INFLUENCE OF SHEAR ON THE PERMEABILITY TENSOR AND COMPACTION BEHAVIOUR OF A NON-CRIMP FABRIC

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Abstract: *The present work presents the results of a study on the permeability and compaction behaviour of textiles under shear deformation. In this study a 0°/90° non-crimp carbon fibre fabric with an areal weight of 200 g/m² is used. The influence of shear is observed under two conditions: constant cavity height and constant fibre volume content (FVC). Permeability measurements were conducted as two-dimensional flow. Additional compaction tests of the sheared textiles lead to a more thorough understanding of the mechanisms at work.*
It is shown that for constant cavity heights the behaviour of the textile greatly changes between a shear angle of 15° and 20°. Up to an angle of 15° the permeability shows a linear increase for the principal axis and a linear decrease for the secondary axis. At shear angles above 20° the behaviour for both is non-linear. Furthermore this change of behaviour can also be observed in the rotation of the flow ellipse and the compaction measurements. Both show a double-linear development with a change of behaviour in the region of 15° to 20°.

1 Introduction

During the draping process of dry preforms, shear forces deform the textiles. This deformation leads to a change in textile properties, influencing compaction behaviour, permeability and mechanical properties. Characterising the influence of shear on permeability plays a key role in conducting proper simulations of the flow front progression in liquid composite processes.
Deformation by shear results in an increase of the areal weight (*Aw*) of textiles because the overall area is decreased whilst the amount of fibres is held constant:

$$Aw(\phi) = \frac{Aw_{initial}}{\cos(\phi)} \quad (1)$$

Keeping cavity height of the tool constant, this increase of areal weight results in an increase of the fibre volume content (FVC) as a function of the shear angle ϕ:

$$FVC(\phi) = \frac{FVC_{initial}}{\cos(\phi)} \text{ , for } h = \text{const.} \quad (2)$$

Another approach to the increase of areal weight as a result of shear deformation is changing the tool design in a way that allows for the FVC to remain constant. To achieve this, for regions in the tool where the textile is known to be in sheared state, the cavity height of the tool has to be adjusted according to the following formula:

$$h(\phi) = \frac{h_{initial}}{\cos(\phi)} \text{ , for } FVC = \text{const.} \tag{3}$$

Due to the increase of the FVC in the approach with constant cavity height, the working hypothesis for the experiments was that the permeability function of the used textile under shear would be similar to that for increasing FVCs. This assumption was based on the works done by M. Louis and U. Huber who investigated the influence of shear on woven textiles and found the described correlation [5]. However for the given non-crimp textile, this working hypothesis could not be confirmed. Therefore a more thorough analysis of the textile was conducted. This indcludes compaction measurements and permeability measurements under shear but with constant FVC.

2 Material and Processes

2.1 Material Used

The material used in this study is the textile HexForce NLT00 HR1270 0200 UGZ0F from Hexcel. It has an areal weight (Aw_{fibres}) of 200 g/m², and is a balanced, non-crimp carbon fibre textile with a 0°/90° orientation, which is made from Zoltek Panex 35 50 K fibres. The stitching yarn was assumed to be 6 g/m² and have a density (ρ_{yarn}) of 1 200 kg/m³. For the experiments five layers of textile (n) were stacked in a non-symmetrical fashion by putting them on top of each other in the same orientation. For these five sheets an initial cavity height (h) of 1.25 mm was chosen and a density of the fibres assumed to be 1 800 kg/m³, resulting in a FVC of 46.4 %, taking the stitching yarn into account, or 44.4%, in terms of carbon fibre.

$$FVC = \left(\frac{Aw_{fibres}}{\rho_{\text{fibres}}} + \frac{Aw_{yarn}}{\rho_{yarn}}\right) \cdot \frac{n}{h} \tag{3}$$

2.2 Apparatus for the Measurement of Permeability

The permeability was measured using an apparatus devised by the authors, which allows for an optical tracking of the flow front. The textile is placed between a glass plate and a steel plate. To avoid deflection of the cavity, the steel plate and the glass plate are both supported by a block of cross beams with a height of 15 cm each. These blocks are bolted together to achieve the compaction of the textile. The height of the cavity is determined by a set of spacers, which are inserted around the textile. Moreover, the height of the cavity is also measured ex-post using waxen pellets that are placed along the sides of the textile and compacted along with it. This allows for determining the actual height and for noticing possible deflections of the cavity.

The injection fluid is a vegetable oil of a known, temperature-dependent viscosity of about 100 mPa·s and the injection pressure is adjusted using a pressure control valve. To deduct the correct viscosity of the fluid, the temperature prevailing during the experiment is measured.

Due to the special nature of sheared textiles it was necessary to measure the permeability of the textile in 2D experiments. This means that the flow front spreads in an elliptical shape from a central injection point (figure 1).

A camera captures the advance of the flow front using continuous shooting mode. The obtained images are then evaluated using semi-automated Matlab software and the permeability is calculated by the application of Darcy's law. As shown in figure 1 the considered data are the permeabilities along the principal (a) and the secondary axis (b) of the flow ellipse as well as its rotational angle γ.

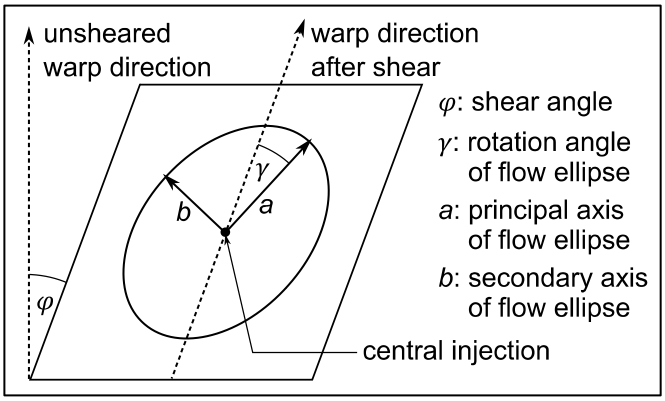

Figure 1. Schematic drawing of the flow ellipse for sheared textiles

2.3 Preparation of the Textile for Permeability Measurements

To shear the textile for the permeability measurements, the shear frame shown on the right in figure 2 was used. The textile is fixated on two adjacent sides by clamping the warp rovings on both ends. To minimise the friction between the sheets of fabric, thin metal plates keep them at small distance at the point of fixation. The textiles are then sheared to the desired angle and resetting is prevented by tightening the bolts of the shear frame; a circular hole with a diameter of 10 mm is punched into the centre to act as injection point. Because of their reset forces, the sheared fabrics are put into the tool cavity with the shear frame still in place. After closure of the tool, the friction forces hinder the textile from resetting, leaving it in the set state of shear even after removing the shear frame.

Due to the decrease of area during shear, the dimensions of the fabrics were chosen depending on the shear angle. The maximum textile dimensions were 605 mm length and 375 mm width.

Figure 2. Shear frames – left for the use for compaction experiments, right for permeability measurements

2.4 Conduction of the Compaction Experiments

For measuring the compaction behaviour of the textile, a smaller shear frame (picture frame – left-hand image in figure 2) was used. The sheets of fabric were again fixated and sheared in the same manner, with the metal plates not being necessary due to the small dimensions of the sample. After shear the angle was locked and the picture frame placed into a universal testing machine. This was done in a way that allowed the textile to remain in the picture frame during compaction. For this the picture frame was suspended in a manner that the textile merely touched the upper die of the universal testing machine, applying a pressure of 1E-6 MPa onto it. The area of compaction was determined by a 50 mm x 50 mm steel plate that was placed on the lower die.

The material was compacted at a speed of 0.5 mm/min up to a maximum pressure of 1.0 MPa using a single cycle of compaction.

3 Results and Discussion

3.1 Experiments with Constant Cavity Height

For the non-sheared textile the dependency of permeability on the FVC was investigated to serve as reference for the further investigation about the dependency on shear. The results of these measurements are shown in figure 3. As expected [1] the decrease of permeability follows an exponential function with increasing FVC. The permeability in warp and weft can furthermore be assumed to be equal in the non-sheared textile.

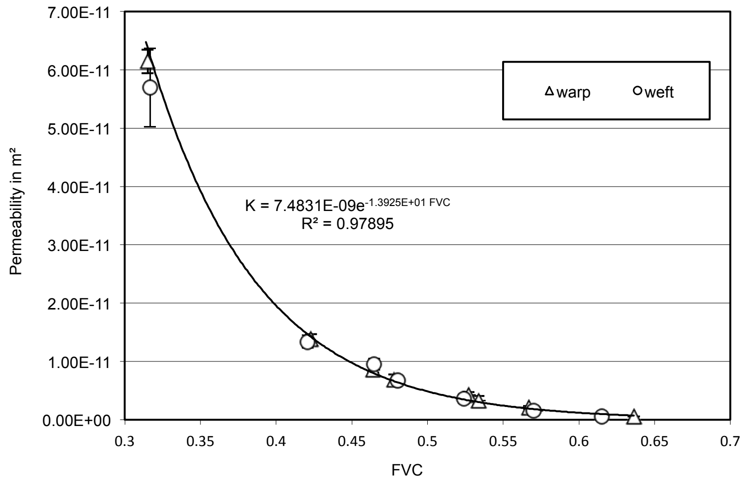

Figure 3. Dependence of permeability on FVC

When it comes to sheared textiles, this behaviour changes. Figure 4 shows the development of permeability with increasing shear angle at a constant cavity height. In this setup the FVC increases according to equation 2. It is notable that up to a shear angle of 15° the increase of permeability for the principal axis and the decrease of permeability on the secondary axis of the flow ellipse can be approximated with a linear function. Between 15° and 20° of shear an abrupt decrease of the permeability is observed for both, principal and secondary axis.
As seen in figure 5, the rotation angle of the flow ellipse shows a major change in the same range of shear angle.

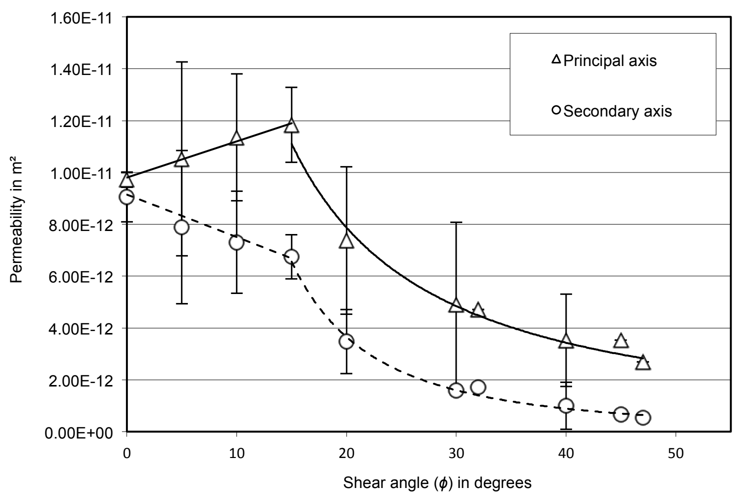

Figure 4. Dependence of permeability on shear angle with constant cavity height

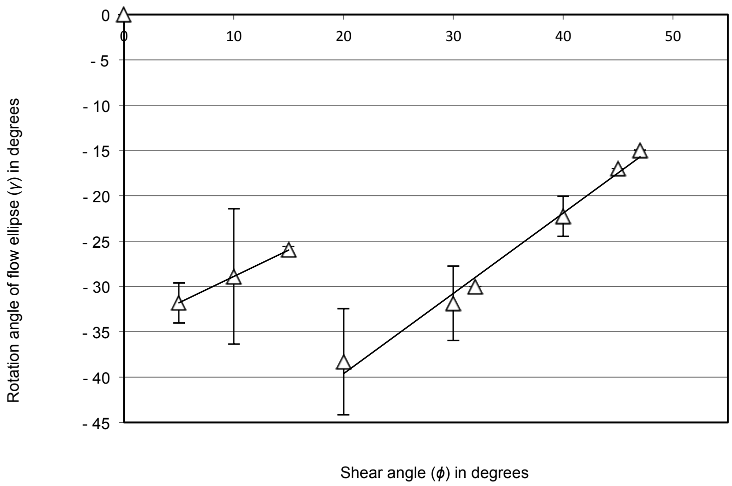

Figure 5. Rotation angle of the flow ellipse for permeability measurements with a constant cavity height of 1.25 mm

Plotting the results from the permeability measurements of sheared textile at constant FVC over the actual FVC as determined by the ex-post measurement of the cavity height and equation 2, it becomes very clear, that the hypothesis of having the same decrease of permeability as with increasing FVC for unsheared textiles has to be rejected for this textile (see figure 6).

The authors theorise that the increase of permeability along the principal axis is related to the properties of non-crimp fabrics: The yarn of the textile constricts the rovings, increasing the size of the macro flow channels in the textiles. This leads to an increased permeability in the direction of the constricted rovings. The observed constriction of the rovings is shown in figure 7:

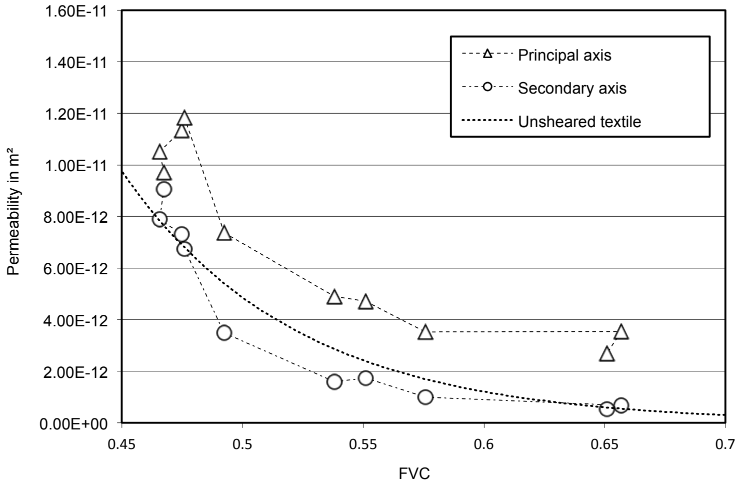

Figure 6. Permeability of sheared textile at 1.25 mm cavity height over its respective FVC

While in the non-sheared textile hardly any gaps between the rovings are visible, the sheared textiles at 15°, 20° as well as 30° show a spacing between the rovings. It can also be seen that this effect is mainly affecting the rovings in warp due to the stitching type used for the textile. This effect can be considered the cause for the difference in the development of permeability over shear angle, but does not explain the change of behaviour between 15° and 20° of shear.

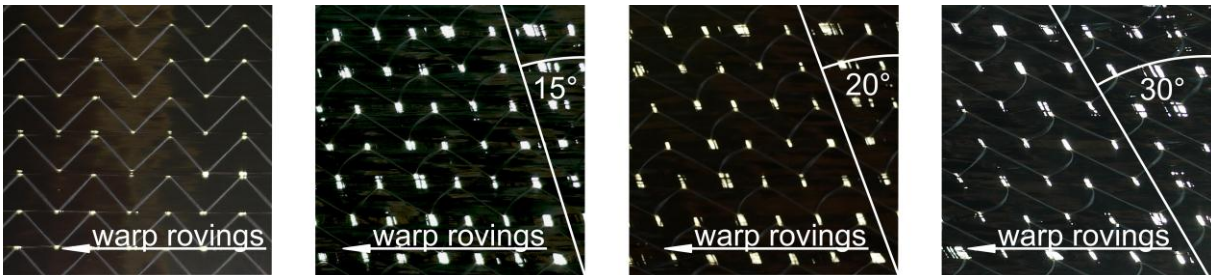

Figure 7. Textile structure at different shear angles

The change of permeability between 15° and 20° of shear correlates with an observation made in compaction experiments: as shown in figure 8 the compaction pressure needed in order to reach a cavity height of 1.25 mm can be approximated as a double-linear function of the shear angle. The intersection of those lines lies between 15° and 20° of shear, suggesting a correlating change of compaction behaviour in this region of shear angle. However as seen in figure 7 no significant changes can visually be observed in sheared single layers of fabrics. Therefore the authors attribute the change of permeability between 15° and 20° to changed nesting effects between the textile layers. This theory is further supported by figure 9: it shows that the compaction pressure needed to achieve a certain FVC is higher, when the change of FVC is induced by shear than it is, when the change of FVC is induced by a change of cavity height. This behaviour suggests a strong influence of geometric parameters on the nesting of the textile layers.

3.1 Experiments with Constant Fibre Volume Content

When keeping the FVC constant, there is no change of the permeability trend of the secondary axis in the given range of shear angle. However, the trend of the principal permeability changes despite the constant FVC. The strong decrease of both, permeability along the principal axis as well as the secondary axis, confirms that permeability does not only depend on the overall porosity of a textile but on its inner geometry.

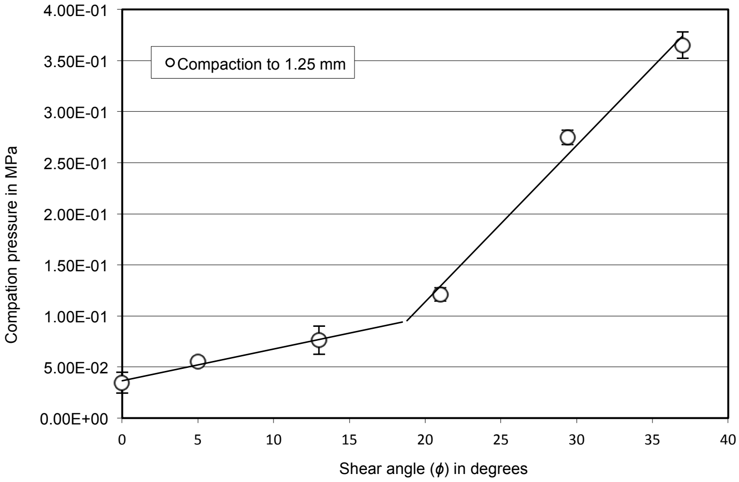

Figure 8: Compaction pressure needed for compacting to 1.25 mm at different shear angles

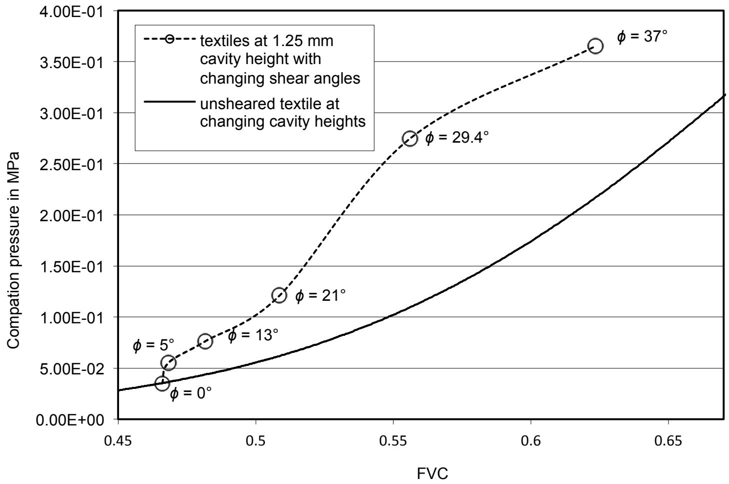

Figure 9. Compaction pressure needed to reach a certain FVC

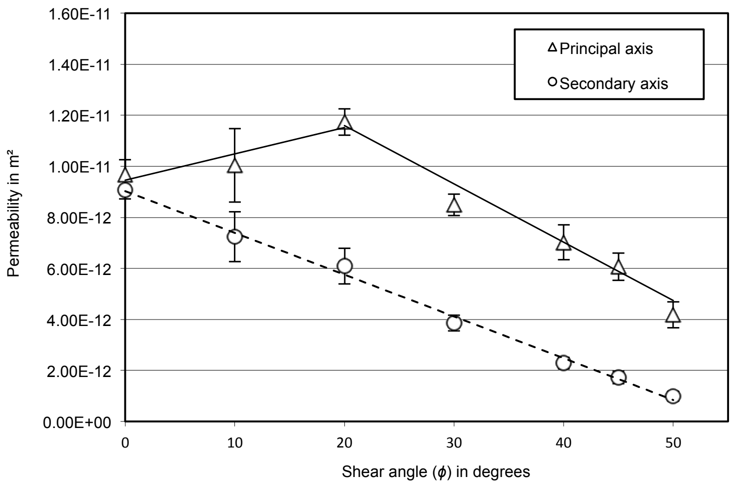

Figure 10. Dependence of permeability on shear angle with constant FVC

4 Conclusion

The experiments have shown that the shear of non-crimp fabrics induces a change of properties, which cannot easily be modelled. The original hypothesis that the development of the permeability over shear can be characterised based solely on the increase of fibre volume content has to be rejected for the given non-crimp fabric. Furthermore it was observed, that the textile displays a significant change of behaviour between the shear angles of 15° and 20°. Because no apparent change of the textile structure can be observed for single layers, the authors attribute this change mainly to nesting effects. It is therefore concluded that an exhaustive acquisition of permeability data will also in the future be a viable part of the simulation of impregnation processes. Furthermore the authors conclude that the effects of shear on important process parameters like permeability and textile compressibility needs to be more closely considered in tool design and simulation to reflect the limitations that they impose.

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