NUMERICAL PREDICTION OF IN-PLANE PERMEABILITY FOR WOVEN FABRIC WITH MANUFACTURE-INDUCED DEFORMATION

X. Zeng*, A Endruweit, A.C. Long

Division of Materials, Mechanics and Structures, The University of Nottingham, Nottingham, UK, NG7 2RD
** Corresponding author's e-mail: Xuesen.Zeng@nottingham.ac.uk*

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Introduction

During preforming for Liquid Composite Moulding processes, woven reinforcement fabrics are subject to a combination of shear, compression and nesting. Previous studies have shown that the fabric permeability, which determines the subsequent impregnation with a liquid resin system, is highly sensitive to deformations of the fabric architecture. While a number of approaches are documented in the literature, in most cases based on macro-scale analysis and localised homogenisation of the fabric structure, reliable and accurate predictive quantification of the permeability tensor remains challenging, especially for woven fabric preforms under realistic manufacturing conditions. In this study, unit cell deformation is modelled in detail to allow permeability prediction based on CFD flow analysis.

Unit cell modelling

Fabric deformations are modelled geometrically based on relative spatial constraints, self-imposed by the fabric architecture. The angle of yarn rotation as well as changes in yarn cross-sectional area and shape are calculated as functions of shear angle and compaction level of the fabric. This method for modelling fabric deformation is implemented in the TexGen software (http://texgen.sourceforge.net/). In addition, nesting between fabric layers is approximated by a statistical sampling technique. This approach is validated by comparing the geometric model with the 3D x-ray μ-CT image data of composites with woven reinforcement (Figure 1). Here, the example of three layers of a plain weave glass fibre fabric is studied. At 2 mm thickness, the fibre volume fraction is 0.53 for the case of non-sheared fabric. Six lay-up models with random nesting were generated for each of the shear angles 0°, 10°, 20° and 25° (Figure 2).

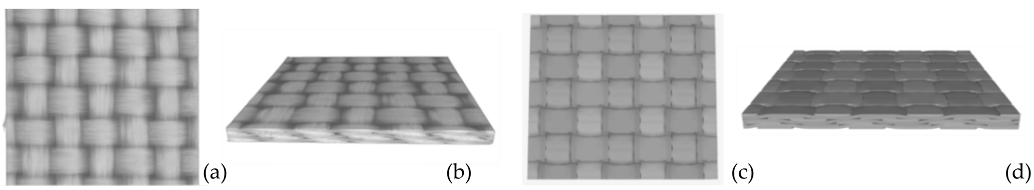

Figure 1: *Three layers of plain weave glass fibre fabric at 2 mm thickness: (a) and (b), reconstructed x-ray CT volume views; (c) and (d) automatically generated TexGen model.*

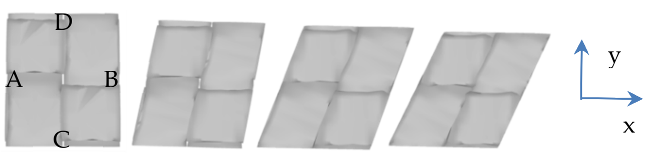

Figure 2: *Automatically generated unit cell models with shear angles of 0°, 10°, 20° and 25° relative to the y-axis.*

Permeability prediction

Darcy's law for a 2D flow problem can be expressed in global x-y coordinates as

$$\begin{bmatrix} u \\ v \end{bmatrix} = \frac{1}{\eta} \begin{bmatrix} K_{xx} & K_{xy} \\ K_{yx} & K_{yy} \end{bmatrix} \begin{bmatrix} \partial p / \partial x \\ \partial p / \partial y \end{bmatrix} \quad (1)$$

where K_{xx}, K_{yy}, and $K_{xy}=K_{yx}$ are the components of the permeability tensor to be determined by unit cell based CFD analysis. For a sheared unit cell domain, translational periodic boundary conditions are applied on the pairs of face A/face B and face C/face D (Figure 2). From each CFD simulation, a flow velocity vector is calculated on faces A, B, C and D as averaged nodal velocity weighted by the area of the respective face. The permeability tensor in Eq. 1 is determined based on two flow cases.

In case I, a pressure drop, ΔP, is imposed between face C and face D, such that $\frac{\partial p}{\partial x} = 0, \frac{\partial p}{\partial y} \approx \frac{\Delta P}{H}$. With the resulting vector, $\begin{bmatrix} u_1 \\ v_1 \end{bmatrix}$, Eq. 1 can be solved:

$$K_{xy} = K_{yx} = \frac{u_1 \eta H}{\Delta P}; \; K_{yy} = \frac{v_1 \eta H}{\Delta P} \quad (2)$$

In case II, a pressure drop, ΔP, is imposed between face A and face B, such that $\frac{\partial p}{\partial x} \approx \frac{\Delta P}{L}, \frac{\partial p}{\partial y} \approx \frac{\Delta P}{L} \tan(\gamma)$, where γ is the shear angle. With $\begin{bmatrix} u_2 \\ v_2 \end{bmatrix}$ and Eq. 1:

$$K_{xx} = \frac{\eta L}{\Delta P} \left[u_2 - \frac{H \tan(\gamma)}{L} u_1 \right] \quad (3)$$

The permeability tensor is then transformed to the diagonal form (K_1 and K_2), to allow direct comparison with experimental data.

Validation

In Figure 3, numerical predictions are compared with experimental data for the permeability of woven fabric specimens subjected to shear, compression and nesting. The results match well, except for the 0° case. The exception has been traced back to one of newly implemented TexGen's internal functions for automated yarn intersection correction after shear deformation. The function has reduced local tow volume excessively in the 0° case. The identified function will be improved in the future. Overall, this study has demonstrated that advanced numerical techniques enable accurate prediction of permeability by considering manufacture related material deformation and variability.

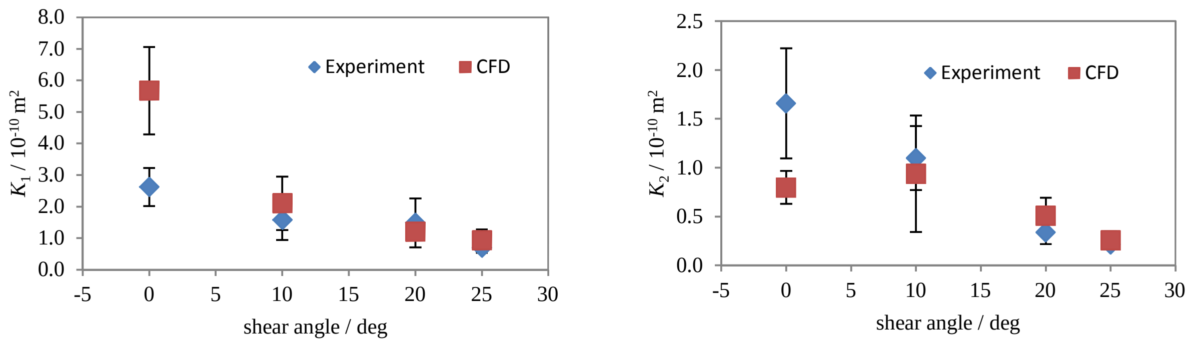

Figure 3. *Permeability predictions of K_1 and K_2 at different shear angles by CFD compared with the experimental data.*

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