FORMABILITY OF THE THREE-DIMENSIONAL TUFTED COMPOSITE REINFORCEMENTS

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ABSTRACT:
Three-dimensional (3D) fabrics as one type of multilayered reinforcement become more and more popular, due to its better performance in thickness direction of part. Recently, tufting technique is developed and applied to manufacture the 3D textile composite reinforcements. The present study investigates the influence of tufting density and tufting pattern on the formability behaviours and forming defects. High tufting density can reduce the size of wrinkles significantly. The tufting pattern influences slightly on the wrinkling phenomenon. However, square spiral pattern can eliminate buckles of tufting yarns at four corners, especially in the deep-draw forming.
Key Words: Fabrics/textiles; 3-Dimensional reinforcement; Forming; Tufting

1. INTRODUCTION

In the production of composite parts, Resin Transfer Molding (RTM) as one of the main manufacturing processes is widely used[1]. The first step of the RTM process is the forming of dry fabrics which can induce a complex variation of physical behaviours and mechanisms influencing the next manufacturing stage (resin infusion stage). Meanwhile, many input parameters have a strong impact on this step, such as the architecture of reinforcement, punch shape, black-holder pressure, the orientation of laminates, etc. Some previous experimental works[2–5] have illustrated the measurement criteria which can be used in the quantification of the formability behaviours of dry textile reinforcements including material draw-in, homogeneity of fibre and interlayer sliding. Forming defects (such as wrinkling[4,6–8], buckling[9], misalignment of fibres[10], etc.), which are not acceptable for the final composite part, may be related to these formability behaviours to some extent. In many industry applications, multilayered reinforcement is widely used to obtain complex composite parts. However, the weak properties of the multilayer reinforcements in the thickness hint that thick parts are sensitive to delamination. As a result, the use of 3D preforms is quite interesting, making it possible to obtain good mechanical properties while improving the resistance to delamination and to impact. Moreover, 3D reinforcement can be realized by different technologies, such as 3D weaving, stitching, tufting, knitting, braiding and Z-pinning. Some experimental and numerical works about the deformability of the 3D woven interlock preform have been studied in [3,11]. Some researchers investigated the forming behaviours of the NCF (Non-Crimp Fabrics) reinforced by stitching technique[12]. However, few works are dedicated to forming of the tufted preforms. Liu et al[13] found that tufting technique can improve the formability behaviours of 3D tufted preforms. Nevertheless, in these experimental results, the influence of the tufting patterns on the deformability was not studied. The aim of this paper is to further improve the understanding of tufting density on the formability behaviours. Furthermore, the effect of tufting pattern (circle-spiral and square-spiral) on the occurrence of defects in different double curved shaping of dry woven fabric was investigated.

2. METHODS AND MATERIALS

2.1 Tufting process

Tufting technology based on conventional stitching process was invented originally for the manufacture of carpet and warm garments and recognized recently as an important way to develop the through-the-thickness reinforcement of composites [14]. Thanks to a hollow needle, the thread is inserted into the dry preform through the thickness from only one side without any tension. This tension-free thread introduction system can reduce the degradation of the in-plane properties during the forming of loops. The tufting routines and the tufting parameters can be programmed and controlled by the computer.

2.2 Forming device

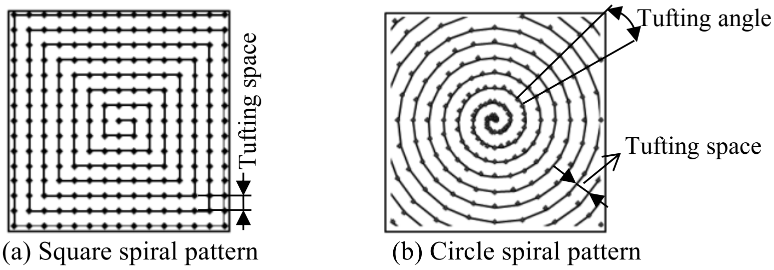
The punch/open-die system can be easily changed to obtain different double curvature shapes. The punch is controlled by an electric jack to reach its target location at a given speed. A load sensor (500N ± 0.3%) records the variation of punch force during preforming. The continuous recording of images is carried out by a digital camera connected to a computer. The material draw-in, inter-layer sliding and fibrous structures can be measured due to this equipment. A hemispherical punch and a square-box punch were chosen in the present study to investigate the influence of different tufting patterns on the formability of tufted preforms. The forming parameters are noted in Table.1.

Table. 1 Forming parameters

Parameter	Value
Stamping speed	45 mm/s
Blank-holder pressure	0.05 MPa
Punch pressure	0.2 MPa

2.3 Materials

E-glass plain woven fabric with an areal density 157±5 g/m^2 was used in the forming tests. The preform with a sequence of $[0°/90°, \pm 45°]_2$ is chosen in the present study. The dimensions of the tested preforms are 280×280×0.5 mm^3. All the samples were tufted with TENAX® carbon thread into two different patterns, via a hollow needle of 2 mm diameter. The tufting patterns are illustrated in Figs. 1a and 1b: square spiral and circle spiral. As important tufting parameters, tufting space and tufting angle are defined in Fig.1. Tufting programme starts always from the centre of preform to assure only one tufting thread is used to insert continuously in both warp and weft directions.



(a) Square spiral pattern (b) Circle spiral pattern

Fig. 1. Schematic description of the different tufting patterns.

Some main properties of tufted 3D preforms used in the presenting study are listed in Table.2. The samples of circle spiral pattern (C10/10, C10/20 and C10/30) with a variation of tufting angle were prepared for the tufting density tests. Furthermore, a circle spiral pattern and a square spiral pattern (C20/15 and S20) with the same tufting number were specially chosen to investigate the effect of tufting pattern in the forming process.

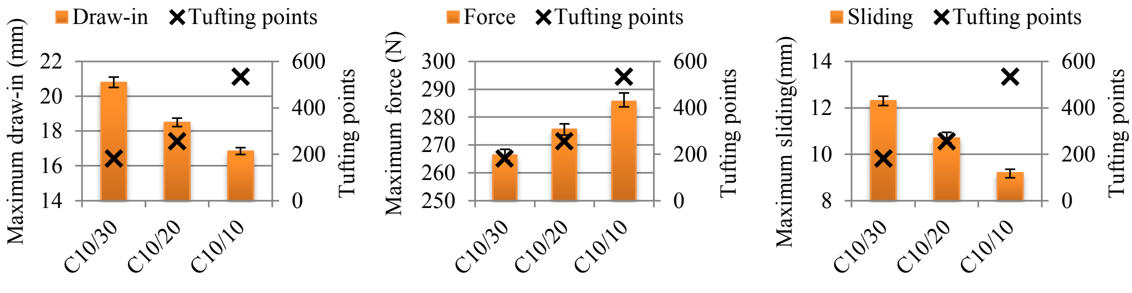
Table.2 Main properties of the test specimens

Tufting pattern	Ref. of samples	Tufting space (mm)	Tufting angle (°)	Total of tufting points	Areal density (g/m²)
Square spiral	S20	20	-	169	649.2±7.0
Circle spiral	C10/10	10	10	535	672.2±7.0
	C10/20	10	20	256	659.9±6.0
	C10/30	10	30	182	659.4±5.0
	C20/15	20	15	169	651.8±5.0

3. FORMING RESULTS

3.1 Formability behaviours

The preforms tufted in circle spiral pattern with different tufting densities were tested in hemispherical forming process. Maximum material draw-in was measured and the effect of the number of tufting points on it was as well as shown in Figs.2a. Impact of tufting points can be noted clearly in the figures. The material draw-in decreases with the increasing of the number of tufting points. The inserted thread strengthens the reinforcement through-the-thickness of the preform and the linkage among plies. The tufted preform becomes more rigid and is deformed more difficultly when more tufting thread is inserted into the preform, which can be confirmed by the observation of punch load during forming demonstrated in Figs.2b. Compared to the C10/30 sample, the maximum draw-in of C10/10 reduces 19% for circle spiral pattern after the hemispherical forming. As one of the important parameters in the multi-layered forming, the inter-layer sliding can explain the relative slippage among the plies due to the different deformation of each ply and slightly influenced by the changed curvature of each layer, as the thickness of ply is taken into account. It can be observed that the inter-layer sliding can be reduced significantly by tufting when the tufting density augments (Fig.2c).



(a) (b) (c)

Fig. 2. Influence of tufting density of circle spiral pattern on the formability behaviours in the hemispherical forming.

3.2 Forming defects

Figs.3 show the wrinkling phenomenon magnified in the useful zone and obtained from the preforms tufted in circle spiral pattern during the hemispherical forming. It can be observed that the sizes of wrinkles can be apparently reduced as the decreasing of the tufting angle (increasing of the tufting density). Since the tufting yarn can bond the four plies together, the fabric is hard to bend at the tufting place. The wrinkles normally appear between the tufting points; consequently, the width of wrinkle can be much reduced owing to the decrease of tufting angle.

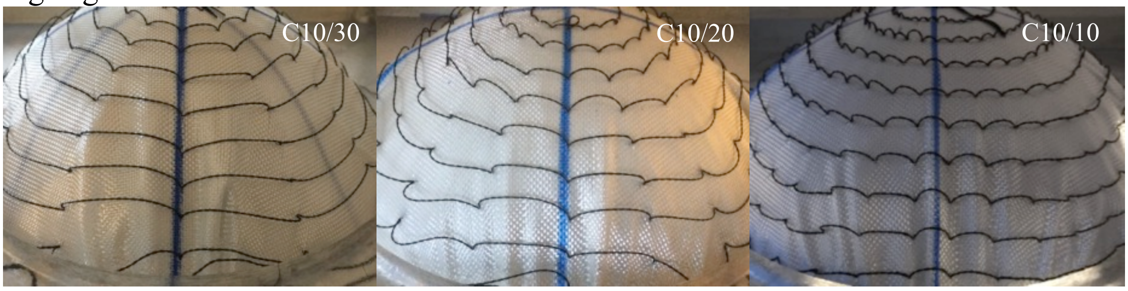


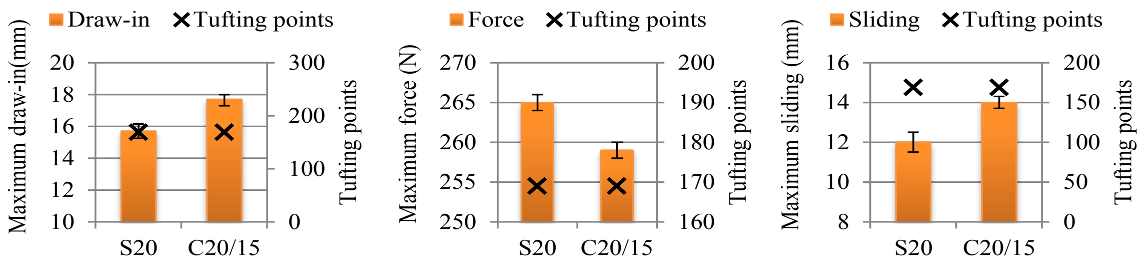
Fig.3. Influence of tufting density on the wrinkling phenomenon in the hemispherical forming.

4. DISCUSSION

Two types of samples (S20 and C20/15) are chosen and compared to each other, for studying the influence of tufting pattern on the formability behavior and forming defect. Their main parameters are listed in Table.3. These two samples have almost the same areal density and the same total tufting points. However, the distribution of tufting points is different for each sample in useful and useless zones. Figs.4 and 5 show the forming results of S20 and C20/15 tufted reinforcements after the hemispherical and square-box forming respectively. It can be observed that the forming of the square-spiral pattern is more difficult than the circle-spiral pattern. With respect to the main characterizations of S20 and C20/15 samples, it can be considered that the tufting in the useless zone brings out more limitation between the plies during forming. Regardless of which forming punch is applied, the tufted preform with square-spiral pattern is always more rigid and has less movement among plies in comparison to the circle-spiral pattern. Consequently, when simples have the same areal density, the tufting points in the useless zone have a more significant impact than the consistency between the tufting pattern and the punch shape.

Table 3. Main parameters of S20 and C20/15 samples

Forming	Ref. of samples	Areal density (g/m²)	Tufting points		
			Total points	Tufting points in the useful zone	Tufting points in the useless zone
Hemispherical forming	S20	649.2±7.0	169	97	72
	C20/15	651.8±5.0	169	133	36
Square-box forming	S20	649.2±7.0	169	129	40
	C20/15	651.8±5.0	169	141	28



(a) (b) (c)

Fig. 4. The comparison of two tufting patterns during hemispherical forming

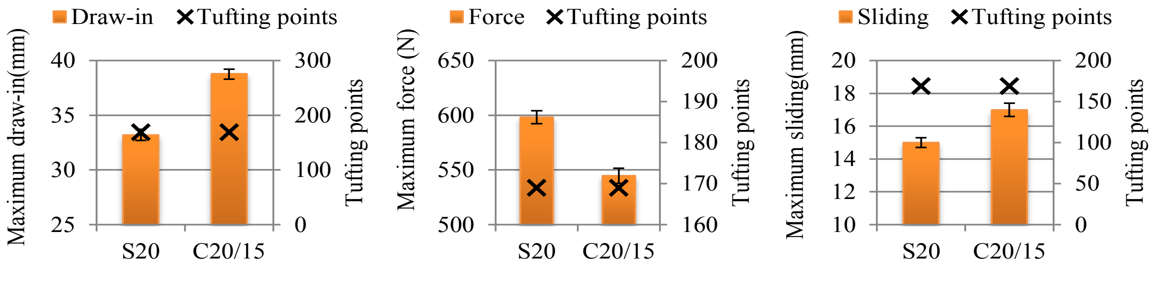


Fig. 5. The comparison of two tufting patterns during square-box forming

Regarding the wrinkling phenomenon, it seems that no apparent difference of the number and the position of the wrinkles can be observed during the hemispherical and the square-box forming with the two tufting patterns (Fig.6). By contrast, the width of wrinkles in S20 forming is slightly smaller than C20/15 forming. Consequently, the forming results depend more on the number of the tufting points in the useless zone than the tufting pattern.

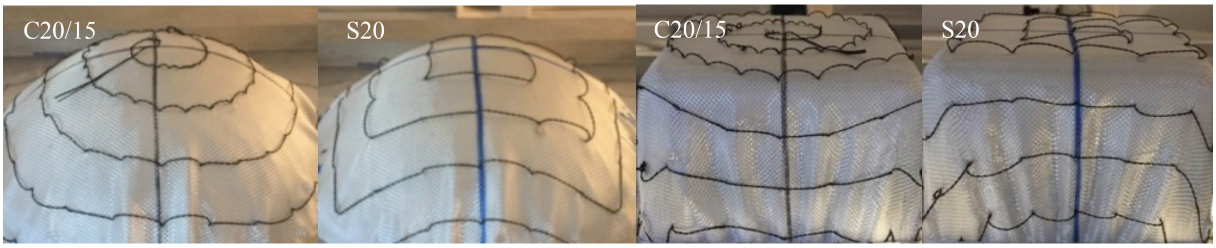


Fig.6. The comparison of wrinkling phenomenon between two tufting patterns.

A type of out-of-plane defect (buckles of tufting yarns) can be always observed in the circle spiral tufted preforms forming (see Fig.7). Therefore, using the square spiral pattern can avoid the generation of this out-of-plane defect localized in the high shear deformation zone (at the corner during square-box forming). In addition, if the preform is not submitted to a high shear deformation, both two patterns can be applied for tufting. The buckles can also be mitigated by the reduction of tufting angle in the use of the circle spiral pattern (Fig.7).

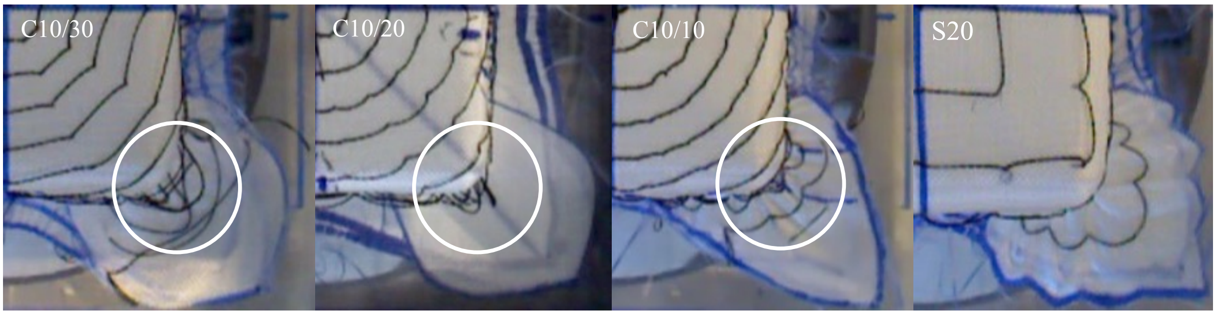


Fig.7. The out-of-plane defect in the tufted preforms forming.

5. CONCLUSION

This experimental study is mainly concentrated on the formability behaviours of 3D tufted preforms. In hemispherical forming, when the tufting angle of the circle spiral pattern decreases (tufting density increases), a more rigid preform with less motion between plies can be obtained. On the other hand, it has been further confirmed that the increasing tufting density can weaken the wrinkling defects. The discussion about the influence of different tufting patterns demonstrates that the forming behaviour mainly depends on the number of the tufting points in the useless zone. Furthermore, according to the wrinkling severity, it can be concluded that there is no need to use the similar tufting pattern to the punch shape. However, the circle spiral pattern is not suitable to the square box forming, as the out-of-plane defects of the tufting yarns can be induced in the high shear deformation zone. Consequently, the optimization of the tufted regions in useless zone to reduce the forming defects will be one of the future works.

6. REFERENCES

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