EXPERIMENTAL INVESTIGATION OF THE TUFTED 3-DIMENSIONAL COMPOSITE REINFORCEMENT FORMING

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ABSTRACT

This paper presents an experimental investigation about the deformability of tufted 3D composite reinforcement during manufacturing, especially comparisons with multilayered forming and the influence of the tufting yarns on the forming behaviours. As one type of 3D textile reinforcements, the tufted 3D fabric is promising for the manufacturing of advanced composite part. Delamination can be reduced due to the existence of transverse reinforcement (reinforced yarns through-the-thickness), and the impact resistance and the damage tolerance are relatively strengthened. The tufting technology is user-friendly and the tufting parameters can be completely controlled (tufting density, tufting length, tufting yarns orientation…). Forming stage is very important as the first manufacturing step of Resin Transfer Molding process. In order to improve the understanding of formability of the tufted 3D fabric during forming, in particular the influence of the tufting yarns, this paper presents an analysis of the preforming behaviours of tufted 3D reinforcement in the hemispherical stamping process. The results demonstrate the significant influence of tufting yarns on the interply sliding and on the forming defects (winkles and misalignment).

1 INTRODUCTION

Liquid Composite Molding (LCM) is one of the advanced manufacturing processes to produce large and thick composite parts in aerospace and defense industries [1, 2]. As the first step of LCM (e.g. Resin Transfer Molding) process, the composite reinforcement forming plays a role very important [3-7]. To well understand the deformability of preform on more and more complex shapes (given by punch and die), the work shown in [8-11] describes the measurement criteria that can qualify the reinforcement formability behaviours such as intraply shearing, material draw-in, load, fibre orientations, and homogeneity of the fibre density. The formability behaviours depend on the process parameters (punch shape, blank-holder pressure, initial orientation of reinforcement, etc…). On the other hand, the forming defects (wrinkling, buckling, misalignment, slippage of network etc…) will be related to the formability behaviours. The forming defects are not acceptable for the deformed preform and consequently for the final composite part.

The preforming of multilayer dry textile reinforcements has been well studied [4, 5]. The inter-ply behaviour is described through numerical and experimental studies concerning inter-ply sliding and the identification of friction laws [12-14]. However, these studies did not measure the quantities in each ply of the multilayer. The criteria of forming are generally the same ones used in the preforming of a single layer and estimated on the top or bottom ply. The work presented in [12-14] show that preforming of multilayer is not yet controlled and demonstrate the influence of the layer orientations on the sliding and therefore on the final shape.

An alternative to the multilayered preforming is to use the preform reinforced through thickness. In order to obtain 3D preforms, the through-thickness fibres can be inserted using a variety of textile processes, such as 3D weaving, stitching, tufting, knitting, and braiding, or by techniques such as pinning and z-anchoring [15, 16]. The literature on preforming of dry 3D preforms is few. Some experimental works on the 3D woven interlock [17, 18] and numerical works on the development of specific behavior laws for the preforming simulation are in ref. [19, 20]. On the contrary, in these studies the influence of the specific parameters of the binder reinforcement (density of stitching, orientation relatively to the punch, stitching yarns direction, etc...) on measurement criteria during the preforming is less demonstrated. Moreover, the influence of through-thickness fibres on the preforming defects is not described. In this paper concerning the 3D reinforcements performed by tufting technology, the analyses of the influence of through-thickness fibres are entirely carried out during the multilayered E-glass plain weave forming.

2 MATERIAL AND METHOD

2.1 Tufting process and tufted specimens

Tufting is a relatively novel technique which is based on the ancient methods of carpet making and recently used for achieving through-the-thickness reinforcement in composites manufacturing. The tufting technology involves the insertion of yarns in the thickness direction in order to strengthen the textile preforms through-the -thickness. As presented in Fig. 1, a threaded needle is inserted into a dry-fabric or bound preform and then removed from the fabric along the same trajectory. The “tuft” of thread relies on friction from the fabric itself and/or hold provided by underlying ancillary material (e.g. foam) to remain in place, and the loop of thread, which appears at the bottom of the work piece or hidden in the fabric preform according to different needs, is not locked in place. The tufting process can be used to bind thick structures because of its need for only one side access. Compared with traditional stitching techniques, where two threads are bound by forming a knot in the preform which weakens the performance of reinforcement, tufting applies a tension-free tuft which can reduce the effect of sewing on interlaminar performance and avoid the zone around the tuft being weakened.

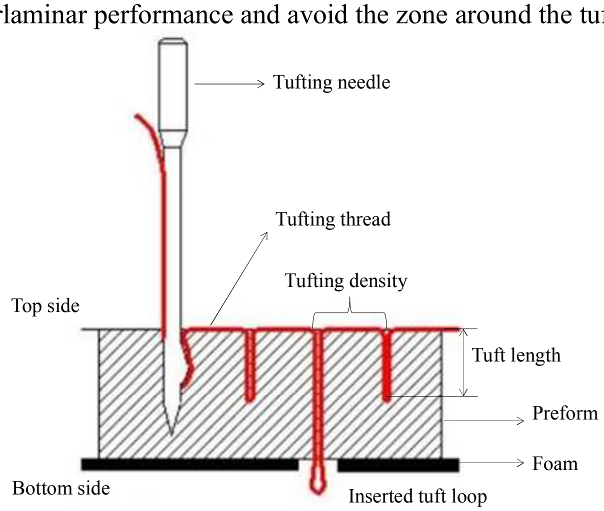
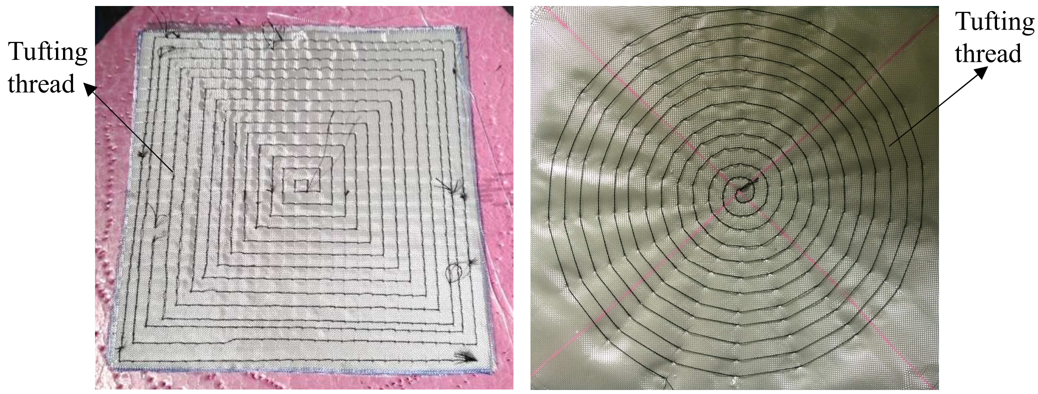


Figure 1: Schema of tufting process.

The specimens of tufted 3D preforms are shown in Fig. 2. The preforms were tufted in square spiral or spiral pattern to assure that the tufting thread is continuous and uninterrupted and inserted in two directions (warp and weft directions). The in-plane tufting densities of square spiral preforms are noted in Table 1. For spiral tufting, the spacing between each circle is 10 mm and the angle between each tuft point in the same circle is 20°.



(a) Square spiral tufting (b) Spiral tufting

Figure 2: Tufted samples.

Ref. of samples	Tufting density (mm)
Non-tufted	-
Tufted 2.0	20
Tufted 1.0	10
Tufted 0.5	5

Table 1: The different tufted 3D fabric specimens.

2.2 Hemispherical preformig

The hemispherical forming was performed on a specific preforming device shown in Fig. 3 [17]. This device was used to analyze the double-curved shape forming with a given textile reinforcement under different conditions. The tufted 3D fabric was placed between the blank-holder and die. Four pneumatic jacks, connecting to the blank-holder, apply an adjustable pressure on the fabric. In order to measure the important forming parameters by optical measurement, such as the inter-layer sliding, the open-die forming was used. An electric jack connected to the punch imposes a movement and a load sensor (500 N ± 0.3 %) acquires the punch force during the forming. The main parameters of the hemispherical performing are noted in Table 2.

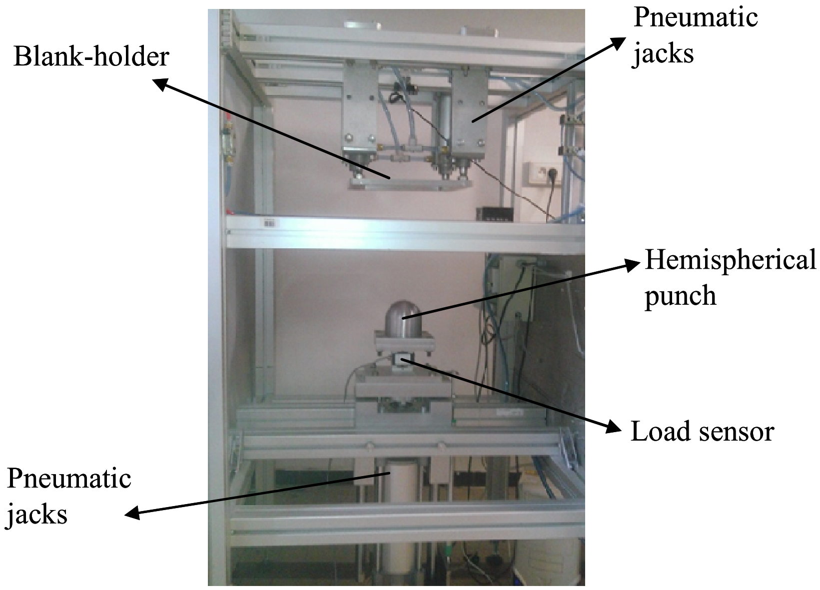


Figure 3: The hemispherical preforming device.

Parameter	Value
Preforming speed	45 mm/s
Diameter of hemispherical punch	150 mm
Maximum punch displacement	65 mm
Blank-holder pressure	0.05 MPa

Table 2: The main parameters of the hemispherical preforming.

3 RESULTS AND DISCUSSION

3.1 Inter-ply sliding

The preforming of four different tufted 3D fabrics shown in Table 1 was carried out. The sequence of tested preform, $[\pm 45°, 0°/90°]_2$. Since the tufting yarns can reinforce through the thickness of preform, the inter-ply sliding can be minimized (see Fig. 4). But, when a weak tufting density was used, the effects of inter-ply sliding can break the tufting yarns (e.g. tufting spacing 10 mm or 20 mm). Consequently, it should adopt a rather high tufting density to reinforce the through-the-thickness direction (e.g. tufting spacing 5 mm). On another hand, a higher tufting density will lead to a heavier and more rigid preform, and hence the preform is more difficulty to be deformed.

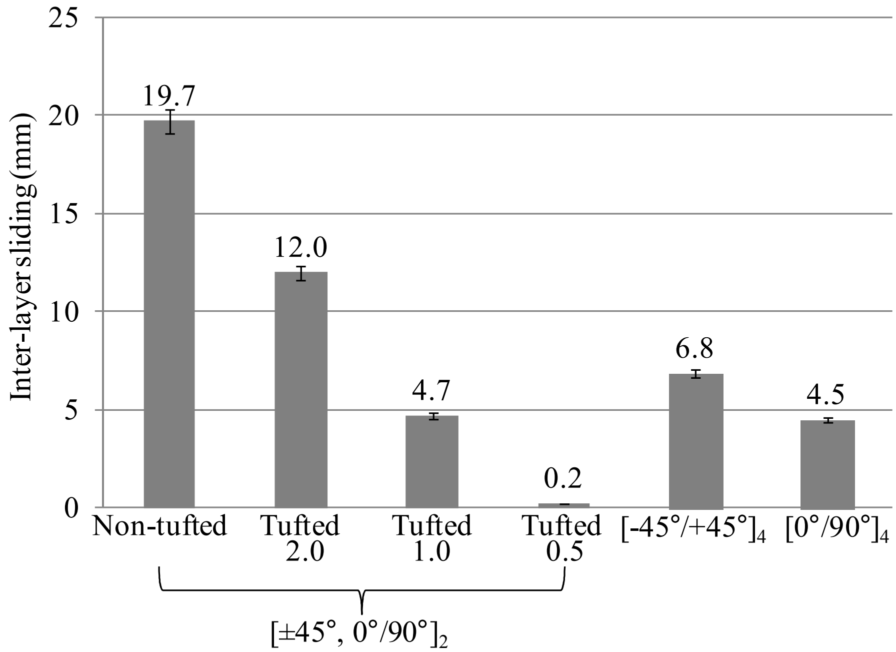
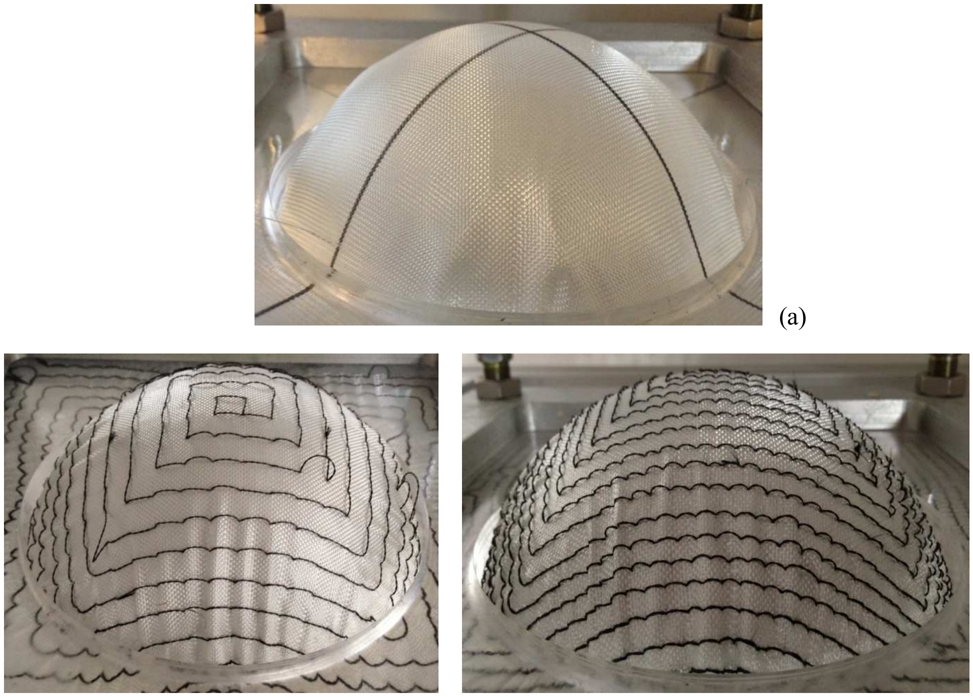


Figure 4: Influence of tufting density on the inter-layer sliding.

3.2 Wrinkling phenomenon during the forming

One of the most common defects in tufting is wrinkling. It has been experimentally shown frequently in textile reinforcement forming [7]. Wrinkling is a global phenomenon that depends on strain and force components and boundary conditions of forming [7]. However, the wrinkling phenomenon can be modified by tufting during the forming of tufted preform. Fig. 5 presents the magnified view of the useful zone. After the forming of non-tufted preform, some big winkles with a non-regular shape can be observed (Fig. 5a). Compared to the deformed non-tufted preform, in the forming of tufted 1.0 and tufted 0.5 preforms (Figs. 5b and 5c) the wrinkles were regularly distributed and the size of wrinkle was much reduced. Furthermore, the number and the size of wrinkle were decreased when the tufting density augments.



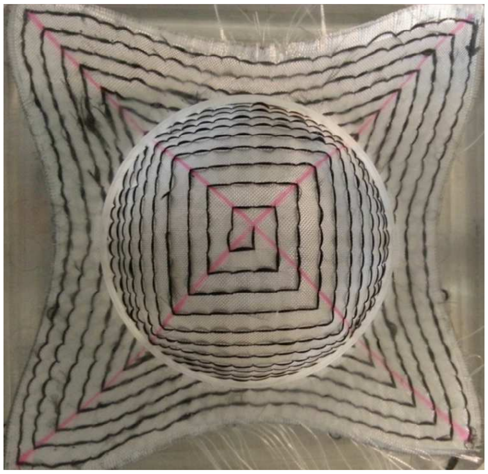
(a)

(b) (c)

Figure 5: Winkling phenomena in the forming of (a) non-tufted, (b) tufted 1.0 and (c) tufted 0.5 preforms.

3.3 Tufting yarn orientations

The influence of tufting yarn orientations was studied during the forming of tufted fabric. Two plies E-glass plain weave were superposed and tufted trough-the-thickness. The tufting yarn orientations were different as shown in Fig. 6. The $[0°/90°]_2$ preforms tufted in 0°/90° and in ±45°. The dimensions of ply and the tufting density were not changed. Comparing the $[0°/90°]_2$ preforms tufted in 0°/90° and in ±45° directions, the change of tufting yarn orientations did not modify the global deformation of preform. On the contrary, the misalignment of tufting yarns is shown in Fig. 6b for $[0°/90°]_2$ preform tufted in ±45° because the orientation of layer is not the same of the tufting yarns. As there is a strong in-plane shear effect in diagonal direction for 0°/90° ply (zones indicated on the figure), each segment of tufting thread between two tufting points was compressed and then the tufting yams in these strong shear zones are misaligned. Fig. 7 shows the deformed shape after forming of the $[0°/90°]_2$ preform tufted in spiral. It means that the forming pattern is very similar to the punch form. The preform is deformed easily and this is not misalignment observed on the deformed 3D preform. But, the out-of-plane yarns can be noted due to the weak tufting density used in the present 3D preform specimen. Thus, the forming pattern related the tufting yarn orientations and the tufting density are very important parameters in tufted 3D preform forming process.


(a) $[0°/90°]_2$ preform tufted in 0°/90°

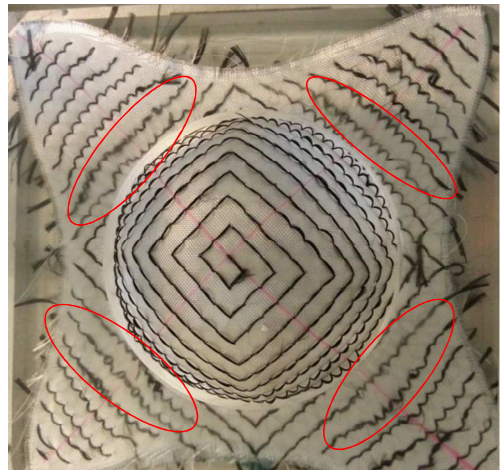

(b) $[0°/90°]_2$ preform tufted in ±45°

Figure 6: Hemispherical forming of different tufted 3D preforms.

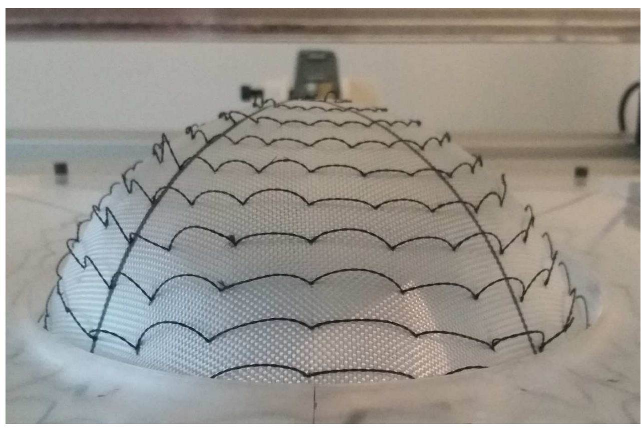


Figure 7: The $[0°/90°]_2$ preform tufted in spiral.

4 CONCLUSIONS

The deformability of tufted 3D textile reinforcements has been studied in the paper. As the tufted preform was reinforced by tufting yarns through-the-thickness, it became more rigid than the multilayered preform. When a quasi-isotropic structure, $[\pm45°, 0°/90°]_2$, was used in the multilayered forming, a significant inter-sliding was observed. After tufting process, the slippage between the plies was reduced following the increasing of tufting density. Winkling as one of the forming defects that can be experienced frequently in textile reinforcements forming. The tufting yarns could modify the winkling phenomenon, the shape of winkles was more regular and the size of winkles was strongly reduced in the present forming of the tufted preforms. Therefore, it is possible to control the winkling phenomenon in the tufted 3D reinforcement forming by tufting process. Moreover, the formability behaviour can be changed during the textile composite forming when the fibre orientations are changed. In tufted 3D reinforcement forming, the tufting yarns orientation did not modify the global deformation of preform. On the contrary, if the reinforced fibres orientation was not same as the tufting yarns orientation, it leaded to the forming defects as misalignment in the strong in-plane shear zones. It has better place the tufting thread through the reinforced fibres orientation.

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