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SIMULTANEOUS IDENTIFICATION OF PREFORM PERMEABILITY AND COMPRESSIBILITY

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1 Introduction

The identification of the transverse properties of fabrics is becoming an important topic, as the transverse flow is significant in advanced liquid composite moulding processes such as resin film infusion (RFI), vacuum assisted resin transfer moulding (VARTM) process and compression resin transfer moulding (CRTM) process. However, it is not easy to characterize the transverse permeability and the compressibility of preform, since the fluid flow and the mechanical deformation of fabrics simultaneously occur in the out-of-plane direction. Due to the strong hydro-mechanical coupling, hence, it has been a common approach to identify the transverse properties separately either under the simplified assumption (uniform fibre volume fraction in the thickness direction) or under the ideal condition where the closed form solution is known. In the previous work, we developed a computer code to simulate the resin film infusion process [1] and an experimental device for the measurement of transverse compressibility and saturated permeability by a continuous technique [2]. In this work, we characterize simultaneously the preform properties (permeability and compressibility) in the transverse direction by incorporating the mathematical models into the full numerical simulation of an actual filling process. To identify the model coefficients, an inverse method is applied with experimental data.

2 Experimental Procedures

2.1 Experimental Hydro-Mechanical Device

We use a device to observe liquid flow through the fabric under various injection conditions such as inlet pressure or flow rate and under various compaction conditions such as stress or

displacement control by universal testing machine. A schematic of the device is shown in Fig. 1.

2.1 Hydro-Mechanical Coupling under Imposed Displacement

The fibrous reinforcement layers are placed between two perforated grids and a test fluid is injected at a constant flow rate. At the same time, the mobile grid moves down, at a constant speed, to compact the fabrics. The time evolutions of the pressure measured at the bottom of the preform and the total stress applied to compress the reinforcement layers are presented in Fig. 2.

3 Identification of Preform Properties

3.1 Resin Flow and Fabric Deformation

The principal resin flow and fabric deformation occur in the same direction (i.e. through thickness direction), in the RFI process. As a consequence, the fabric is not uniformly deformed and the fibre volume fraction is not uniform either, in the direction of applied stress, during the resin flow in the RFI process. For a more precise description of this hydro-mechanical coupling in RFI process, we developed a computer code for mould filling simulation of the RFI process taking into account the differential pressure and compaction stresses in the thickness direction [1]. Terzaghi's Law is used to consider the coupling between the resin pressure and the fabric deformation stress.

$$\sigma_{tot} = \sigma' + P \quad (1)$$

where σ_{tot} is the total external stress applied to the fabric stack, σ' is the effective fibre deformation stress and P is the resin pressure.

The compressibility and permeability of the fibrous reinforcement are given by:

$$\sigma' = c V_f^d \quad \text{and} \quad K_z = a V_f^b \quad (2)$$

where K_z and V_f are the transverse permeability and the fibre volume fraction respectively. a , b , c and d are the model constants.

3.2 Identification of Models Parameters

We present an inverse method to obtain the model constants (a , b , c and d). In general, model parameters are obtained by fitting of experimental data. The deviation between the measured and the computational values is expressed by a least square error norm.

$$S(a, b, c, d) = \frac{1}{2} \sum_{i=1}^N \left[\frac{\sigma_i^c - \sigma_i^m}{\sigma_i^m} \right]^2 + \left[\frac{P_i^c - P_i^m}{P_i^m} \right]^2 \quad (3)$$

where σ_i^c and σ_i^m are the computational and the measured total stress at the i th time step. P_i^c and P_i^m are the computational and the measured pressure (at the bottom of the preform) at the i th time step. N is the number of measurements.

The model parameters $\langle a, b, c, d \rangle$ can be obtained by minimizing the function defined in Equation (3). To minimize the least square error norm, Levenberg-Marquadt method was employed as an optimization method. The computed total stress and resin pressure at the bottom of the preform are updated by changing the model parameter values iteratively through the optimization procedure.

3.3 Results and Discussion

The inverse method is applied to obtain the permeability and compressibility of the preform using the experimental data of total compaction stress and liquid pressure (Fig. 2). Fig. 3 shows the saturated permeability and compressibility obtained by the model parameters identified by the inverse method. ($a=1.4 \times 10^{-14} \text{m}^2$, $b=-7.8$, $c=8 \times 10^6 \text{Pa}$, $d=6.0$)

4 Conclusion

We proposed an experimental device and a numerical scheme to simultaneously identify the saturated permeability and the compressibility of preform in the through-thickness direction. By a single compression of the preform under a specified liquid inlet condition, we can obtain the permeability and the compressibility as a function of fiber volume fraction.

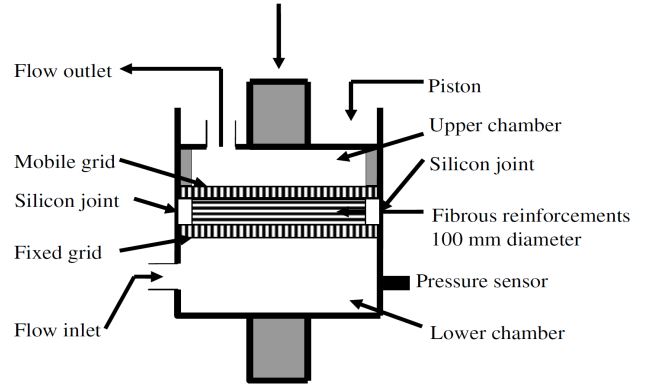


Fig.1. Schematic of the hydro-mechanical loading device.

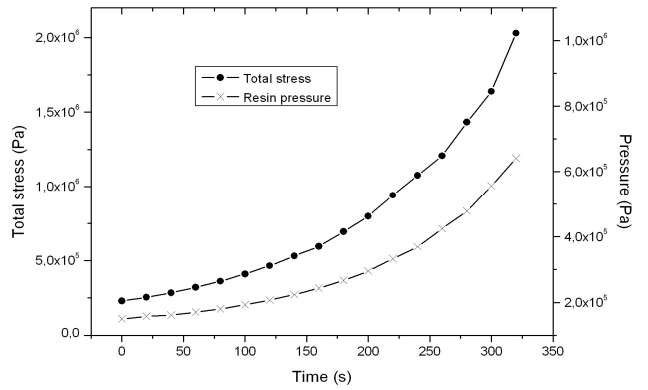


Fig.2. Experimental data of the liquid pressure and the total compaction stress.

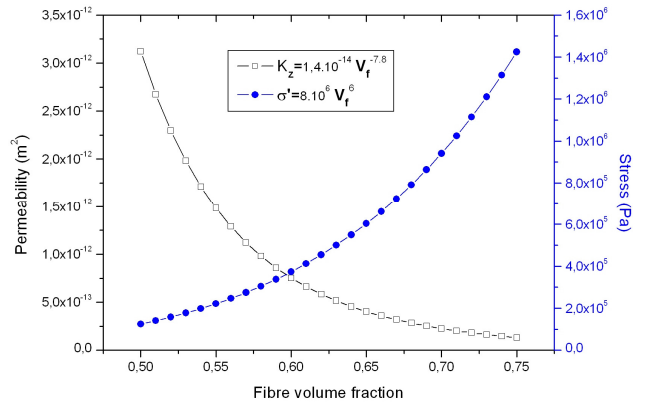


Fig.3. Preform permeability and compressibility obtained simultaneously by inverse method.

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