EXPERIMENTAL FORMING STUDIES ON 3D WARP INTERLOCK FABRICS

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Abstract
The main objective of this study is to highlight the influence of the 3D warp interlock fabric on the forming behaviour of non impregnated structure. Two different warp interlock weave diagrams have been woven using 1100 Tex E-glass/polypropylene hybrid yarns and tested on low speed forming process with a complex shape of punch having edges and corners to analyse different angles on forming behaviour. Different characteristics have been measured to better understand the forming behaviour of these structures and compare them each other. The different analysis reveals a better forming behaviour for a layer to layer 3D warp interlock fabric architecture with long floats of yarns.

1. Introduction

Composite materials are more and more used to substitute metal parts to reduce structures weight for transportation applications. Forming 3D warp interlock fibrous reinforcement appears to be one of the ways to make complex composite parts shape. Analysis of the deformability of dry reinforcements during the forming step, the first step of the RTM process, has been widely studied for thin textile preforms, and these studies are generally restricted to their in plane characteristic analysis [1][2]. The analysis of 3D warp interlock structures forming behaviour appears as less studied.

This work concerns experimental approaches [3] conducted on the forming step to study the influence of processes parameters as the initial shape of the blank holder and its applied pressure, to understand the resulted defects occurring during the process. By the same, many simulations works [4][5][6], correlated with experimental results, tend to develop models reproducing the mechanical behaviour of the fibrous reinforcements during the forming stage [7]. In most of these studies conducted on the forming of single or multiple fabric or laminate plies using tools to produce complex preform, few of them are related to reveal the influence of the fibrous reinforcement characteristics on the forming capability and the associated generation of defects.

Different raw material of fibrous reinforcements have been used in forming experiments as E-glass, carbon, and more recently flax [8], but also commingled yarns [9]. Few studies, applied to 2D fabrics, have been focused on the analysis of the architecture or weave diagram [10]. During the forming process, in-plane shear stress has been considered as essential to the

generation of defects, therefore structures with large in-plane shear deformability, such as NCF, have been recently studied [11].
Thus, 3D woven structures, reinforced in thickness, need to be studied during the forming behaviour [12]. The objective of this study is to investigate the behaviour of non impregnated and thick 3D woven fabrics during the forming step using a complex punch.

2. 3D warp interlock preforms

Three main families of 3D warp interlock preform can be distinguished by their binding yarns path. Those families are: Layer to Layer (O/L), Orthogonal (O/T) and Through the Thickness (A/T) [13].

In the Layer to Layer 3D warp interlock structure, all the warp yarns bind at least two or more weft column and/or layers of the structure, but not in the structure thickness, which corresponds to the Orthogonal 3D warp interlock structure. The Through the Thickness 3D Warp interlock structure links in the thickness of the woven preform, as the Orthogonal, but going through all the weft layers located in several columns. Additionally, straight warp yarns, also called stuffers, can be added to all of the three different 3D warp interlock architectures; which don't affect their binding cluster types.

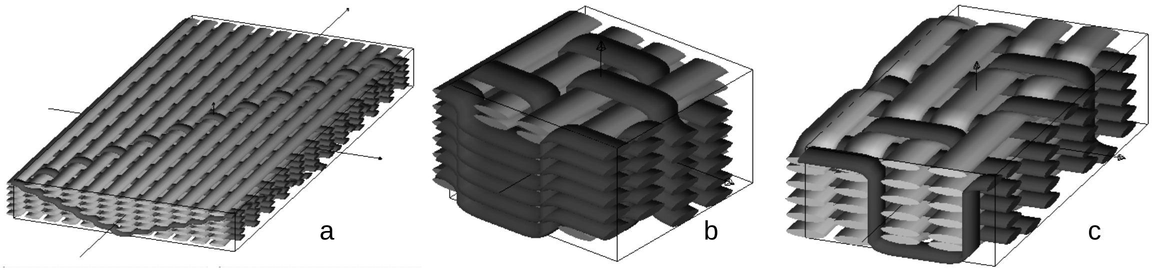

Figure 1. 3D representation on the different structures tested for the first study: a- Through the Thickness, b- Layer to Layer and c- Orthogonal

These different ways of linking yarns give to these families different forming behaviour. In a previous study, these structures have been woven using 360 Tex E-glass/polypropylene hybrid yarns and have been tested using the same forming process as the one described below using the hemispherical punch. These tests have shown that the Layer to Layer 3D warp interlock had the best forming behaviour [14].

Figure 2. 3D warp interlock formed fabrics with different architectures as: a - Through the Thickness, - b – Layer to Layer, c – Orthogonal

For this study, the previous Layer to Layer weave diagram has been woven using a 1100 Tex E-glass/polypropylene hybrid yarn and a second weave diagram with a lower crimp has also been created to compare the role of the crimp of warp yarns on the forming behaviour (cf Figure 3).

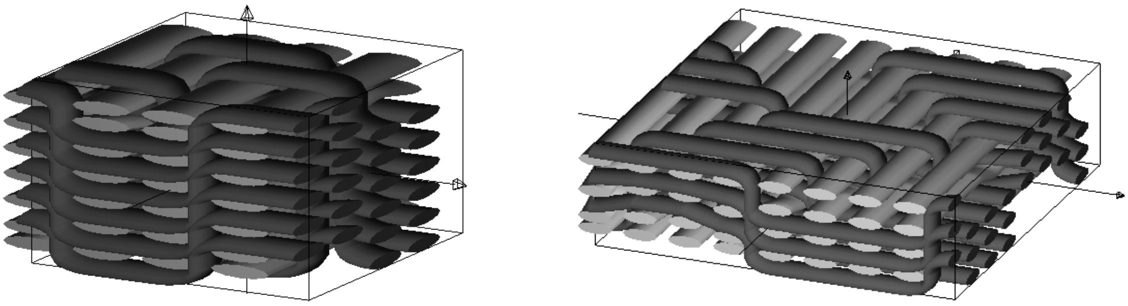

Figure 3. 3D representation on the different layer to layer structures tested for this study: a- initial, b- improved

The samples have been woven as panels of 30cm x 30cm using a 24 frames dobby loom used to produce samples. To directly compare the behaviour of each architecture, all samples have been woven with the same warp and weft densities of 9 yarns/cm. The yarns used for that study was a 1100 E-Tex glass/polypropylene hybrid yarns. Coloured yarns, as marker threads, have been woven on the top of the 3D warp interlock fabric of the samples to form a grid in order to allow easier observations and measurements on the preform surface (cf Figure 4).

Figure 4. Detailed view of a woven preform with tracers

3. Description of forming process

3.1. Forming concerns

Different phenomenon occur during the forming of woven preforms into complex shapes, which will probably impact the impregnation process and disturb the flow velocity of resin inside the mould which can lead to reduced mechanical properties of the final composite material. The main defects are: bulking, out of plane deformation and wrinkling [8]. The rearrangement of the yarns leads to local deformation inside the unit cell of the weave diagram and then widespread to the all fabric structure. If the fabric continues to be deformed, local shear and in-plane compressive forces build up and then directly influence the angle variation between warp and weft yarns [15][16]. This is compensated by buckling or out-of-plane deformation [9]. A number of fabric parameters (friction, tow size and spacing) are related to the locking angle, and once it is reached, yarns interfere and start to wrinkle out of plane. Other phenomenon have also been observed during the forming process, as related in [5][17], as the variation of the volume fraction of fibres on the permeability of the resulted textile structure, the influence of the local orientation of multi-filaments yarns on the global rigidity of the fabric, and the localization of plies on the fabric surface.

3.2. Details on forming process

Taking into account all these research results done on the forming process, the forming bench used for that study, has been adapted to a fast, safe and ambient temperature stamping process.

The forming bench [18] used for this study is composed of a static blank holder and an open die which distribute pressure provided by four jacks to the edges of the preform and a non heating punch which give the desired shape through a vertical and controlled motion given by a pneumatic jack.

The different parameters to settle are the blank holder pressure and the velocity of the punch during the forming process. The blank holder pressure must be sufficient to maintain the preform during the stamping process in order to avoid folds and not too high value to avoid yarn breakage. During the forming step, the position of the punch is controlled by a position sensor. It’s also equipped with a stress sensor to measure forces applied by the punch to the preform during the forming process. Located on the top of the forming bench, a camera can observe the forming behaviour of the sample during the performing process.

Different punch shapes have been tested, as a semi hemispherical shape, to ensure a symmetric double curvature deformation during the forming process which helps to analyse the difference of behaviour between each architecture for the previous study. A more complex shape, which is similar to a box called “gusset”, has also been used to obtain an asymmetric deformation of the fabric (Figure 5) at the edge and at the corner.

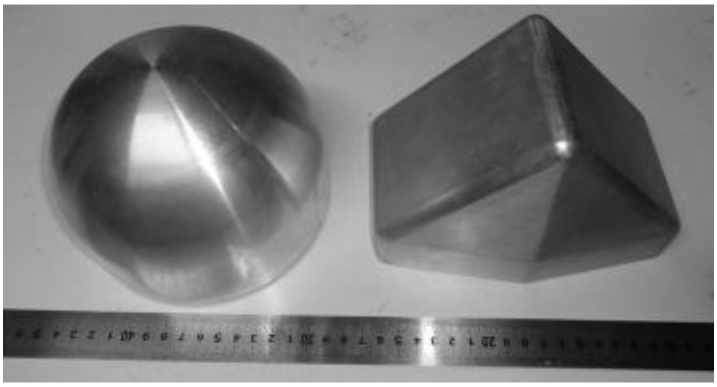

Figure 5. Hemispherical (left) and gusset (left) punches

The hemispherical punch has been first used to analyse the forming behaviour of the 3D warp interlock fabric both in the warp and weft directions and then check the estimated anisotropy to compare the forming behaviour of each 3D warp interlock family of the first study. The “box” shape has been used to analyse more precisely the forming behaviour on a shape with more severe concerns.

Using the same 3D warp interlock fabric for the two different shapes of punch, local and global deformations of the two preformed samples can be check following the different path of yarns inside the structure and checking the resulted locations of initially equal-distant red points marked in the fabric surface at the crossing of warp and weft tracers.

4. Measured characteristics after the forming process

To compare the forming behaviour of each architecture, some characteristics have been chosen: thickness variation, slippage between the two external layers, surface shear angles and material draw-in [19]. The slippage between the two external layers has been developed to understand the variation of thickness during the forming process of thick preforms.

4.1. Thickness variation

The thickness variation has been measured after forming by a destructive cutting process of the different parts of the preform. Different precise locations on the final preform have been selected in order to measure the thickness of the deformed ply after the forming process (Figure 6).

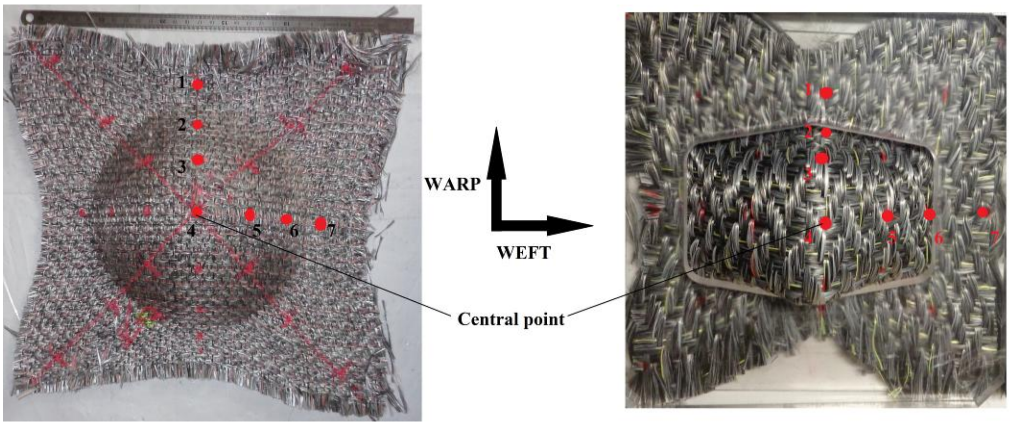

Figure 6. Measurement positions for hemispherical (left) and gusset preforms

4.2. Surface shear angles

Surface shear angles has been optically measured by a camera. As the most important deformation mode of textile composite, the intra-ply shearing effects corresponding to the in-plane shear angle are measured. The shear angle is the orthogonal complement of the angle between warp and weft yarns (Figure 7).

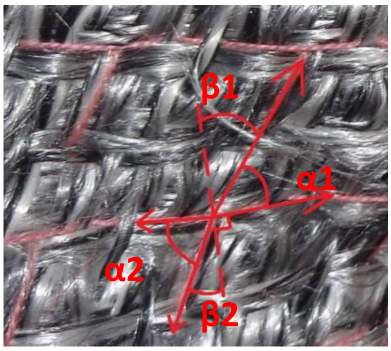

Figure 7. Hemispherical (left) and gusset (left) preforms

4.3. Material draw-in

Material draw-in has also been optically measured by a camera. Generally, the material draw-in values correspond to the consumed length of fabric during the forming process.

4.4. Slippage between the two external layers

Due to the higher thickness value of 3D warp interlock, the exact positions of warp and weft yarns respectively located on the top and bottom of the 3D fabric have been checked and a specific angle has been calculated resulting from the sliding of these two external layers.

To measure the slippage between the external layers, coloured yarns called “tracers” have been woven on the two external surfaces of the 3D fabric to create symmetrical and regular grids. The crossing of these yarns creates different points whom spatial positions are compared once the forming step done. The slippage between external layers is the distance between the point’s projections on the middle plan of the preform (Figure 8). The movement of theses markers will be tracked by an optical method. Then the inter-layer sliding value is determined as the distance between the projections on the mid-surface of two measurement points on the opposite surfaces.

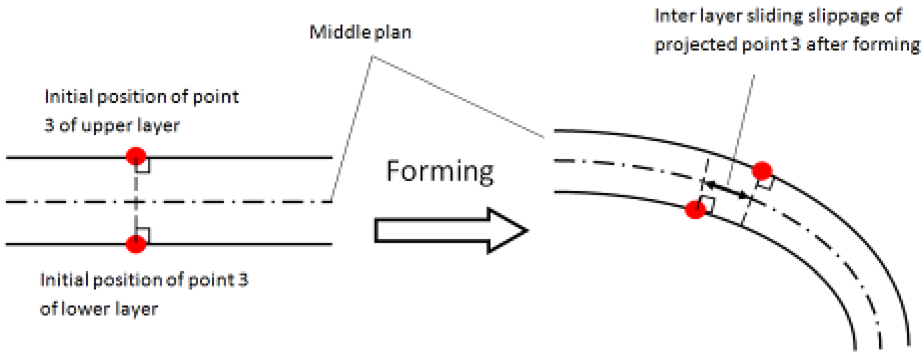

Figure 8. Slippage between the two external layers measurements

5. Forming process results

Results of thickness and slippage between the two external layers are displayed at Figure 9.

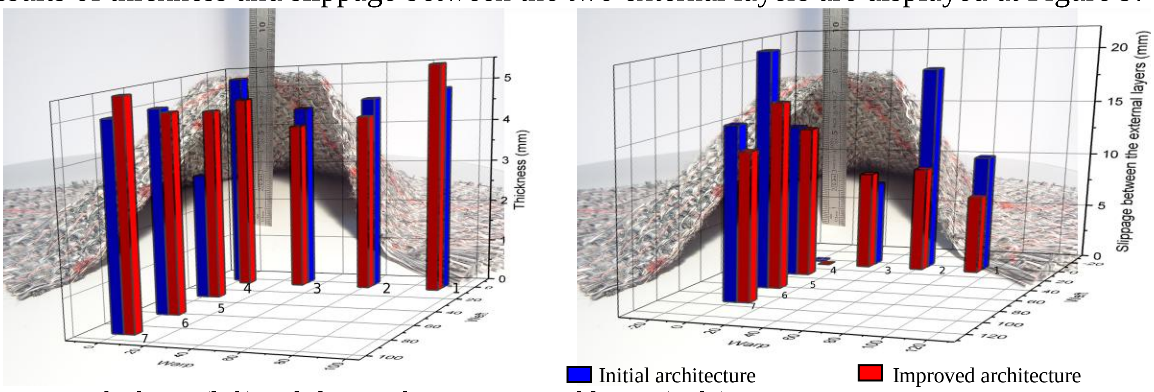

Figure 9. Thickness (left) and slippage between external layers (right) measurements.

The thickness variation is higher in warp direction which can be explained by a more severe shape in that direction. The thickness variation is higher for the initial architecture.

The slippage value between the two external layers is also higher for the initial architecture (Figure 10). This result can be explained by a lower crimp in the second structure which gives to the yarns of that structure a higher mobility without pulling the entire structure.

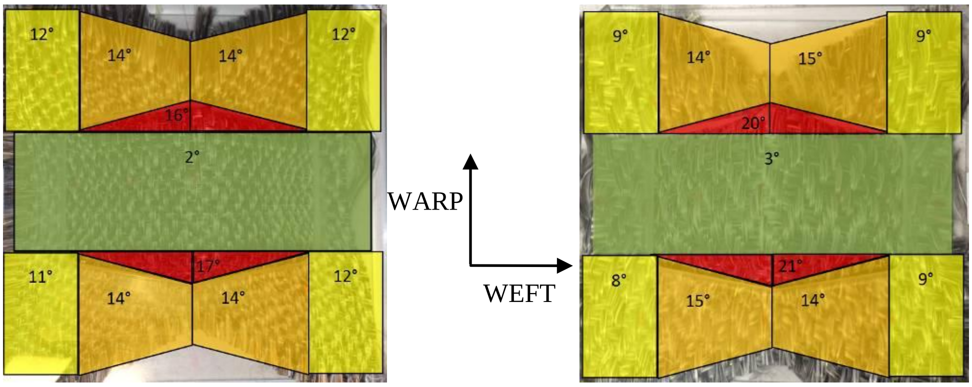

Figure 10. Surface shear angles for the initial architecture (left) and the improved architecture (right)

Regarding the surface shear angles, the initial architecture has slightly weaker shear angles on the useful zone. These results can be explained by the large floats between two linking points which keep the yarns relatively free to shear in the structure.

The improved architecture obtains higher material draw-in with a maximum of 50,0 mm in warp direction and 22,4 mm in weft direction against 43,6 mm in warp direction and 22,4 mm in weft direction for the initial architecture.

6. Conclusion

Different characteristics adapted to 3D warp interlock fabrics have been observed in that study to obtain the effect of architectural modifications, inside the same 3D warp interlock family, of their forming behaviour.

That study has shown that the improved architecture with a lower crimp and higher floats was better as the initial architecture for its lower thickness variation, higher material draw-in and lower slippage between external layers properties. The only property which is better for the initial architecture is the surface shear angles. As expected, those parameters show that layer to layer 3D warp interlock architecture with low crimp and relatively long floats is more suitable to a stamping process of complex shape formed preforms.

The complete length of floating effect on the forming behaviour needs to be developed on a study wherein the length of floating would be increased on different samples to detect the optimum floating for the forming process. All measured characteristics on the formed samples, reflecting the forming quality, could also be inserted into a linear equation gathering these parameters to the 3D warp interlock parameters.

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