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Transient state impregnation simulation of dual scale porosity fibrous mediums

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Abstract. The RTM/LRI-like processes have gained popularity in the preparation of fibre-reinforced polymer matrix composites because of their high efficiency, low pollution and good reproducibility. With the industry willing to produce more and more complex shape parts with a high fiber volume fraction, void formation is still an open problem in term of prediction. Furthermore, simulation of infusion processes with high permeability draining mediums and very low permeability fabrics is an issue. In this paper, we propose to apply the Constrained Natural Element Method to the resolution of both Stokes and Brinkman equations with flow front progression.

Keywords: infusion, injection, simulation, composite, flow front, stokes, brinkman, NEM, LCM, FE

PACS: 83.50.Uv, 83.80.Ab, 81.05.Qk

INTRODUCTION

In the last decade, the aeronautic (and more generally transportation) industry has shown a growing interest for light-RTM processes like LRI. However, due to some specificities of this process, existing simulation tools do not give as accurate results of resin front progression as they do with classical RTM. Indeed, the diffusion media used in LRI processe gives rise to a complex numerical problem [1] that is also experienced in any impregnation process when looking at the meso scale problem where dual scale porous medium comes into play. The figure bellows represents the interface between either two brinkman regions or a stokes/brinkman interface. When the mean speeds in these two regions differ by two or three (or more) orders of magnitude, both the tracking of the front and the difficulty to keep numerical error bellow a reasonable level tend to be problematic issues. This is quite true when one

tries to solve this problem with classical FE formulation but we will show in this work that using a NEM[2] method considerably eases these numerical issues.

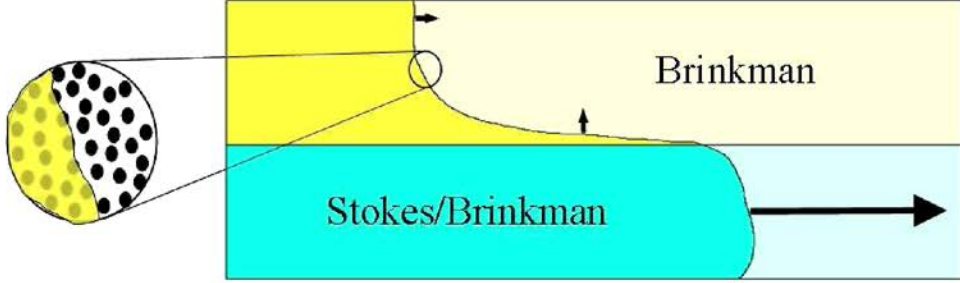


FIGURE 1. typical fluid front during impregnation of a dual scale porous medium.

NUMERICAL METHOD AND GOVERNING EQUATIONS

The method described before has been used to solve both Stokes and Brinkman equations in the case of flow front in porous medium.

$$\begin{aligned} \nabla \cdot v &= 0 \\ \nabla p &= \mu \Delta v \end{aligned} \quad \text{in the Stokes regions} \quad (1)$$

$$\begin{aligned} \nabla \cdot \langle v \rangle &= 0 \\ \nabla \langle p \rangle^f &= \tilde{\mu} \Delta \langle v \rangle - \mu K^{-1} \cdot \langle v \rangle \end{aligned} \quad \text{in the Brinkman regions} \quad (2)$$

Where $\langle v \rangle$ and $\langle p \rangle^f$ respectively denote the phase-averaged velocity and intrinsic phase-averaged pressure of the fluid, $\tilde{\mu}$ an effective viscosity and K^{-1} the homogenized permeability of the Brinkman region. In this paper, $\mu = \tilde{\mu}$.

To solve mixed formulation (speed, pressure) problems together with incompressibility condition, one has to check whether his formulation does respect the LBB numerical test. Any combination of Sibson, Laplace and Thiessen shape function for speed and pressure (Sibson/Sibson, Sibson/Thiessen, ...) do not really pass this test. However, some give much better results than others. The resulting solution for our weak formulation when using the worst of these combinations is a spurious pressure field resulting in a non-physical velocity field for some time-step. In order to overcome this difficulty, we also implemented an enriched version of NEM[4]: the bubble NEM. This improvement allows to enrich the velocity shape functions support so that the numerical scheme does pass the LBB numerical test. The resulting pressure field is not oscillating any more nor is the velocity one unphysical. Another issue in this kind of simulation is how the resin front is tracked. We chose to use a direct progressing front method where the front position is updated as function of it's velocity and time step.

The figure below illustrates a typical configuration where we have a macro-porosity (Stokes channel in blue) next to a fiber tow (Brinkman region in red). It represents the two constrained Voronoï diagrams of the two zones.

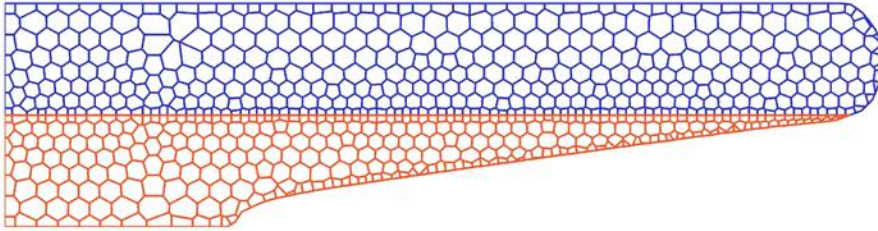


FIGURE 2. constrained Voronoï diagrams of the Stokes and Brinkman regions.

FIRST RESULTS

Using the above-described numerical method to resolve the weak formulation problem of the Stokes and Brinkman equations, we obtained the following results where we prescribed zero velocity at the upper and lower boundaries and prescribed pressure at the inlet.

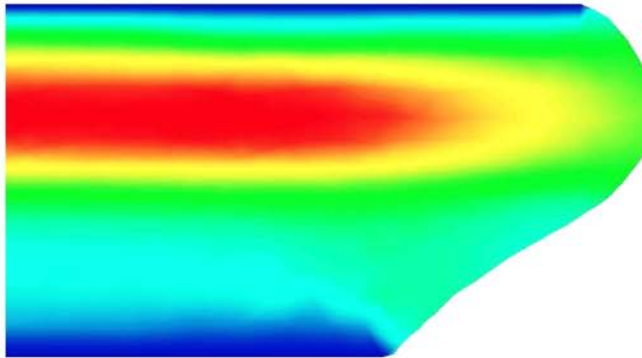


FIGURE 3. magnitude of the velocity field in both regions (Stokes up and Brinkman down) during propagation of the resin front

In this framework, it is easy to introduce other boundary conditions such as periodic or symmetric. We also added the possibility to take into account the capillary pressure which plays an important role in the Brinkman region due to the small size of the pores which may give rise to strong additional pressure (positive or negative). One can also take into account the capillary pressure occurring in the Stokes region as function of the flow front radius. The Figures bellows show the influence of the capillary pressure in the Brinkman region together with upper and lower symmetric boundary conditions. The left picture illustrates the evolution of the front at the very beginning

of the injection/infusion process when the injection pressure is much more important than the capillary one (macro-porosity driven injection). The right picture shows a region of the part quite far from the injection point where the capillary pressure begins to be as much important as the injection one. This figure illustrates the modification of impregnation regime from a macro-porosity driven injection to a micro-porosity driven one.

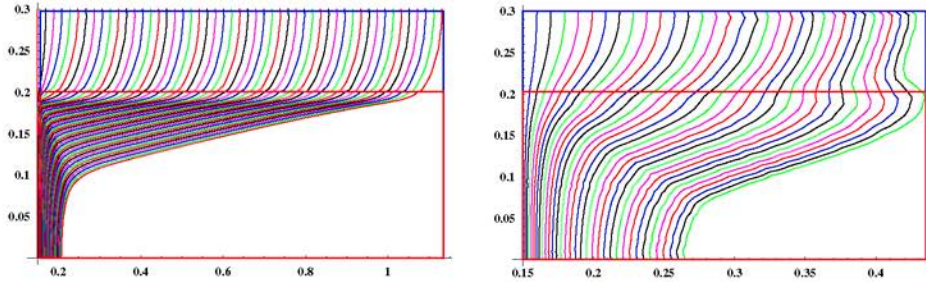


FIGURE 4. position of the flow front vs time for two different set of parameters (Stokes region in the blue and Brinkman region in the red box)

CONCLUSION

This code allowed us to investigate the influence of various injection/infusion process parameters like the capillary pressure, boundary conditions, saturation ... It is still being developed in order to implement further numerical tools like a numerical error based mesh refinement ... Furthermore, the simulation of flow front progression with sharp variation of velocity between two regions (2,3 or more orders of magnitude) is a complex problem which is still not properly treated by commercial codes. In particular in the case of the infusion process where the draining medium is much more permeable than the underlying fabric or at the mesoscale (permeability of the tows versus permeability of the macro porosities), we believe that this kind of approach can be used to gain some understanding in the way the resin is progressing at the mesoscale or may help to resolve infusion problems in specific cases where commercial codes are still not able to predict accurately enough the infusion process.

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