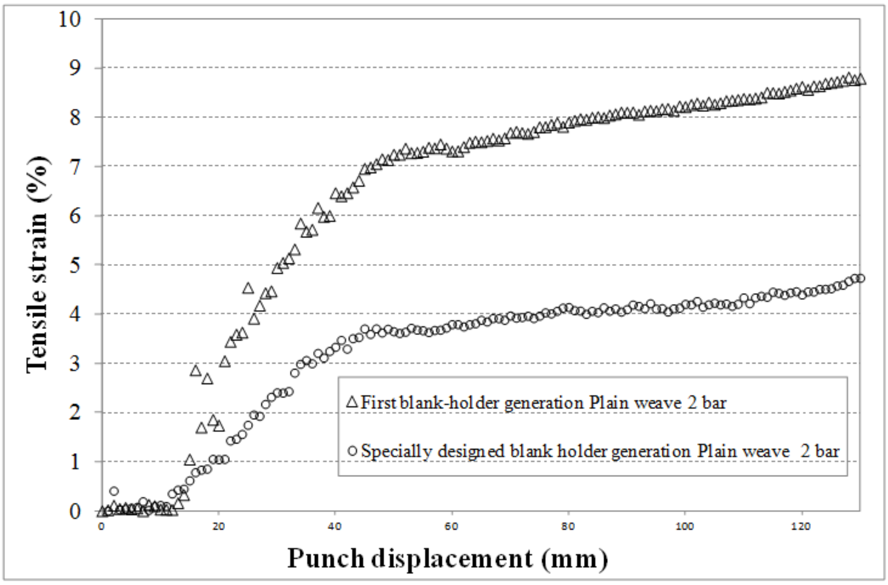

Figure 6: Plain weave fabric: comparison of the tensile strains

Figure 6 shows that a large decrease in tensile strain is observed, particularly at the end of the forming process. The tensile strain values are lowered from 8.8% to 4.7 % indicating that the new set of blank holder has an important beneficial effect on the tensile strain reduction on the tows passing by the triple point in the case of the plain weave fabric. This corresponds to a decrease of about 47%. However, the value of the maximum strain recorded at the end of the forming process on the tightest tow needs to be compared to the limit of the fabric determined by performing biaxial tensile test on the same fabric. The biaxial test procedure has been described in [19, 20]. Figure 7 shows the result of the biaxial test in the case of equal deformation in the warp and weft directions and in the case where the warp tows are left free. The last case would be the one to compare with the tensile strain measured during forming as the warp tows exhibiting the tow buckles are not tight and can be considered as almost free. In this case, the maximum limit above which sliding movements within the tow leading to losses of fibre density may happen is about 4%. This value is lower than the one recorded at the end of the forming process in our forming test (4.7%) suggesting that sliding of group of fibre may have taken place. However, the maximum tensile strains recorded are not very much higher than the strains at which the defects may start to be generated. As a consequence, it is expectable that low displacement between the fibres took place as described by Moothoo *et al* [21], but to a low extent. So the fibre density does not, to our opinion, change. In those conditions, the too high strains in the tow should not therefore be a problem concerning the manufacturing of a composite part either by film stacking process [6] or by the RTM process.

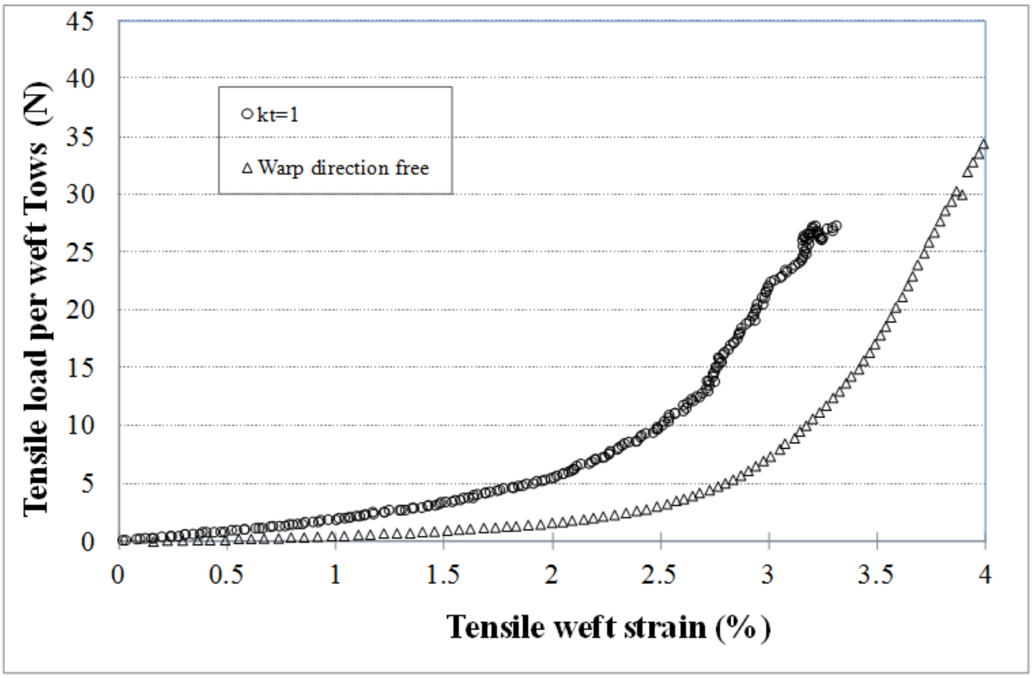

Figure 7: Plain weave fabric: biaxial tension curves

4 Conclusions

Solutions to obtain complex shapes from commercial flax fabrics manufactured using flat untwisted tows have been investigated in this work. This study concentrates on the possibility to form a complex shape such as a tetrahedron using the sheet forming process which is a technique that could be used by the automotive industry because of the interesting cost/cadencies ratio. Particularly, the study investigates the possibility of realising a technical complex preform without defect from two different architecture commercial reinforcements not specially designed. Several defects such as tow buckles and too high strains in tows already described in previous studies [22, 15] need to be avoided and prevented. For this reason a specially designed blank holder set was used to form complex tetrahedron shapes. The defects previously encountered using a non-optimised blank holder set have been suppressed in a great extent. The tow buckles were suppressed by reducing the tension in the vertical tows of the shape and by increasing the tension of the tows exhibiting the buckles. For the plain weave fabric, the buckles were totally suppressed at the end of the forming process, whereas an additional compression stage would probably be necessary in the case of the twill weave to get rid of the tow buckles.

By reducing the tension in the vertical tows of the shape in the zone where tow buckles may take place, the too high strain defect was also reduced to such an extent that it is not a problem anymore.

This study therefore shows that it is possible to form complex shapes using untwisted flax commercial reinforcements not particularly optimised for complex shape forming by well designing the geometry of blank holders. This result is particularly interesting because it is possible to use fabric that do not necessitate as much energy for their production as twisted yarn reinforcement and because the composite parts manufactured using such reinforcements show higher performance because higher fibre volume fraction can be obtained.

5 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] Potter K, Khan B, Wisnom M, Bell T, Stevens J. “Variability, fibre waviness and misalignment in the determination of the properties of composite materials and structures” *Composites: Part A* 39 (2008) 1343–1354.

[15] Ouagne P, Soulat D., Hivet G, Allaoui S, Duriatti D. Analysis of defects during the performing of a woven flax. *Advanced Composites Letters* 20 (2011) 105-108.

[16] Ouagne P., Soulat D., Moothoo J., Capelle E., Gueret S. Complex shape forming of a flax woven fabric; analysis of the tow buckling and misalignment defect *Composites Part A*, 51, August 2013, 1-10.

[17] Ouagne, P, Soulat, D, Tephany, C, Moothoo J, Allaoui, S, Hivet, G.; Duriatti, D. Complex shape forming of flax based woven fabrics. Analysis of the yarn tensile strain during the process.*Key Engineering Materials* 504 – 506 (2012) 231-236.

[18] Soulat D., Allaoui S., Chatel S. “Experimental device for the optimization step of the RTM process“. *International Journal of Material Forming*, 2 (2009), 181–184.

[19] Ouagne P, Soulat D, Tephany C, Duriatti D, Allaoui S, Hivet G. Mechanical characterisation of flax based woven fabrics and in situ measurements of tow tensile strain during the shape forming. *Journal of Composite Materials,* 2013; 47: 3498 - 3512.

[20] Buet-Gautier K., Boisse P. Experimental analysis and modeling of biaxial mechanical behavior of woven composite reinforcements. Experimental Mechanics 2001; 41 (3): 260-269

[21] Moothoo J, Allaoui S, Ouagne P, Soulat D. A study of the tensile behaviour of flax tows and their potential for composite processing. *Materials & Design*, 2014 ; *55* : *764-772*

[22] Allaoui S, Hivet G, Soulat D., Wendling A, Ouagne P, Chatel S. Experimental preforming of highly double curved shapes with a case corner using an interlock reinforcement. *International Journal of Materials Forming*. DOI 10 1007/S12289-012-1116-5.