ARCHITECTURE AND PERMEABILITY OF SHEARED CARBON FIBRE NON-CRIMP FABRICS

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SUMMARY

The geometric characteristics of relaxed and sheared non-crimp fabric (NCF) were studied. Spacing between the fibre bundles, initial interply angle misalignments and compression behaviour are presented as a function of the shear angle. Premature premeability results show a similar trend as found in the literature.

1. INTRODUCTION

The permeability of a fibrous reinforcement depends on its geometry, which is affected by its deformations due to draping. The main deformation mode is shear. Here the geometrical characteristics of sheared non-crimp fabrics (NCF) are analysed.
Previous work on sheared fabrics revealed that fibre reorientation and an increase of local fibre content affect the permeability tensor [1,2,3]: it rotates and the anisotropy increases. Dungan and Senoguz *et al*. [4,5,6] developed a cell method which is capable of predicting the reorientation of the permeability tensor for woven fabric. NCF has not been implemented in the model. Lundström [7] has developed a model that links the permeability of an NCF to the (idealised) geometry of the fabric, but he has not incorporated the effects of shear on the geometry.
Models implemented in the *WiseTex* software, Lomov *et al*. [8,9,10], describe the geometry of a fabric. The obtained

geometrical features are used as input for either a lattice Boltzmann [11] or a pore network [12,13] based permeability prediction.
The geometrical description of an NCF given in [10] only concerns undeformed fabrics. In this paper we study the influence of the shear deformation on the NCF geometry for shear angles up to 60º. A simple picture frame is used to shear the fabric. Additionally the initial interply angle deviation of an NCF is investigated and results of permeability measurements are shown.

2. GEOMETRY OF AN NCF FABRIC

The important data in the model [10] are the stitch yarn properties, the stitch pattern, the “crack” width *b* and length *l* (see Figure 1). A “crack” is an opening between the fibres caused by the stitches. These openings are discontinuous due to non-matching spacing of the needles in the fibre direction. The data is obtained by image analysis. Figure 1 shows six scans of carbon fibre material in relaxed and sheared state.

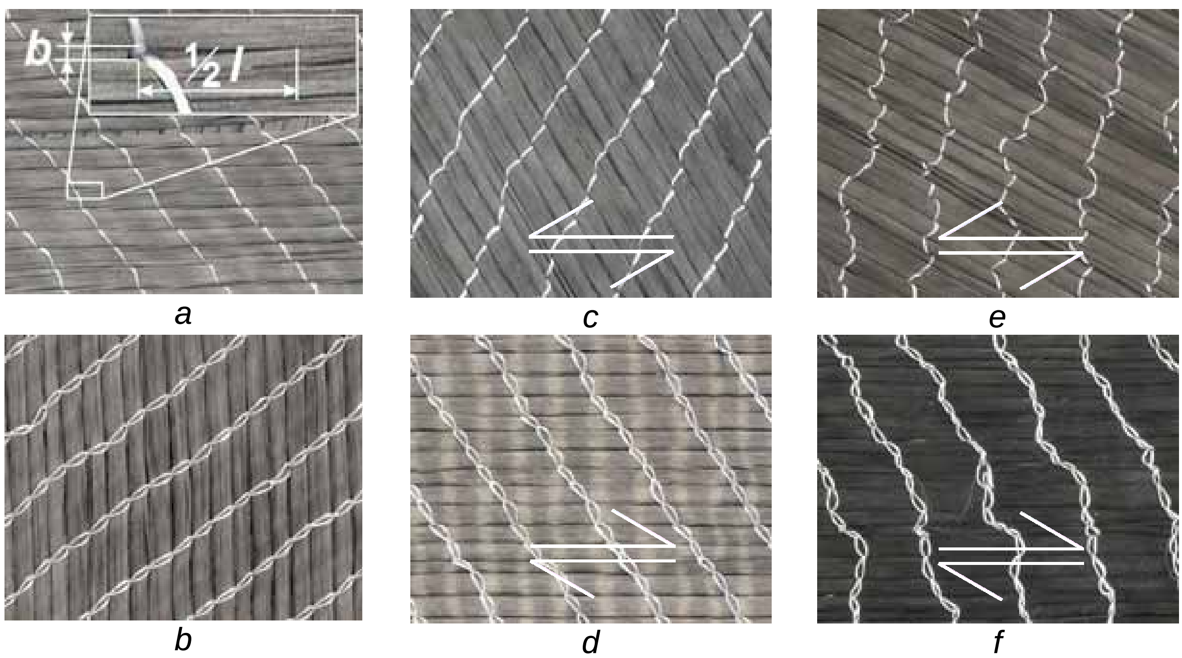

Figure 1: face and back of relaxed (a,b), 30º (c,d) and 60º (e,f) sheared fabric. The shear direction is indicated with arrows.

The tested material is a Devold ±45º chain knitted NCF (541 g·m^{-2}) with Tenax HTS 5631 12K carbon fibres. The stitch yarns are Sinterama polyester 50dtex stitch yarns.
Two different types of cracks are recognised [10]: face cracks and back cracks. It is assumed [10] that the crack width *b* is proportional to the compacted stitch yarn diameter d_0, according to:

$$\begin{aligned} &\text{(Face)} \quad b = k \cdot 2d_0; \\ &\text{(Back)} \quad b = k \cdot (2 + 2\cos\alpha)d_0, \end{aligned} \tag{1}$$

with *k* an empirical factor and α the angle between the fibres and the machine direction. Lomov [10] found a value of 1.6 for *k*. Figure 2 shows *k* and *l* for various shear angles.

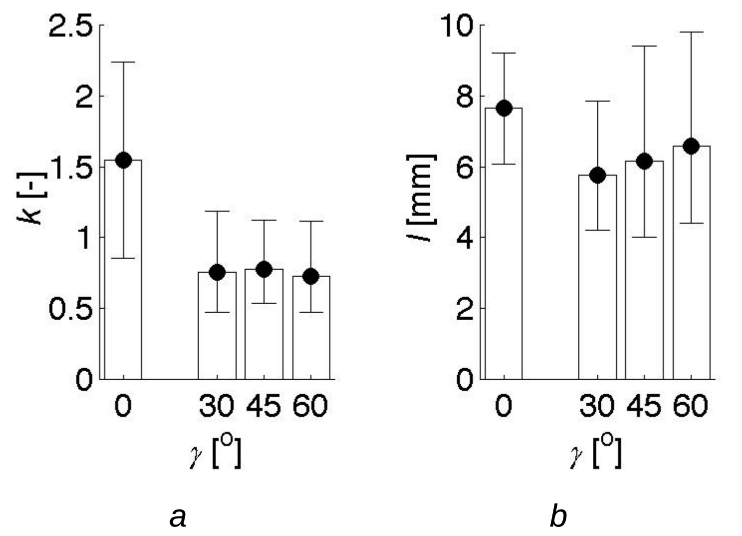

Figure 2: Emperical factor k (a) and crack length l (b) for various shear angles. The error bars show the standard deviation.

Although a different fabric is used, the value of *k* is close to the value found by Lomov in the relaxed state. For sheared fabrics the value converges to 0.7. This is what can be expected when shearing pushes stitching yarns closer together (for an ideal placement of them inside a crack $k \approx 1/\sqrt{2}$). The length of the cracks is roughly constant, with a certain decrease as can be expected in sheared configurations.
The scatter shown in Figure 2 is based on the distribution of the crack widths. For the relaxed state a normal distribution is found, for the sheared states a logarithmic normal distribution is found, as indicated by Figure 3.

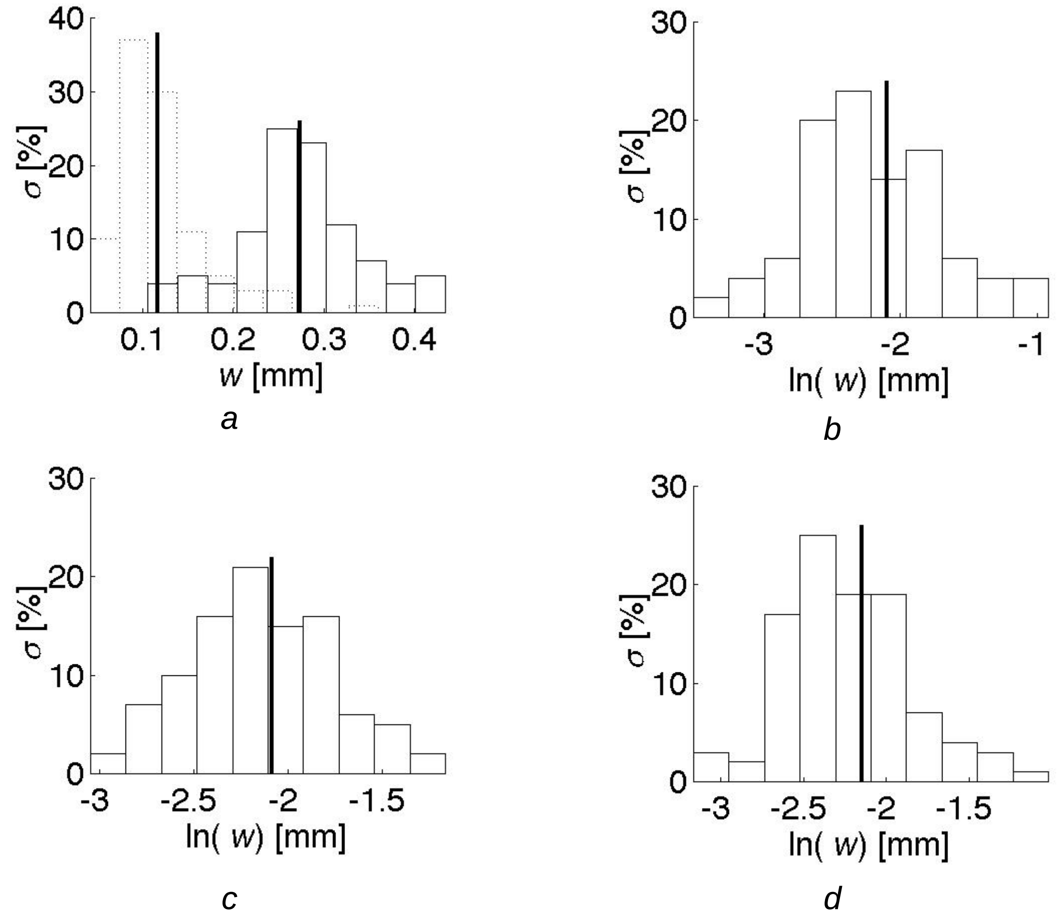

Figure 3: Distribution of k. (a) relaxed state (solid bars) and 60º sheared state (dotted bars) on a linear scale; (b,c,d) 30º, 45 º and 60º sheared state respectively on a logarithmic scale. The thick line indicates the average crack width.

The ±45º stitched fabrics are sheared easily, resulting in large interply angle deviations after the first handling of the fabric. Experiments were performed with a Saertex IM7 MPC 705 12K warp knitted NCF material. The interply angle α_{ply} is calculated by comparing the measured shear angles of top and bottom side of the fabric with each other. In Figure 4 the deviation of the interply angle $\Delta\alpha_{ply}$ is plotted as a function of the shear angle γ of the picture frame. $\Delta\gamma_{up}$ and $\Delta\gamma_{down}$ are the differences of the shear angles of the fibres with the shear angle of the picture frame.

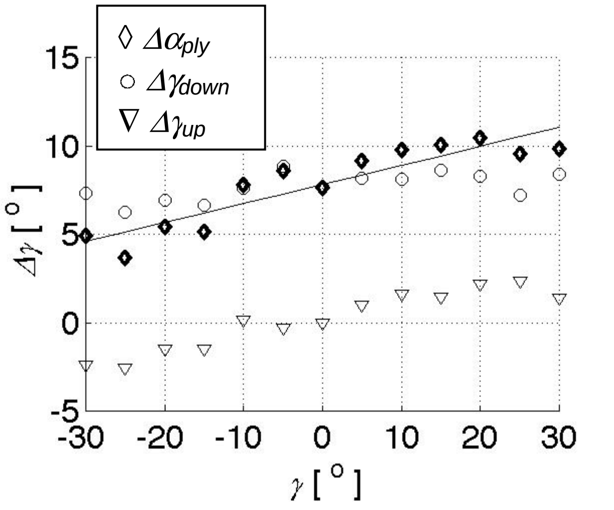

Figure 4: Deviation of the interply angle for various shear angles. The solid line is a least square fit on $\Delta\alpha_{ply}$

The misalignment of the ply angles $\Delta\alpha_{ply}$ consists of two superimposed parts: 1) a constant shift of nearly 8º, due to an initial mis-alignment of the plies; 2) a small lag between the measured ply angles and the shear angle of the picture frame, which is roughly proportional to the shear angle.

The permeability will be strongly affected by this misalignment and may contribute to large scatter in permeability measurements.

2. COMPRESSIBILITY

A compression test was performed to obtain the compression curves of the unsheared and sheared dry fabrics. For the low compression range (up to 5 kPa) a Kawabata test machine was used, for the higher compression range (up to 400 kPa) an Instron type 4467. Relevant data is presented in Table 1.

Figure 5 shows the compression curves for various shear angles. A shift is observed between the Kawabata measurements and Instron measurements. The origin of the deviation is yet unclear, but it can be concluded that the Instron machine cannot be used to determine the uncompressed thickness. The graphs show that the oftenly applied as-sumption of constant volume of the fabric is invalid since the fibres are compressed during shear.

		Kawabata	Instron
Range	[kPa]	< 5	< 400
Loadcell	[N]		1000
Type		flat, cylindrical	
D	[mm]	15.96	50

Table 1: Compression equipment data.

Note that the slopes of the Kawabata and the Instron measurements are similar near P = 5kPa, the maximum pressure for the Kawabata measurements.
Measurements with the Instron machine on the relaxed fabric proved to be reproducible with a good accuracy, but additionally measurements will be performed for sheared fabrics.

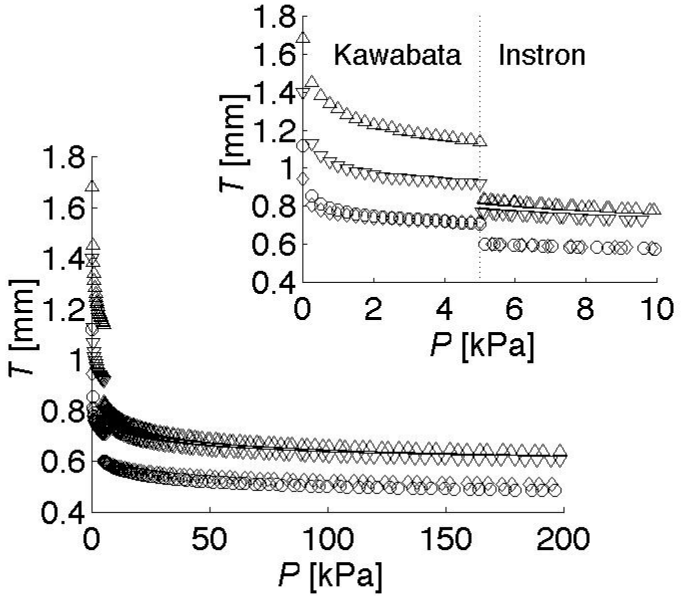

Figure 5: Compression curves for 0º (◊), 30º (○), 45º (∇) and 60º (Δ).

3. PERMEABILITY

The experimental set up available at the KU Leuven was used for permeability measurements. Axson F18 Polyol, which is the not curing component of a fast cast polyurethane resin, is used as test fluid. The fluid behaves Newtonian and the viscosity of 100 mPa·s is comparable to the viscosities of resins used in RTM.
The results can only be analysed in a qualitative way due to the limited number of tested specimens. Quantitative results can only be obtained when a large number of specimen is tested [9,14,15]. The first experiments show an increase of the anisotropy κ (see Figure 6), which corresponds with results found in the literature [1,2,3]. More results will be shown in the presentation.

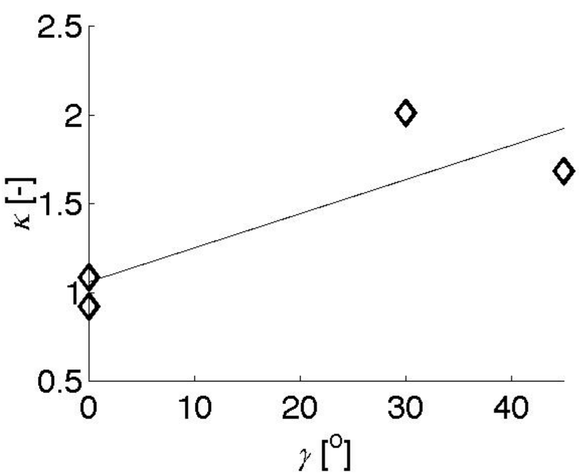

Figure 6: The anisotropy κ for various shear angles. The solid line is a least square fit.

4. CONCLUSION

The geometrical features of NCF material have been presented in this paper. It is shown that:

- The emperical factor *k* is close to earlier observed values for relaxed fabrics and converges to 0.7 for sheared fabrics;
- The length of the cracks is roughly constant for all shear angles and decreases by ~10% of the unsheared configuration;
- A normal distribution is observed for crack lengths and widths in the relaxed state and a logarithmic normal distribution in the sheared state. The distribution remains roughly constant for shear angles between 30º and 60º;
- Initial deviations of the interply angle are of the order 10º and will contribute to the scatter in measured permeability data;
- Compression curves show a shift in the Kawabata and Instron measurements. The uncompressed thickness cannot be measured accurately with the Instron machine;
- The measured increase of the uncompressed thickness for various shear angles shows that the assumption of a constant volume of the fabric is invalid;
- First permeability measurements show that the anisotropy of the material increases with increasing shear angle. More measurements are required to obtain quantitative results.

5. ACKNOWLEDGEMENTS

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