PERMEABILITY OF TEXTILE REINFORCEMENTS: EFFICIENT PREDICTION AND VALIDATION

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1 Introduction

For the manufacturing of composites with textile reinforcements, the permeability of the textile is a key characteristic. It is of particular importance for the simulation of the injection stage of Liquid Composite Moulding, since software tools for simulating the impregnation process like PAM-RTM or LIMS require the assignment of the permeability at different positions in the preform model. The permeability is a geometric characteristic related to the structural features of the textile at several length scales. Textiles are porous media and the permeability tensor is defined by Darcy's law

$$\langle \vec{u} \rangle = -\frac{1}{\upsilon\rho} \underline{\underline{K}} \cdot \nabla \langle P \rangle, \qquad (1)$$

with *u* the fluid velocity, υ and ρ the fluid viscosity and density, P the pressure, < > volume averaging and K the permeability tensor of the porous medium.

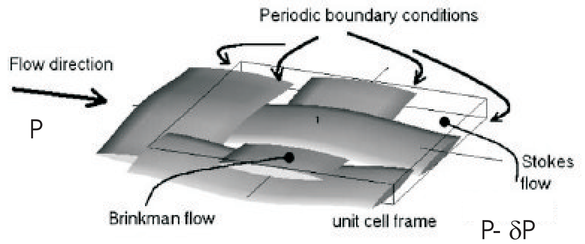

Fig. 1. A unit cell of the textile model

In this paper we present two methods to compute the permeability and we give theoretical and experimental validation. The first method performs a full Computational Fluid Dynamics (CFD) simulation to compute the flow field and pressure distribution. The second method reduces the 3D simulation problem to a 2D problem, which leads to a reduction of the computational cost.

For the creation of the unit cell models of the reinforcements (Fig. 1), we use the TexGen [1] and WiseTex software [2].

2 Computation of the permeability

2.1 Finite Difference CFD

In the case that the model is limited to creeping, single-phase, isothermal, unidirectional saturated flow of a Newtonian fluid, the inter-yarn flow is described by the incompressible Stokes equations (here in dimensionless form),

$$\begin{cases} \Delta\vec{u} - Re\nabla P = 0 \\ \nabla \cdot \vec{u} = 0 \end{cases} . \qquad (2)$$

To avoid problems with the meshing of the fluid matrix in between the yarns, we solve these equations on a regular grid with a finite difference discretisation [3]. The code is an extension of the 3D finite difference Navier-Stokes solver NaSt3DGP, developed at the Institute for Numerical Simulation of the University of Bonn [4,5].

2.2 Grid2D

In the Grid2D approach [6], the domain is first divided into basic volumes consisting of the open channels and porous tows. Bisecting surfaces in the direction of flow are then identified for each basic volume. Each of these surfaces will retain the height and permeability of the volume that it represents. The domain is then discretized into a regular rectangular grid in the x–y plane. For each element, the local 2D permeability tensor components, K_{ij}, are calculated as the weighted average of the permeabilities of the volumes below the point, and assigned to every point of the 2D grid. Darcy's law is used to estimate the velocity field and pressure distribution. Finally, the unit cell permeability is calculated.

3 Validation

3.1 Theoretical validation

For a parallel array of cylinders, theoretical permeability values are available via the formulas of Gebart [7] and Berdichevski [8]. Table 1 shows that for a flow transversal to a square packed array of cylinders, the permeability values agree well for both the CFD method as for the Grid2D method. For the flow along the cylinders, the CFD method is more accurate than the Grid2D method.

Vf (%)	Gebart	Grid2D	FD-CFD
Along a square packed array			
20	3.50e-02	6.64e-02	4.09e-02
45	9.00e-03	3.30e-02	9.86e-03
62	3.00e-03	1.03e-02	3.10e-03
Transversal to square array			
20	1.80e-02	5.04e-02	2.02e-02
45	3.00e-03	8.13e-03	3.80e-03
62	4.50e-04	4.40e-04	4.50e-04

Table. 1. Permeability values for a parallel array of cylinders (mm^2)

3.2 Experimental validation

The monofilament fabric Natte 2115 (Fig. 2) is a realistic impermeable fabric, although designed for experimental purposes only. For a single layer model, the CFD method results in a permeability of 0.00033 mm^2, the Grid2D method gives 0.00099 mm^2. The average experimental value is about 0.00027.

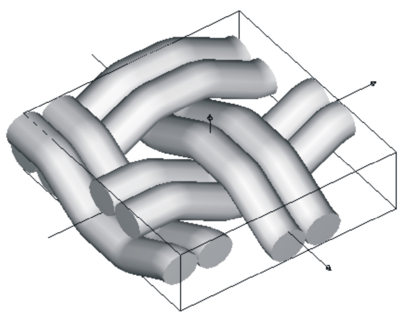

Fig. 2 Model of the monofilament fabric Natte

4 Conclusions

Two methods for the efficient computation of the permeability are compared in this paper. The full CFD finite difference solver is more accurate, but requires a substantially larger calculation time than the Grid2D solver. The fast Grid2D solver provides the correct order of magnitude, and may be well suited for parametric studies.

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References

[1] Robitaille F., Long A., Jones I., Rudd C. "Automatically generated geometric descriptions of textile and composite unit cells". *Composites part A,* Vol. 34, pp. 303-312, 2003.

[2] Lomov S., Huysmans G., Luo, ea. "Textile composites models: Integrating strategies". *Composites part A,* Vol. 32, No. 10, pp 1379-1394, 2001.

[3] Verleye B., Klitz M., Croce R, ea. "Computation of permeability of textile reinforcements". *Proc. of IMACS 2005,* Paris, CD-edition, 2005.

[4] Griebel M., Dornseifer T. and Neunhoeffer T. "*Numerical simulation in fluid dynamics, a practical introduction*". SIAM, 1998.

[5] Http://wissrech.iam.uni-bonn.de/research/projects/nast3dgp

[6] Wong C., Long A., Sherburn M., ea. "Comparison of novel and efficient approaches for permeability prediction based on the fabric architecture". *Composites part A,* Vol. 37, No. 6, pp 847-857, 2006.

[7] Gebart B. "Permeability of unidirectional reinforcements for rtm", *Journal of Composite Materials.* Vol. 26, No. 8, pp. 1100-1133, 1992.

[8] Berdichevski A. and Cai Z. "Preform permeability predictions by selfconsistent method and finite element simulation", *Polymer Composites.*Vol. 14, No. 2, pp. 132-143, 1993.