Accounting for capillary effects in finite element simulation of impregnation in fibrous media

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ABSTRACT

Capillarity is the ability of a liquid to maintain contact with a solid substrate without the help of any external force. This phenomenon occurs when three phases are in presence, here a liquid, a gas and a solid, due to the surface energies of each interface. Capillary effects are involved in many areas of engineering. For example, they can affect significantly the manufacture of structural composites by liquid resin infusion processes [1]. In this context, this work aims to simulate capillary flows in a fibrous microstructure using a finite element (FE) method and at the fibre scale.

Fibres are considered as rigid and are represented by holes in the 2D computational domain. It is assumed that both liquid and gas behave as Newtonian and incompressible fluids. The capillary flow is then described in terms of velocity and pressure by Stokes equations supplemented with appropriate conditions on the liquid - gas, liquid - solid and gas - solid interfaces, and importantly, the static mechanical equilibrium of the triple junctions. All these conditions are treated as Neumann conditions in the weak form of the equations. The FE strategy adopted here, detailed in [2, 3], is based on a continuous and piecewise linear approximation of both velocity and pressure fields on an unstructured simplicial mesh. The discrete formulation is then stabilised by using a Variational Multi-Scale method. In addition, the discrete pressure space is enriched in the elements cut by the liquid-gas interface, in order to accurately capture the pressure jump. Moreover, the CFL-like constraint on the capillary time-step, is overcome by considering an interfacial shear stress that dissipates surface energy and prevents the propagation of capillary waves. Finally, the moving interfaces are captured through a level-set methodology. In a staggered procedures, two algorithms are investigated to couple weakly or strongly Stokes (the flow) and level-set (the interface geometry) solvers.

Two types of circular fibre microstructures are investigated: hexagonal arrangements and arrangements generated by a stochastic algorithm, with a fibre volume fraction equal to 52% and 45% respectively. The saturated permeability of these structures is first computed numerically. For the hexagonal structure, the results are in good accordance with the literature models (Gerbart model and Kozeni-Carman model). Next, a method is proposed to calculate the capillary pressure, a quantity that corresponds to an average of the capillary effects, and which can be taken into account at an upper scale, in the Darcy's equations for example [1].

REFERENCES

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