

A RADIAL INFUSION MODEL FOR TRANSVERSE AND IN-PLANE PERMEABILITY MEASUREMENTS OF FIBER REINFORCEMENT IN COMPOSITE MATERIALS

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Introduction

Resin transfer molding (RTM) techniques are popular manufacturing methods renowned for their simplicity, reduced time-to-market design, lower cost, and high quality in producing thermoset composite parts and structures. Numerical simulation of these techniques requires knowledge of physical properties such as the values for permeability tensor components. There are many theoretical and experimental studies related to permeability evaluation from different perspectives considering in-plane and transverse permeability or saturated and unsaturated permeability [1-8]. Saturated transverse permeability has been studied by Wu et al. [1], however, for RTM processes unsaturated transverse permeability is more important for the analysis of initial fabric wet-out.

Transverse permeability

Three general problems make the study of unsaturated transverse permeability more difficult relative to all other permeability measurements. The first related to inability to visualize resin flow passing through fiber reinforcement in transverse direction. The second related to the measurements of elapsed time necessary for the resin flow to pass in the transverse direction. Time duration of resin flow in the transverse direction may be much shorter and its measurements less accurate, in comparison with the time of in-plane mold filling. Finally, the third problem related to the dimension of the flow inlet. In many practical situations this dimension is comparable with the thickness of the preform, and therefore with the displacements of the flow front. Thus, it cannot be neglected.

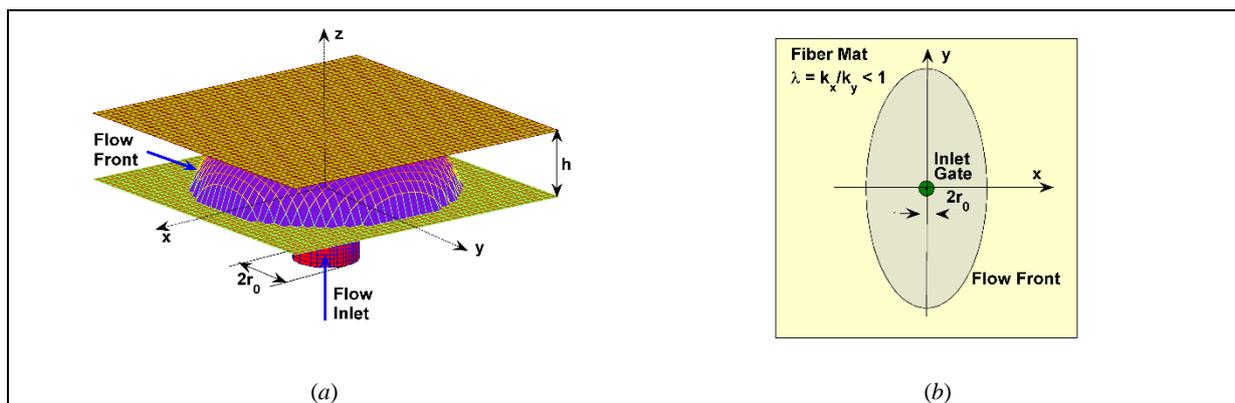


Figure 1: Physical models for transverse (a) and in-plane (b) permeability measurements showing the inlet gate and the front of the fluid injected through the fiber matrix.

The goal of this paper is to present a method for simultaneously determining the principal values of an unsaturated permeability tensor for fibrous reinforcements, which accounts for finite dimension of the inlet gate, when its diameter is comparable or larger than thickness of a fabric preform (see Figure 1). An analytic solution for the direct problem of liquid spreading in a transversely orthotropic fabric

perform is derived and analysed. This solution compared with a point source approximate solution used by other authors. Algorithms for evaluating principal components of transverse and equivalent in-plane permeability are proposed

In-plane permeability

The principal components of in-plane permeability of fiber reinforcement during resin infusion can be determined by unidirectional or by radial flow experiments. Using unidirectional flow, two separate experiments are required to determine both components if the directions of principal axis are known. In radial flow, both principal components can be determined by performing one experiment when the directions of principal axis are known. However, developed models that apply to this method require iterative procedures and are highly sensitive to the radius of the injection port. Measurements of the flow front displacement have to be taken when the wetted area becomes large enough in comparison with the size of the inlet gate.

In this presentation, it is shown that the anisotropy coefficient and consequent permeability may be evaluated at any stage of the flow front displacement. This implies that the pressure difference does not necessarily need to be constant during the experiment, as usually required for most previous models. Asymptotic analysis for very small and very large flow front displacements is also conducted and comparison with point source algorithms is provided. Three accurate and relatively simple algorithms that do not require iterative procedures for evaluation of in-plane components of permeability are proposed.

Conclusions

Mathematical details of the presented models and solutions are published in [9, 10]. Based on the obtained results, an experimental methodology was proposed such that in-plane and transverse permeability can be evaluated directly from experimental data using these analytic solutions. It has already been applied for evaluation of in-plane and transverse permeability of flax fiber preforms for biocomposite materials [11]. This approach allows composite process designers much greater ease and accuracy in determining permeability constants to use in large scale, resin flow simulations.

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