AN EFFICIENT SCHEME TO MODEL RESIN FLOW IN A DEFORMABLE POROUS MEDIA USING RTM INFUSION SIMULATION

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Introduction

In Liquid Composite Molding (LCM) process, complete saturation of reinforcement with resin during the injection step is crucial for successful part manufacturing. To assist with this task, flow simulation software has been successfully developed and tested to help with flow predictions during Resin Transfer Molding (RTM) process [1-2]. The model has also been widely used for most other LCM infusion processes variations, despite the fact that in majority of these processes the mold is compliant. Therefore, preform thickness and porosity change during the flow are ignored and in most cases the comparison of flow front motion with experiments tends to be reasonable. This is generally attributed to the use of "VARTM" permeability and its measurement, which indirectly provides a correction for the change of fiber volume fraction and permeability during filling.

To address the infusion into compliant preform, several approaches have been followed. First approach was to neglect the deformation and assume that it is small and will not influence the dynamics of flow. This is simple but while the comparisons with experiments are encouraging, the accuracy of such approach has been so far uncertain.

The second approach is to develop a specialized code for coupled deformation and pressure field. This approach suffers from two drawbacks. First, it tends to be computationally inefficient. Second, the necessary material characterization is rather demanding as the compaction behaviour is complex. So far, the latter approach was only partially successful.

The third possible approach: to use the RTM solver but to apply correctional steps to address the changes in fiber volume fraction and thickness encountered due to the use of compliant molds. This approach has been previously attempted [3] but is computationally expensive which precludes it use in flow simulations for optimization and control when molding complex geometries.

Approach

Two issues are addressed in this work. First a methodology to address the physics of flow within deformable media maintaining computational efficiency is introduced. This requires certain assumptions concerning the constitutive material behaviour: as the usual RTM models deal with explicit, quasi-steady solution, the viscous delay for thickness (fiber volume fraction) change must be introduced. This can be either based on material behaviour as characterized, or artificially introduced if the characterization works with "elastic" preform. The magnitude of this delay is bounded by a requirement for numerical stability and is examined herein. The resin source or sink is introduced over the entire filled domain to preserve resin volume within the changing geometry. Lastly, the preform parameters – porosity and permeability – have to be modified to reflect any change in thickness.

As any change of material parameters during the filling simulation slows down the solution algorithm, restricting these changes to certain time steps can prove advantageous to performance without significant deterioration in accuracy. On the other hand, iterating the material parameters within each time step [3] can maintain the simulation accuracy. The contribution examines these two possibilities within the framework of LIMS simulation package [4].

While a judicious analysis may provide better computational efficiency than the other approaches, the constant permeability/thickness computation remains the most efficient way for flow prediction. So far, the ad-hoc assumption for such modelling was that as long as permeability is measured in an experiment for VARTM setting with VARTM infusion, the flow predictions will be "sufficiently" accurate. This has been confirmed by laboratory experiments and shop floor manufacturing experience.

Using the developed model, the paper analyses this assumption. VARTM experiment for deformable preform is simulated and proper constant equivalent "VARTM permeability" is fitted to the simulated results. Then the simulated part filling is executed with the fully deformable model, original (fully compacted) permeability and the VARTM permeability. The result shows that even for large thickness relaxation, the equivalent VARTM permeability provides rather accurate flow predictions.

Consequently, the suggested modelling approach would be to use the equivalent constant thickness and permeability for process design and/or optimization and whenever the compaction data are not available but the permeability was measured by VARTM experiment. The model with compliant preform can be executed to verify the result accuracy.

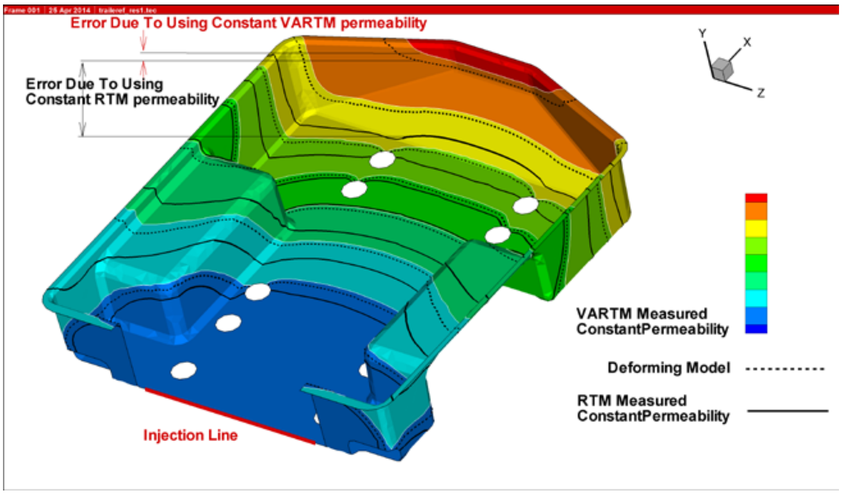

Figure 1: *Comparison of predicted flowfronts using the RTM filling simulation with permeability measured with VARTM methodology (colour contours), permeability measured with RTM experiment (solid lines) and fully deformable model (dashed lines). Maximal change of preform thickness set to 10%.*

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References

[1] M. Bruschke, S.G.Advani, "Finite Element/Control Volume Approach to Mold Filling in Anisotropic Porous Media," Polymer. Composites 11, pages 398-405, 1990

[2] F. Trochu, R. Gauvin, D.M. Gao, "Numerical Analysis of the Resin Transfer Molding Process by the Finite Element Method." *Advances in Polymer Technology* 12(4), pages 329-342, 1993

[3] 19. N.C. Correia, F. Robitaille, A.C. Long, C.D. Rudd, P. Simacek, S.G. Advani, "Use of Resin Transfer Molding Simulation to Predict Flow, Saturation and Compaction in the Vartm Process," *Journal of Fluids Engineering*, 126(2), 2004

[4] P. Simacek, S.G. Advani, "Desirable Features in Mold Filling Simulations for Liquid Composite Molding Processes," *Polymer Composites*, 25(4) , pages 355-367, 2004