INFLUENCE OF THE STITCH THREAD TENSION ON THE PERMEABILITY OF CARBON FIBRE NON-CRIMP FABRICS

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Abstract

The effect of the stitch thread tension on fibre bundle geometry and in-plane permeability of unidirectional carbon fibre non-crimp fabrics (NCFs) was studied. Constraining the bundle mobility by increasing the stitch tension was found to result in decreasing levels of fibre bundle waviness. The stitch thread tension affects the size and geometry of fibre bundles and inter-bundle gaps in the fabric. Experimental observations suggest that this has an effect on the in-plane permeability, particularly transverse to the fibre bundles.

1. Introduction

Non-crimp fabrics (NCFs) generally comprise one or more unidirectional layers of fibre bundles at defined orientations, which are fixated relative to each other using through-thickness stitches. Composite components with NCF reinforcement are frequently manufactured employing Liquid Composite Moulding (LCM) processes, where a liquid resin system is injected into a dry fabric. The impregnation process in LCM is determined by the applied pressure gradient, the resin viscosity and the reinforcement permeability. Accurate determination of the reinforcement permeability is a pre-requisite for prediction of the component quality and optimisation of the process parameters in LCM.

The permeability of NCFs depends on the properties and the arrangement of the fibre bundles as well as the configuration of the stitching thread pattern. It was observed before that even small variations in the stitching pattern can significantly affect the permeability of NCFs [1]. For examples of NCF architectures, increasing the stitch length was found to result in increased in-plane permeability [2], while the through-thickness permeability was found to increase with increasing stitch density [3]. The mechanism for changing the permeability is the formation of resin flow channels in the fabric structure through application of stitches.

Here, the effect of tension in the stitch thread on the in-plane permeability of uni-directional NCFs with a specific architecture is studied.

2. Materials

The NCFs studied here comprise of unidirectional carbon fibre bundles (50 K), which are aligned in the warp direction.

On both faces of the fabric, glass fibre support threads (68 tex) are added in the weft direction at a spacing of 5.6 mm. The support threads are attached to the carbon fibre bundles using a polyester stitch thread which alternates with the carbon fibre bundles (in the warp direction). The fabric architecture is illustrated in Fig. 1. During manufacture of the fabrics, the tension in the stitch threads can be set. Here, three fabrics with different values of the stitch thread tension were manufactured (Table 1) to experimentally study the effect of the stitch tension on the fabric properties.

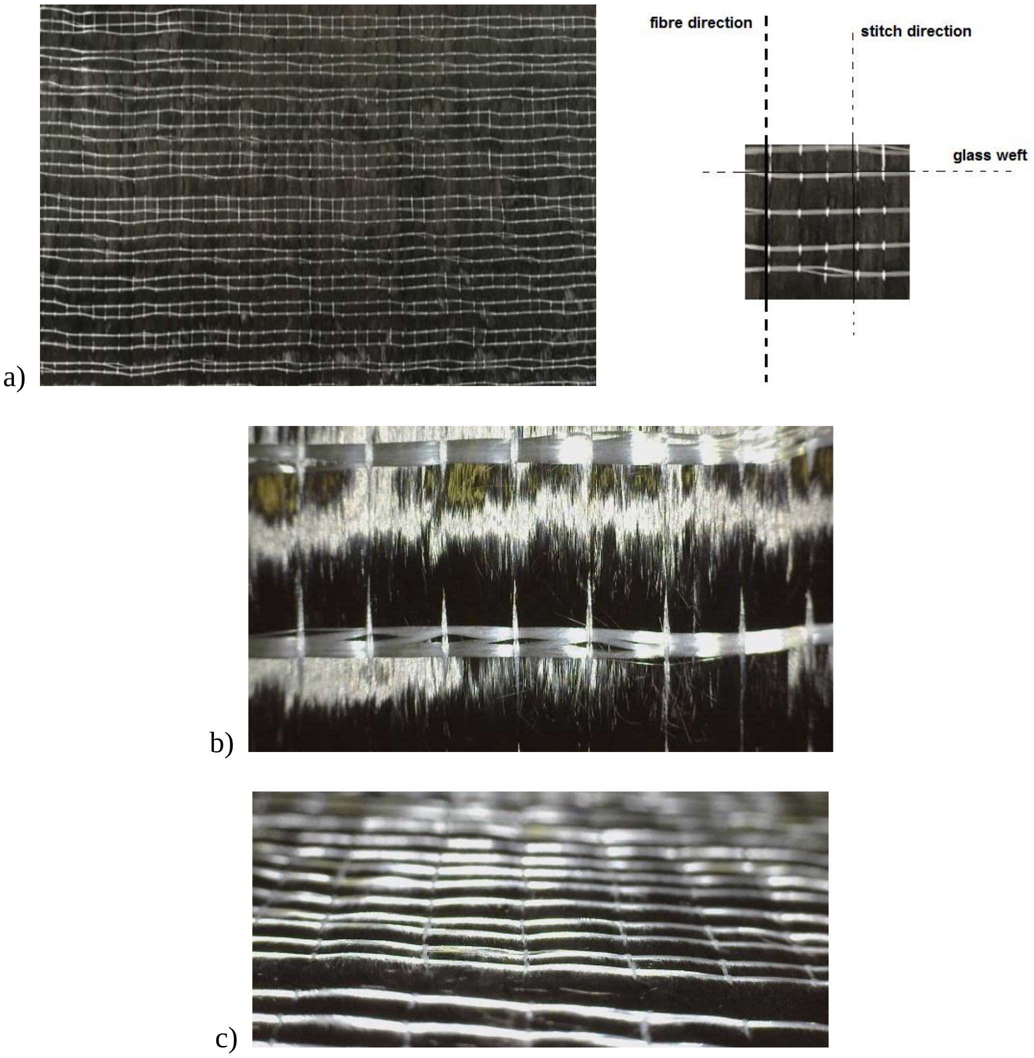

Figure 1. a) Overview of the fabric and description of fabric elements, b) top view of the fabric – close-up, c) top surface of the fabric shown at an angle to emphasize the stitch and weft thread geometry.

Table 1. Fabric stitch parameters.

Set	Fibre type	Stitch material	Stitch type	Stitch gauge (number of stitches per 25.4mm)	Stitch length (mm)	Stitch tension (cN)
1	Zoltek Panex 35	Polyester	Pillar	5	3	14.6
2	Zoltek Panex 35	Polyester	Pillar	5	3	12.4
3	Zoltek Panex 35	Polyester	Pillar	5	3	10.2

3. Permeability Characterisation

The in-plane permeability of the fabrics was characterized in unsaturated radial flow experiments at constant injection pressure, using the Hexcel Leicester in-house permeability measurement rig (Fig. 2). A silicone fluid (Xiameter PMX-200) with known viscosity-temperature characteristics was used as a test fluid. Here, the two principal in-plane permeability values, K_1 and K_2, and the angle indicating the main flow direction, θ, were calculated by applying Darcy's law in 2D to measured dimensions of the elliptical flow front as a function of time. The flow front propagation was tracked using an array of pressure sensors. A Labview^{TM} code was used for data acquisition and instantaneous permeability calculation [4]. Since no time-consuming post-processing of raw data ia required and operator input is minimal, the implemented method is particularly suitable for material characterization in an industrial environment.

Figure 2. Experimental set-up for measurement of in-plane permeability.

3. Results

Three fabrics with different stitch tension are analysed here. In a first step, the effect of stitch tension on the quality of the fabrics was characterized quantitatively. The in-plane waviness of the carbon fibre bundles was selected as a descriptor of the quality. The number of in-plane "waves" of the bundles was counted for fabric specimens with a length of one metre. To avoid any distortions which may potentially be induced during fabric production and handling, no specimens were taken from the first 3 metres from the end of the fabric rolls. The results shown in Fig. 3 indicate that the highest stitch thread tension tends to result in the lowest number of in-plane waves of fibre bundles.

It was also observed that the number of in-plane waves was higher on the top surfaces of the fabrics than on the bottom surfaces. It is thought that this may be a result of how the fabrics were pulled and rolled-up during production.

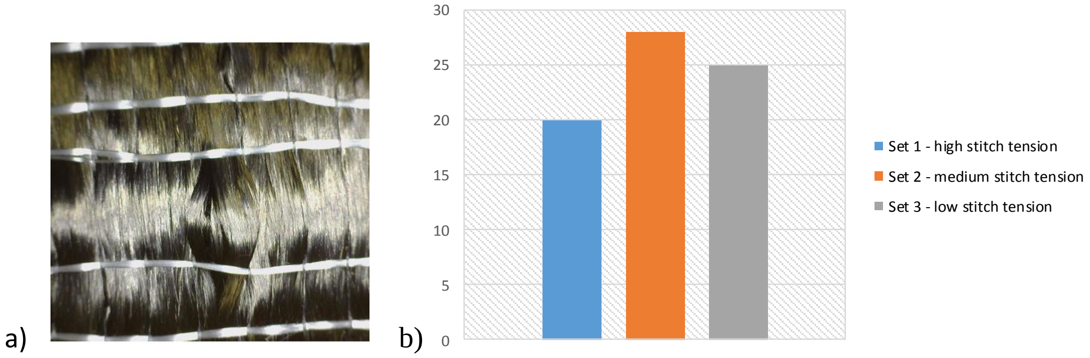

Figure 3. Defect analysis of the fabrics: a) image of an in-plane wave b) number of in-plane waves of fibre bundles at a specimen length of one metre.

The permeability of the fabrics was analysed at three fibre volume fractions, which were obtained by combining an appropriate number of fabric layers in the specimens with the height of the cavity in the permeability measurement tool (Table 2). Results are plotted in Fig. 4. In the range of fibre volume fractions studied here, the principal in-plane permeability values, K_1 and K_2, appear to decrease almost linearly with increasing fibre volume fraction, V_f. Values of K_1 are similar for Set 1 (high stitch tension) and Set 3 (low stitch tension), while values for Set 2 (medium stitch tension) tend to be higher. On the other hand, K_2 is similar for Set 2 and Set 3, and significantly lower for Set 1. The ratio of anisotropy in permeability, K_1/K_2, shows significant scatter, but appears almost constant for all fabrics. As expected for unidirectional fabrics, K_1/K_2 indicates strong anisotropy. For all tests, the main flow direction is aligned with the fabric warp direction ($\theta = 0°$).

Table 2. Combinations of numbers of fabric layers and cavity height to obtain target fibre volume fractions.

target V_f	number of layers	cavity height / mm
0.40	2	2.5
0.50	1	1.0
0.60	3	2.5

When interpreting the experimental data, it is to be considered that the stability of the fabrics is generally low. This may introduce uncertainty in the measured permeability values due to

- deformation of the fabric during handling, which was severe for some of the tested specimens.
- fibre wash, in particular at the lowest fibre volume fraction, where the level of fabric compression is low.

The effect of nesting of fabric layers is also to be considered here. Nesting may occur at the highest and lowest fibre volume fractions (2 and 3 layers of fabric, respectively), but not at the medium fibre volume fraction (only one layer of fabric). This may result in formation of different flow channel networks in the specimens at different fibre volume fractions. In particular, the flow channels at medium V_f, where no nesting occurs since only one fabric layer is used, are greater in cross-section than they would be at the same V_f with nesting. This may explain why values of K_1/K_2 appear to be higher at a target fibre volume fraction of 0.50, and why K_1 and K_2 as a function of V_f show almost linear behaviour.

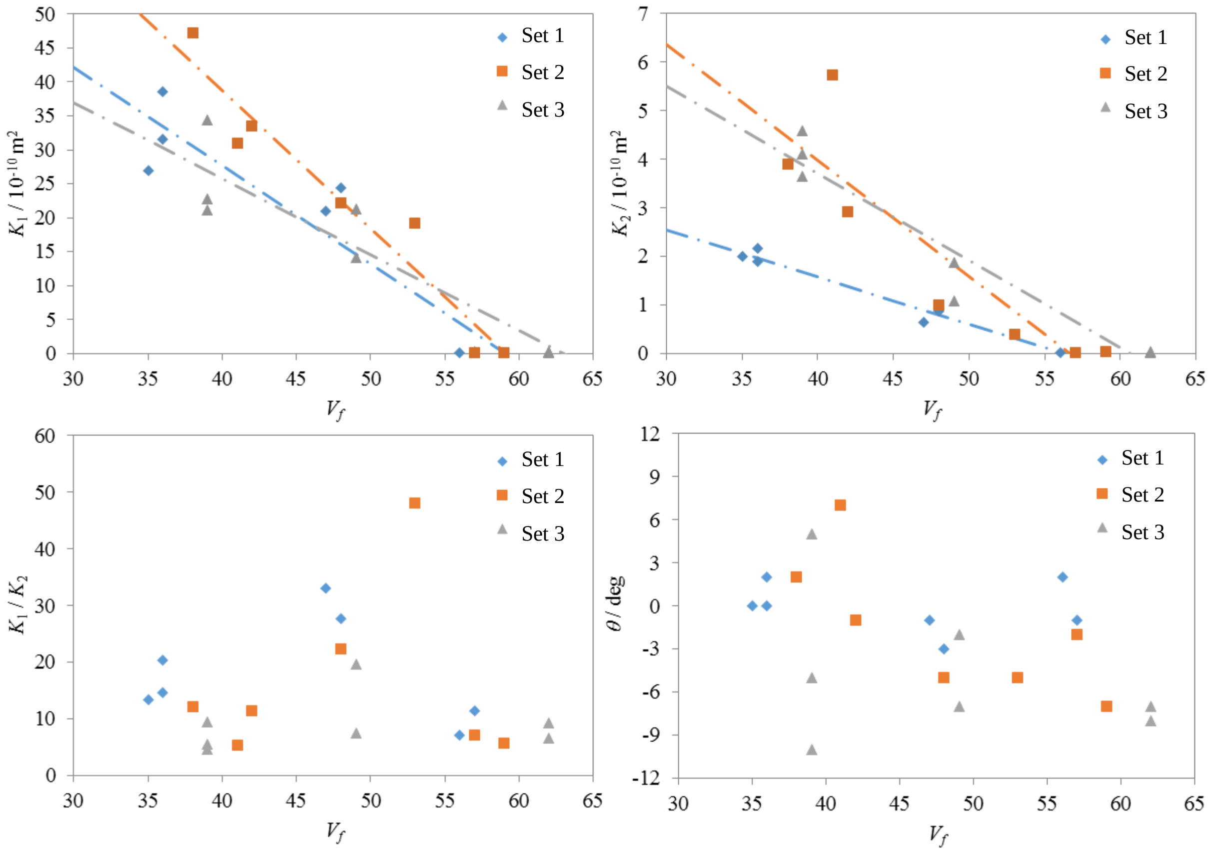

Figure 4. Experimentally determined data for principal permeability values, K_1 and K_2, ratio of anisotropy, K_1/K_2, and angle θ (describing the orientation of the main flow direction) as a function of the fibre volume fraction, V_f.

4. Discussion

High tension in the stitch thread pulls the glass support threads from the surface of the fabric into the gaps between the carbon fibre bundles. As illustrated schematically in Fig. 5, this results in changes in cross-sectional shape of the carbon fibre bundles and of the gaps between the individual bundles. Geometrical changes resulting from increased tension in the stitch thread constrain the movement of fibre bundles and increase the stability of the fabrics. This explains that the waviness of fibre bundles is lowest at the highest stitch tension (Fig. 3).

Changes in the shape of gaps between fibre bundles also affect flow paths during resin injection. As a result, the permeability parallel and transverse to the carbon fibre bundles may change with increasing stitch thread tension, as documented in Fig. 4. This is evident particularly for K_2, where the experimentally observed significant reduction in values for Set 1 is consistent with a reduction in the transverse permeability due to lateral compression and increasing thickness of the carbon fibre bundles at the highest stitch thread tension. However, the effect of the stitch thread tension on the gap geometry needs to be characterized in more detail to allow correlation with the permeability values.

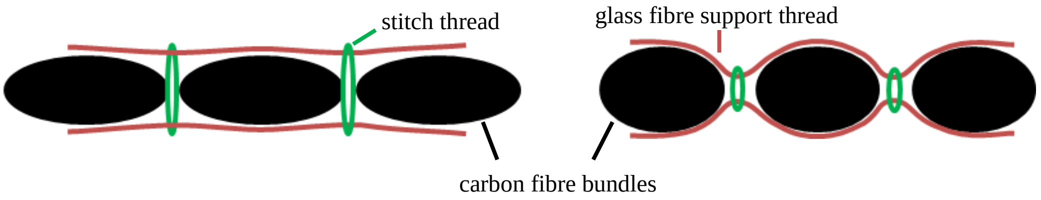

Figure 5. Schematic illustration of fabric cross-section at low stitch tension (left) and at high stitch tension (right).

5. Conclusions

For unidirectional NCFs of the specific architecture studied here, changes in the stich thread tension affect the cross-sections of fibre bundles and inter-bundle gaps in the fabric. Constraining the bundle mobility by increasing the stitch tension tends to result in decreasing levels of fibre bundle waviness. Experimental observations suggest that the in-plane permeability of fabrics, which is determined by the size and geometry of flow channels forming in the material, is affected by the stitch tension. Particularly the permeability transverse to the fibre bundles appears to decrease with increasing stitch tension. However, trends are hard to identify, since low stability of the fabric means that experimental data show a high level of scatter.

Acknowledgments

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