Numerical simulation of coupled fluid-solid problems during filling and post-filling stages of porous media: application to composite manufacturing processes

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ABSTRACT

Specific technologies such as Liquid Resin Infusion (LRI) processes have been developed in the aeronautics industry to manufacture high performance composites with the quality required (low void contents, high fiber volume fraction. . .) for primary aircraft parts. The aim of the present work is to simulate theses processes which consist in coupling fluid-solid mechanics at different stages. First, the filling step consists in infusing or impregnating a stacking of fibrous preforms (assimilated to orthotropic porous media) with a thermo-reactive liquid resin (the fluid) under a vacuum pressure. During the impregnation of the porous medium, a competition between viscous and capillary effects may occur leading to the formation of porosities [1]. Then, still under vacuum pressure, the supply of fluid is cut off. Due to the porous medium deformation the fluid flow continues after the filling stage is complete as it does take a finite resting time for the pressure field to become uniform during this post-filling period. In this work, the fluid mechanics problem describes the fluid flow into a distribution medium and then into the porous medium. Hence we have to deal with the coupling of Stokes and Darcy equations to describe the filling step where capillary forces may act as a complementary pressure discontinuity on the flow front. The fluid flow is coupled with the non-linear solid mechanics problem which describes the finite deformations undergone by the preforms due to both an external mechanical pressure applied during the compaction stage and the fluid pressure acting in the porous medium. The Stokes-Darcy coupled problem is solved using a Finite Element Method (FEM) based on a linear approximation for the velocity and the pressure (P1-P1). A pressure enriched space may be locally introduced at the fluid interface in order to capture the pressure discontinuity due to capillary forces. Then, a Variational Multiscale Stabilization (VMS) method is selected to take into account the subgrid effects on the finite element solution and hence ensure the consistency of the finite element formulation. The fluid front is represented by a level set function, convected with the fluid velocity thanks to a finite element scheme stabilized with a Streamline-Upwind/Petrov-Galerkin (SUPG) method [1]. The coupled problem is validated both on numerous tests cases and various 2D and 3D simulations. Comparisons with existing experimental measurement are also discussed. Finally, the governing equations to model the post-filling flow, in which the porous medium is allowed to deform, are based on a poromechanics approach with saturated medium assumptions [2]. The coupled fluid-solid mechanics is developed to simulate the time dependent pressure distribution during the post-filling stage. The model is implemented using a FEM. The change in pressure distribution inside the porous medium during the post-filling stage is discussed for different conditions (drained and undrained conditions).

REFERENCES

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