FINITE ELEMENT-ASSISTED ANALYSIS OF THROUGH-THICKNESS IMPREGNATION BEHAVIOR OF POLYMER COMPOSITE REINFORCEMENT TEXTILES

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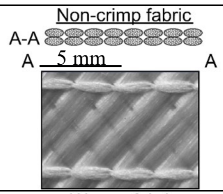
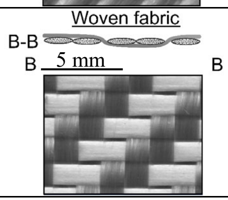
Abstract

The accurate characterization of out-of-plane permeability is crucial for the process design of composite parts involving through-thickness resin impregnation. Through-thickness permeability measurement of reinforcement textiles is however extremely challenging due to the dynamic interaction of fluid and reinforcement. In order to design the measurement equipment correctly and decide on correct processing parameters, (in particular, injection pressure for different stiffness materials at different fiber volume fractions) complimentary finite-element based simulations can be used to help analyze and understand the complex behavior, which occurs during physical experiments. The simulation results, which can only be validated through certain outputs available from the experiments, provide quantitative indications of the non-uniform through-thickness fiber volume fraction distribution (not possible to measure via experiments) and therefore deviations from the measurement target fiber volume fraction. In this work, this methodology is used to analyze two reinforcement materials with significantly different compaction and permeability characteristics to provide possible insights into differences between saturated and unsaturated permeability measurements. The tests were carried out using two different glass fiber reinforcement textiles, a woven fabric (WF) and a non-crimp fabric (NCF) chosen due to their significant differences in permeability and compaction behavior. The details of the two materials along with their geometric configurations are listed in Table 1. The test fluid used for the permeability measurements was rape-seed oil with a density of 916 kg/m3 and a constant average viscosity of 79.07 (±-2.21) mPa·s, at the target test temperature of 20°C.

Table 1. Specifications of the glass fiber reinforcement textiles used in the experimental investigations.

Manufacturer	**Designation**	**Area weight**	**Textile type**	**Architecture**	**Structure**
Saertex	X-E-444	444 g/m²	NCF	45° 217 g/m² E-Glass 300 tex 90° 2 g/m² E-Glass 68 tex 0° 2 g/m² E-Glass 68 tex -45° 217 g/m² E-Glass 300 tex	
Hexcel	HexForce 01202	290 g/m²	WF (2x2 twill)	0° 145 g/m² 90° 145 g/m²	

The "*Virtual HykoPerm*" is an advanced 3D simulation model of the IVW through-thickness permeability measurement cell created in ESI's Visual-RTM (PAM-RTM) software. It consists of over 13 million elements and contains detailed information regarding the equipment geometry, its various sensor positions and replicates the real equipment's working principle. The model consists of 139 individual parts, most of which are currently defined as rigid bodies leaving the opportunity in the future to calculate loads, stresses as well as deflections on the various components themselves, which occur during (and may affect) the experiment. By depicting the system in whole, unwanted influences such as that of the distribution media or other working elements of the system on the uniformity of the injection could also be investigated and accounted for. In the current work however, the focus lies on examining hydrodynamic compaction effects of two different glass fiber reinforcement materials, when 6 mm thick textile stack specimens are injected uniformly through their thickness with a viscous test fluid (rape-seed oil). The simulation model uses the fluid-structure-interaction capabilities of Visual-RTM, which couples Darcy's law and solid mechanics to assess deformation in both unsaturated and saturated porous media. In this case, the porous media is the fiber reinforcement textile sample and its resulting "*hydrodynamic compaction*" behavior is the phenomena of interest. Figure 1 shows the results of a test on one of the investigated materials, a Saertex444 non-crimp fabric, with an initial fiber volume content of 49 %. The material is initially dry and impregnated with an injection pressure of 0.45. Following saturation, the injection pressure is increased in a step-wise manner. The graph to the right shows the development of the fiber volume fraction distribution at different elements over the entire thickness of the sample. It can be seen that the hydrodynamic compaction (fiber volume fraction inhomogeneity) becomes more and more prominent with increasing fluid injection pressure. The model on the left side (and zoom-in image) show the state of the simulation model at t = 24.0 seconds of the experiment, i.e. in a saturated state. The velocity vectors visualize the fluid flow into the device, while color contours visualize the through-thickness variation of the fiber volume fraction in the specimen, due to hydrodynamic compaction effects.

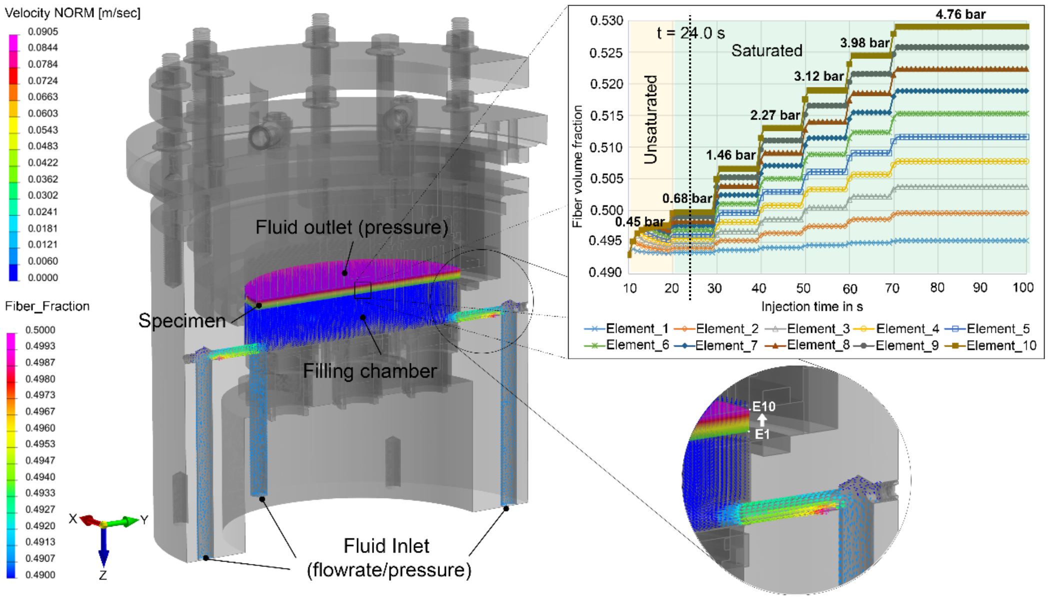


Figure 1. Cross-section plot of the advanced finite element simulation model "*Virtual HykoPerm*" showing the fluid flow vectors and z-direction V_F contours of the reinforcement stack during a through-thickness permeability measurement.

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