

Experimental Investigation of Reinforcement Fabric Cohesion in order to Prevent the Tow Sliding Defect.

M. M. Salem^{1, a)}, A.R. Labanieh^{2, b)}, E. De Luycker^{1, c)}, M. Fazzini^{1, d)},
C. Garnier^{1, e)}, P. Ouagne^{1, f)}.

¹University of Toulouse, INP-ENIT, LGP, 47, avenue d'Azereix, F-65016 Tarbes, France.

²University of Lille, GEMTEX, ENSAIT, 2 allée Louise et Victor Champier, 59056 Roubaix, France.

^{a)}Corresponding author: mohamed-medhat.salem@enit.fr

^{b)}ahmad.labanieh@ensait.fr

^{c)}emmanuel.de-luycker@enit.fr

^{d)}marina.fazzini@enit.fr

^{e)}christian.garnier@enit.fr

^{f)}pierre.ouagne@enit.fr

Abstract. In order to understand the causes and the formation process of the tow sliding defect, shape preforming tests were performed on a hemispherical punch. Variable orientation and blank holders' pressure were investigated in order to assess the phenomena and a cohesion pull-out test was proposed to investigate the cohesion of the reinforcement which was determined in a previously developed analytical model to be of utmost importance.

INTRODUCTION.

During complex shape forming process of textile woven reinforcement, tow (flat yarn) sliding may happen as shown in Figure 1. This defect was observed in the work of Ouagne et al. [1] during the forming of a single layered flax plain weave fabric. The importance of applying a relatively low blank-holder pressure was highlighted to prevent the appearance of the sliding defect. Allaoui et al. [2] came to similar conclusions for the forming of an interlock reinforcements on a highly curved geometry. Nezami et al. [3] experienced similar tow sliding on a boomerang-shaped tool while forming single layer reinforcement under homogenous blank holders' pressure.

Labanieh et al. [4] noted the effect of tow tension, shear angle, relative orientation of the reinforcement to the tool, fiber/fiber and fiber/tool friction on the tow sliding and proposed an analytical framework to determine the friction force imposed by the blank holders causing tow sliding. To this day the tow sliding defect has yet to be fully understood and accurately simulated [5] even though this was already attempted by Gatouillat et al. [6] by aiming towards an individual geometrical modeling of tows in a woven structure to reproduce the sliding defect.



FIGURE 1. Tow sliding defect during complex shape forming of flax plain weave fabric

YARN SLIDING.

The yarn sliding appearance was studied using an experimental forming device designed at ENSAIT Roubaix [7] and illustrated in figure 2. Different blank-holder pressure and geometries are studied so that to investigate the importance of process parameters as well as the design of the pressure application device. The device is instrumented with Digital Image Cameras, so that to evaluate the evolution of the shape as well as the defect appearance and evolution.

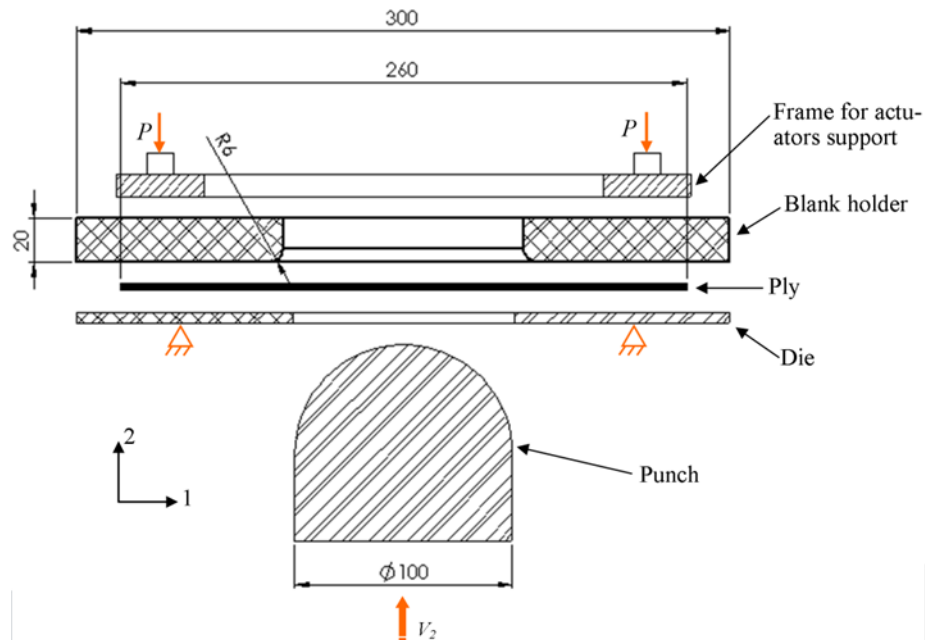


FIGURE 2. Forming machine scheme with characteristic dimensions. All dimensions are in millimeters [4].

Yarn sliding defects can be observed on specific zones of the shape as shown by figure 3. The defects are globally located close to the output of the blank holder on unsheared zones.

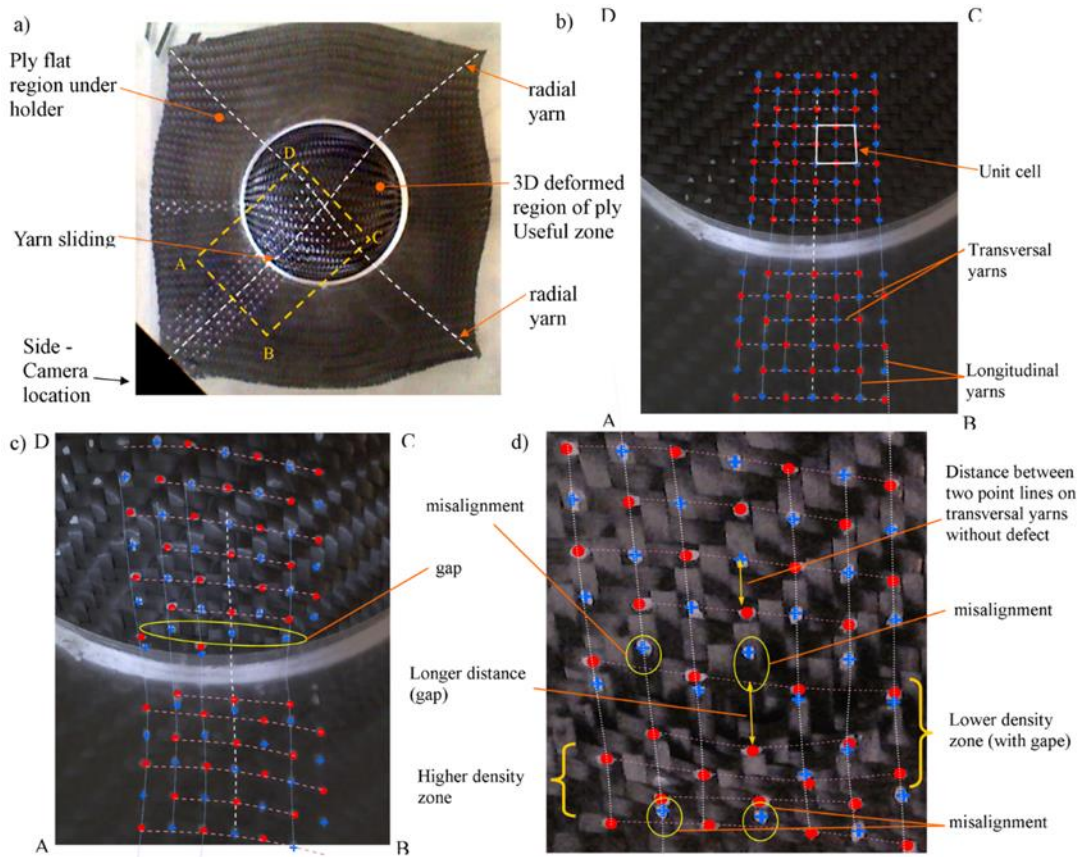


FIGURE 3. Localisation of yarn sliding during the hemispherical forming of a carbon-woven fabric. Image from Labanieh et al. [4].

To analyze the defect appearance into more details, an analytical model, developed in [4] was used in order to analyze the importance of the process parameters as well as the machine elements on the appearance of the yarn sliding defect and, on the ways, to prevent it.

By observing the defect appearance, it was noted that the yarn sliding defect appears when the friction forces between the reinforcement and die/blank holder was superior to the tension of the radial yarn. It has also been observed that the radial yarn tension is related to its length between the two machine plates. This therefore indicates the importance of the pressure application on the fabric and also the geometry of the blank holder. The model also shows that the radial yarn tension depends on the radius of the blank-holder corner edge. Increasing the curvature angle of the edge has for consequence to reduce the tension in the yarn.

The previous observations and analyses were used to propose solutions to prevent or delay the yarn sliding appearance. As an example, changes in the blank holder geometry and in the blank holder extremity radiuses were proposed. The blank holder extremity radiuses were increased and the surface of the blank holder was decreased as recommended by the model conclusions. The yarn sliding defects that originally took place disappeared. This work, therefore showed that it is possible to prevent the appearance of this defect by adjusting the process or the machine element parameters.

REINFORCEMENT COHESION.

While performing the fabric, the tows are driven up into shape by the friction existing between fibers. Once the friction force between fiber and tool exceeds the friction force between fibers, a tow sliding defect is observed. As noted in [3.4] and observed in the previous paragraph, the fabric/fabric and fabric/tool frictions are also heavily influenced by the reinforcement's relative orientation, tension and thickness which in turn is dependent on the shear angle. A simple friction test (slide test) is therefore inadequate to describe the actual friction mechanics taking place during the shaping process. Thus, a fabric cohesion test has been developed. The test device consists of a picture frame developed in the "Laboratoire Génie de Production" that enables applying tension individually to each tow while shearing the whole reinforcement. The frame is then placed within the column of a mechanical testing machine so that to perform pull-out tests on unrestrained tows, as presented in figure 4.

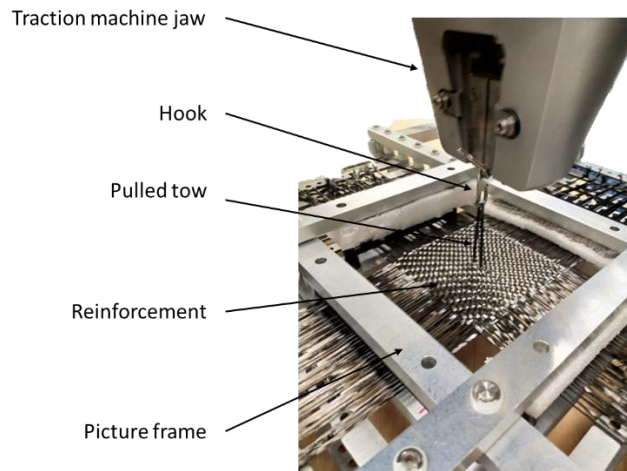


FIGURE 4. Tow pull-out setup.

The pull-out force recorded as shown in figure 5, presents a maximal value corresponding to the load required to cause the decohesion of the tow from the reinforcement followed by an oscillation of values as the wavy tow gets pulled through the reinforcement from which (oscillation) we get the average load value. The results are plotted, in figure 6, against different reinforcement shear angles for the "HexForce 48,600 U 1250" carbon woven 2x2 serge loaded at 1 N/tow for all tows except the pulled tow.

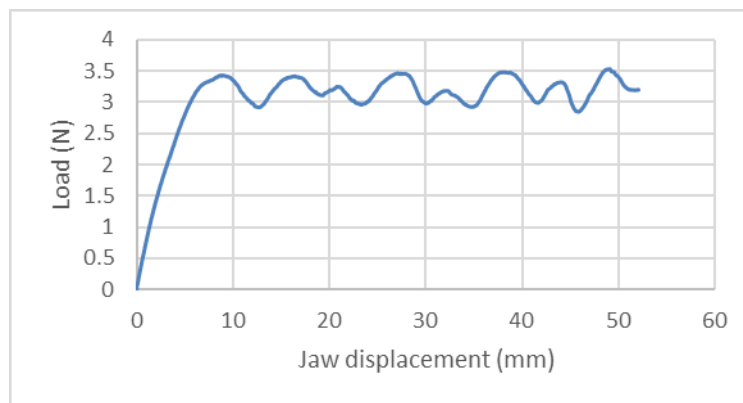


FIGURE 5. Tow pull-out recorded force against jaw displacement.

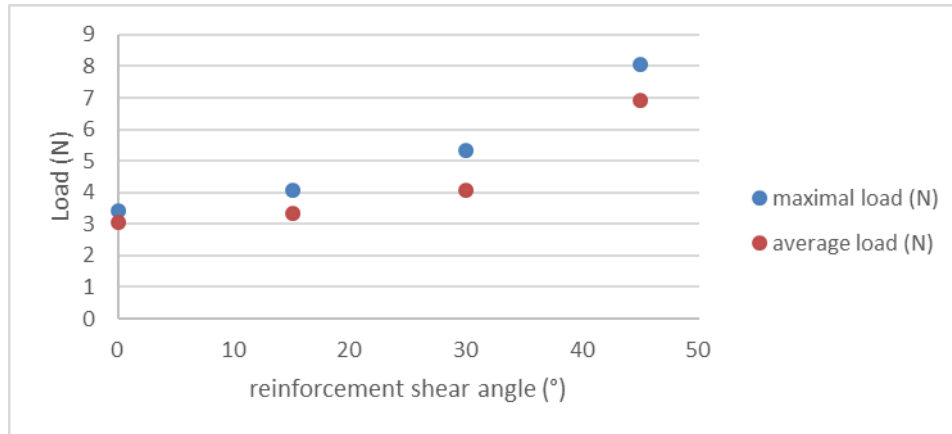


FIGURE 6. Tow pull-out forces.

As the shear angle increases, so does the required force to pull out the tow and thus the reinforcements cohesion. Starting from 3 N at 0° shear angle, average the pull-out force moderately increases at 15° and 30° to reach 4 N and then rapidly increases at 45° up to 7 N. This nonlinear increase of the pull-out load according to the shear angle explains the appearance of the sliding defect on the unsheared less coherent zones.

CONCLUSION.

During this work, we investigated the appearing conditions of the tow sliding defect and compared some of the results obtained by performing a reinforcement on a hemispheric punch to the results obtained from a cohesion pull-out test. More parameters are to be investigated and their effect on the cohesion of the reinforcement and compared to tool/fiber friction in order to predict the tow sliding defect.

REFERENCES.

1. P. Ouagne, D. Soulat, J. Moothoo, E. Capelle and S. Gueret, “Complex shape forming of a flax woven fabric; analysis of the tow buckling and misalignment defect,” *Compos. Part A*, vol. 51, no. 1, Aug. 2013, pp. 1–10.
2. S. Allaoui, G. Hivet, D. Soulat, A. Wendling, P. Ouagne, and S. Chatel, “Experimental preforming of highly double curved shapes with a case corner using an interlock reinforcement,” *Int. J. Mater. Form.*, vol. 7, no. 2, Jun. 2014, pp. 155–165.
3. F. NosratNezami, T. Gereke, and C. Cherif, “Analyses of interaction mechanisms during forming of multilayer carbon woven fabrics for composite applications,” *Compos. Part A Appl. Sci. Manuf.*, vol. 84, May 2016, pp. 406–416.
4. A. R. Labanieh, C. Garnier, P. Ouagne, O. Dalverny, and D. Soulat, “Intra-ply yarn sliding defect in hemisphere preforming of a woven preform,” *Compos. Part A Appl. Sci. Manuf.*, vol. 107, Apr. 2018, pp. 432–446.
5. P. Boisse, N. Hamila and A. Madeo, “Analysis of Defect Developments in Composite Forming,” In P.W.R. Beaumont, C. Soutis, and A. Hodzic: *The Structural Integrity of Carbon Fiber Composites*. Springer International Publishing, 2017.
6. S. Gatouillat, A. Bareggi, E. Vidal-Sallé, and P. Boisse, “Meso modelling for composite preform shaping—Simulation of the loss of cohesion of the woven fibre network,” *Compos. Part A Appl. Sci. Manuf.*, vol. 54, 2013, pp. 135–144.
7. P. B. Jacquot, P. Wang, D. Soulat and X. Legrand. “Analysis of the preforming behaviour of the braided and woven flax/polyamide fabrics,” *Journal of Industrial Textiles* 46 (3), 2016, pp 698–718.