Permeability of sheared woven flax fibres reinforcements; Definition of parameters to model complex shape composites part processing by LCM

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Abstract

This paper describes a method to characterise the influence of in-plane shear on the permeability of fibrous preforms used in Liquid Composite Moulding (LCM) processes. An optical method for measuring the local shear variation of the woven textile is presented and used in conjunction with an in-plane permeability measurement system. The aim is to define the material parameters such as the orientation of the in-plane permeability depending on the shear applied to the reinforcement. The system presented here can either be used as a validation tool for permeability prediction models, or to compile semi-empirical permeability models for LCM process simulation tools.

1. Introduction

Weight reduction is a main target for energy saving in the transportation industry products. A significant number of manufacturers in areas including aeronautic, railroad or automotive are using an ever increasing amount of composite materials in their products because of their low weight compared to their mechanical performance.

In order to reduce the amount of fossil carbon in structural composites while maintaining their mechanical performances and the ability to use direct processes to manufacture large and complex shaped parts, the use of bio-based resins and reinforcements are currently studied. Through a less regular geometry (as observable in Figure 1) and shorter length of the individual fibres, using such materials tends to exacerbate the scientific bottle necks met in composites manufacturing by Liquid Composite Moulding (LCM) processes. At last, dispersion in bio-based reinforcements properties is also an issue and a lot of studies are currently ongoing on this specific topic.

Roving and textile methods applied to flax fibres enable the production of preforms that are suitable for manufacturing bio-based composite parts by LCM processes. The properties of these bio-based reinforcements are a-priori different from those of similar reinforcements specifically developed for composite processing. Further complexities are also introduced by the fact that the fabrics used for complex shaped composite parts manufacturing are deformed before being impregnated by resin in the cases of injection in moulds with double curvature [1-4]. These deformations can have an effect on the impregnation as, for example, preferential direction of flow or lower local permeability. Those moulds can also have an effect on the residuals stresses [5] that can induce premature micro-damages in the part but this aspect will be the focus of further studies [6-8].

The present study focuses on the measurement of in-plane permeability [9-17] on a flax twill weave. More precisely, in order to gather information on the behaviour of such reinforcements during manufacturing by LCM processing, the permeability of the fabrics under in-plane shear has to be estimated [18-19]. The fabrics have thus been sheared prior to permeability testing in order to simulate preforming in a complex shaped mould [20-23]. These deformations have an effect on the manufacturing parameters such as compaction behaviour and permeability [9-10;24-27]. Effects of several shearing levels measured locally by optical method have been studied at strictly controlled fibre volume fraction. It is important to note that the previous studies have been realised at constant thickness, thus coupling the change in shear angle with change in fibre volume fraction. The measurements presented in this paper are made at constant fibre volume fraction.

The textiles permeability properties have thus been experimentally characterised, highlighting the effects of shear on the behaviour of bio-based textiles at different fibre volume fractions.

2. Materials and method

The method used in this study is here described on flax twill weave with an areal weight of 525 gsm (grams per square meter). It can be seen that the tows are made up of several circular pack of twisted flax fibers (Figure 1). This has an effect on the crimp of the fabric and its ability to be sheared without damaging the fibres.

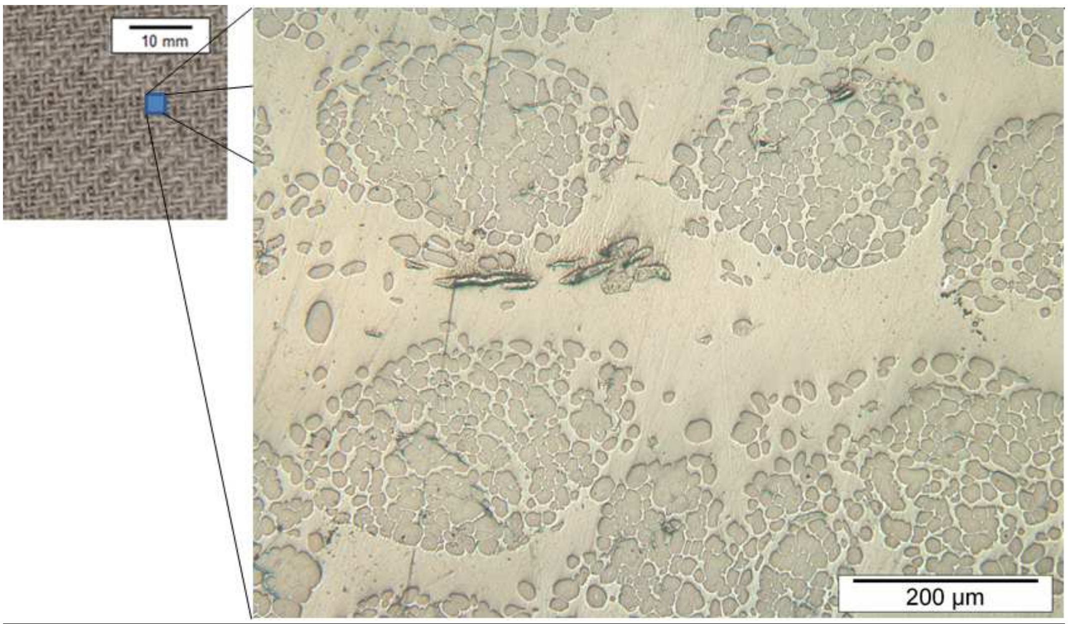

Figure 1. Flax twill weave ; reinforcement from above (left) and section of a composite (right)

The set up developed in this study is relatively simple, although it results from several iterations. The sample corners were cut prior to shearing, as illustrated in figure 2. This prevented out of plane wrinkling of the woven fabric, which is normally present in the regions of sharp angle changes [10]. Willems et al. [28] advised to maximise the ratio L_{Frame}/L_{ROI} (L_{ROI} is characteristic of the region of interests as described in figure 2). For this study however, this had to be balanced with the need to have a sufficiently large area (so large L_{ROI}) on which to perform the permeability measurement. Previous studies [10] have recommended removing the loose yarns, i.e. no longer maintained by neighbouring yarns, parallel to the frame on the edges of the preform. This operation was not performed in this study to minimize handling and deformation of the fabric to be characterized.

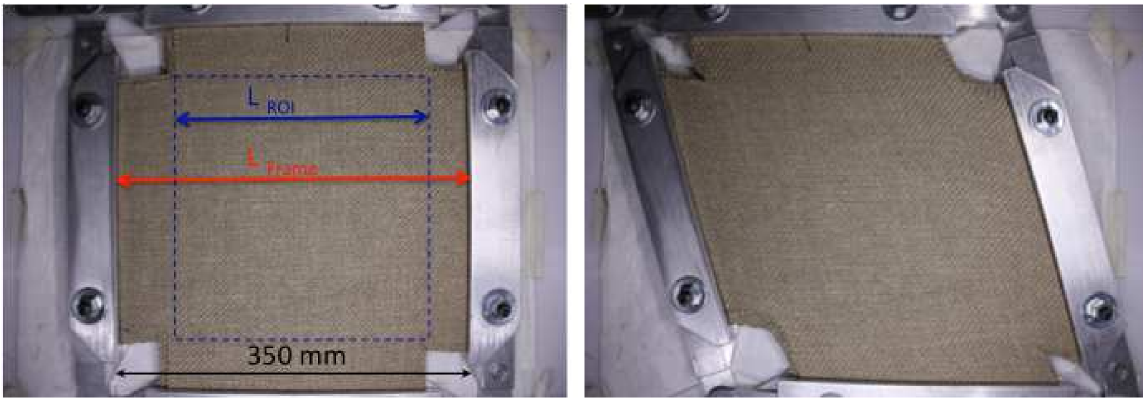

Figure 2. Coarse twill in shear rig initial state (left) and sheared at 15° (right); LROI=250mm

While the rig described above governs the overall shear of the reinforcement, it was deemed necessary to control the actual shear angle imposed on the fabric [11]. Shear variations within the material were present due to shear induced by the cutting and placement of the textile in the rig, as well as sample sliding in the grips as described above. Photographs of the samples were therefore taken just before and after deformation in order to evaluate the local variations due to the rig loading. The pictures of the reinforcement were converted to greyscale, cropped to eliminate the rig, and then divided into squared sub-pictures to analyse the spatial dispersion. The pictures were usually defined by 4000x3000 pixels with a spatial resolution of approximately 0.01mm² by pixel to be analysed. The angle between weft and warp directions of the fabric can thus be measured independently in different areas of the sheared preform (figure 3).

3. Results and discussion

The effect of fabric shear on the permeability behaviour is presented and discussed on the basis of figure 4 presenting a schematic description of an elliptic flow front on a fabric. The components on the in-plane permeability tensor are defined as the principal directions of the ellipse extracted from the flow front with a method very similar to Comas-Cardona et al. [29]. Those principal directions are different from the warp and weft directions (represented as a grid in figure 4) and this is distinguished by the angle θ that describes the angle between the weft direction and the direction along the largest principal component of the in-plane permeability tensor.

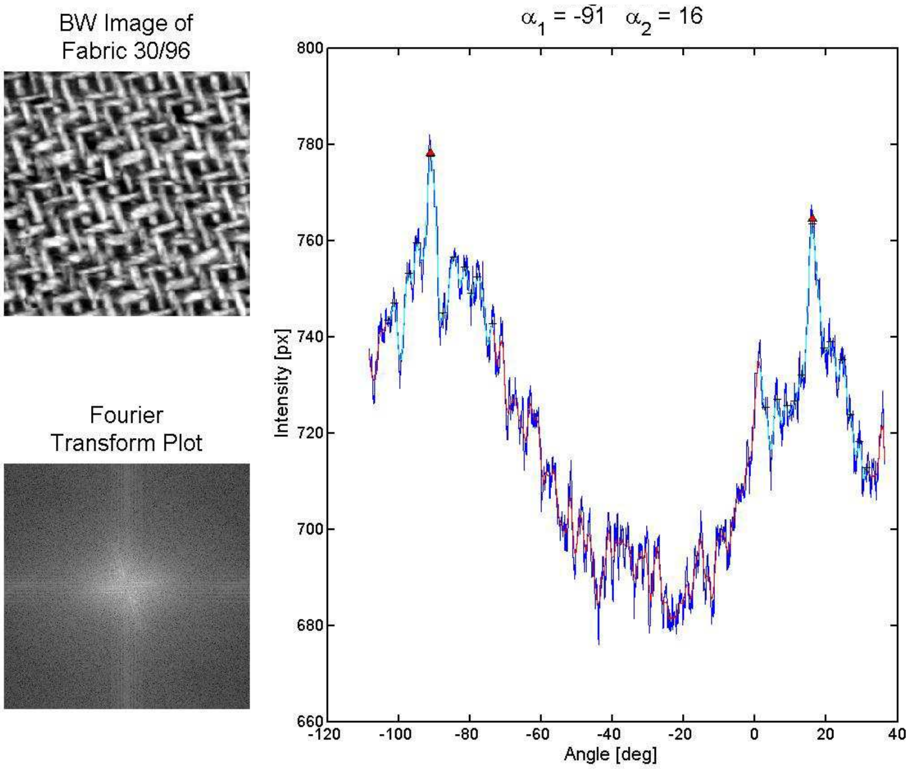

Figure 3. Example of measurement of the local shear on a coarse twill sample with an overall shear of 20°

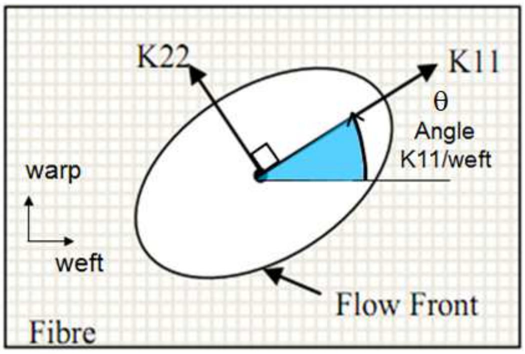

Figure 4. Presentation of the variable θ, angle between K11 and the weft direction.

Figure 5 shows the influence of the applied shear (at constant fibre volume fractions (V_f = 54%) on the K11 and K22 permeability values of the reinforcement. As shown in this figure, K11 is significantly affected by shearing whereas the changes in K22 are not relevant.

The angle between the weaving direction decreasing below 90°, it seems normal that the permeability along K11 becomes higher (angle θ weft/K11; figure 4). However, when comparing the permeability at constant thickness, the effect of increased V_f will result in a slight decrease of K11 and a steep drop in K22 with increasing shear. That is why those tests have been performed at constant V_f and not constant thickness.

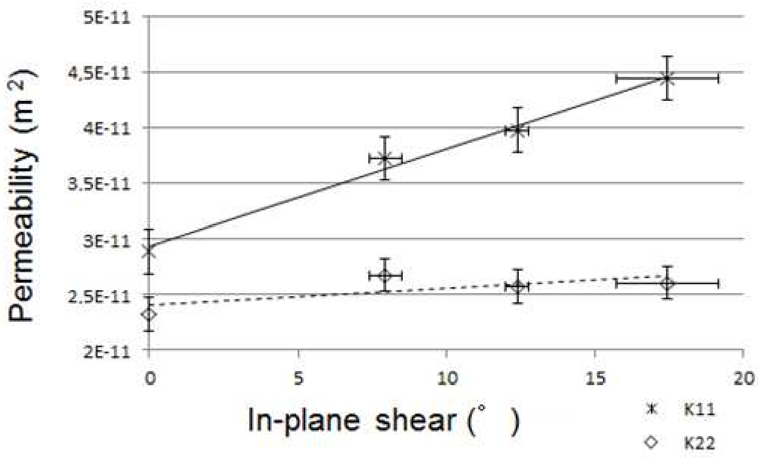

Figure 5. K11 and K22 at constant Vf (Vf=54%) at different measured in-plane shear.

The ratio between the K11 and K22 components depends on the fabric shearing. The angle between the weft direction and the principal direction of the permeability tensor K11 (angle θ weft/K11; figure 4) is also significantly influenced by the shear angle applied. The evolution of the angle with the measured shear of the reinforcement is presented on figure 6. An example of the effect of the shear on the angle weft/K11 is presented in figure 7. This highlights the importance of accurately characterising the influence that these parameters have on the material permeability behaviour in order to increase the accuracy of the LCM process models.

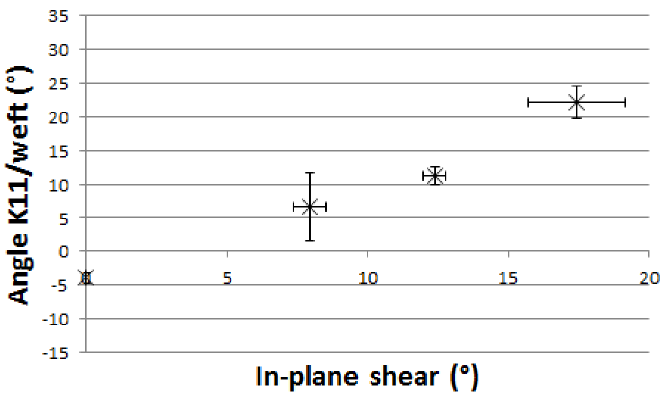

Figure 6. Angle K11/weft depending on the nominal shear angle at constant fibre volume fraction (Vf=54%)

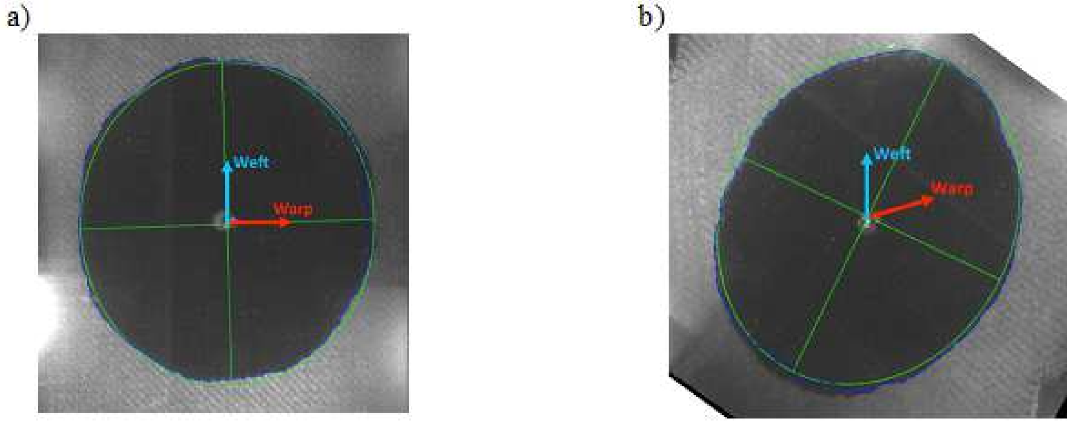

Figure 7. Ellipse of saturated fabric during in plane permeability characterization at constant fibre volume fraction (Vf=54%). a) non-sheared fabric; b) nominal shear angle 20°.

4. Conclusion

While it is well known that in-plane shear affects the permeability values and anisotropy behaviour of a fabric, it was also demonstrated here that it also affects the orientation of the permeability tensor relative to the fabric orientation (weft and warp). With the refinement of the liquid composite moulding process simulation capabilities, it has become important to be able to provide more accurate and detailed material data to the model. While there is a drive to try and predict the compaction and permeability behaviour of reinforcement materials through simulation, the large number of parameters and the variability generated through the weaving process does make it difficult and expensive to rely solely on prediction to obtain material data. Semi-empirical models based on experimental material characterisation provide economic benefits.

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