MULTI-SCALE AND MULTI-PHYSIC APPROACH OF LCM PROCESSES FOR FLOW PREDICTION AND PREFORMS SHOWING VERY LOW PERMEABILITY.

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The aim of the present work is to propose a multiscale approach of the flow of resin inside fibrous reinforcements. At the macroscale, a multi-physical model based on the coupling between Stokes and Darcy (permeability down to 10^{-15} m²) flows and the fluid/structure interaction due to the resin flow in the highly compressible preform submitted to large deformation is considered. This Stokes-Darcy coupled problem is modelled here by using a monolithic approach which consists in using one single mesh for both Stokes and Darcy problems. A mixed velocity-pressure formulation stabilized by a Variational Multi-Scale (VMS) method has been used to stabilize the Stokes-Darcy discrete problem, namely the Algebraic Sub-Grid Scale (ASGS) method which involves stabilization terms for both velocity and pressure [1,2]. In addition, a specificity of this modelling is the order of permeability which is very low (down to $10e^{-15}$ m²) and its orthotropy (permeability tensor) that leads to use specific stabilization tensor to simulate flows in the porous medium. A level set method is also used to represent the Stokes-Darcy interface and to capture the moving flow front.

To improve the stability and the quality of numerical results, interfaces (i.e. Stokes-Darcy interface) given by the zero iso-surface of a level-set function are locally reconstructed. This method, called SLR (Surface Local Reconstruction) method consists in approximating linearly this surface by a segment in 2D or a plane in 3D for each element cut by the interface [3]. Once the interface has been locally reconstructed, the contribution of the element to surface and volume integrals can be explicitly computed by Gaussian integration. It has to be pointed out that this approach is local to each element, the whole surface is never reconstructed and no additional degrees of freedom are added. Finally, porous medium deformations (preforms deformations) are represented through an Updated Lagrangian formulation for large deformations. The dry preform behaviour is modelled by a non-linear orthotropic elastic response given by experimental measurements. The presence of the fluid (resin) in wet preforms is accounted for through its hydrostatic pressure using a Terzaghi's equivalent model [4]. This coupled flow formulation is then validated both on test cases and using the method of manufactured solutions. Various 2D and 3D simulations were also performed.

At the microscale, a triple junction between three physical domains is considered. The considered domains are typically a liquid, a gas and a solid. The solid domain is assumed to be a rigid substrate. The main novelty of the approach presented here is to consider the Laplace's law not only over the liquid - gas interface, but also over the liquid - solid and gas - solid interfaces. Hence the triple line motion is not driven by the curvature, but by the jump of the surface tension parameter. For taking into account this discontinuity, the Laplace's law is expressed in a weak form [3], which makes the equilibrium at the meeting point a natural boundary condition. From a practical point of view, both liquid and gas are assumed to be incompressible Newtonian fluids with different viscosities. Inertia effects are neglected, and the resulting Stokes's equations are solved by using finite elements, linear both in velocity and pressure, stabilised by a variational multiscale method. Note that a dissipation term is taken proportional to the velocity in order to take into account dynamic conditions and get closer to dynamic contact angles simulation. This methodology, combined with a mesh adaptation technique, allows the 3D-simulation of droplet spreading or of capillary-driven flows when the curvature is not described. This will open a path to simulate capillarity on new morphologies, considering sharp angles or non-cylindrical fibres.

The main objective of an industrial chair started in 2015 (Figure 1) is to merge the two approaches in order to take into account capillary effects in reinforcements that show a very low permeability. The first step will be to define capillary pressures (or capillary stress) in the reinforcement main directions [5] and then to predict the flow at micro and mesoscales to be freed from the definition of a permeability.

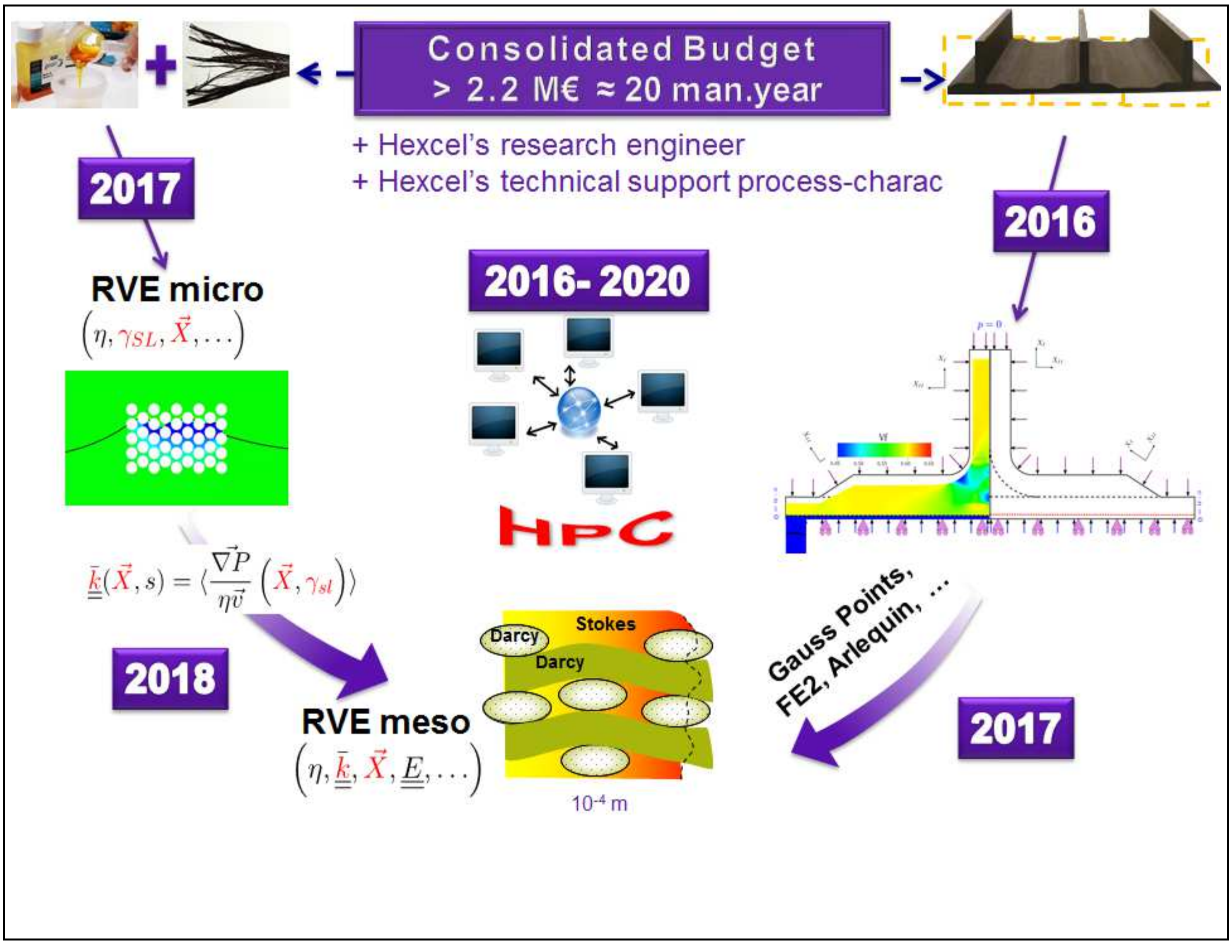

Figure 1: *Aim of the HEXCEL industrial chair.*

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