Flow Analysis Software for RTM: design and applications

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Keywords: *flow simulation, flow modelling, optimization, resin transfer moulding, resin infusion.*

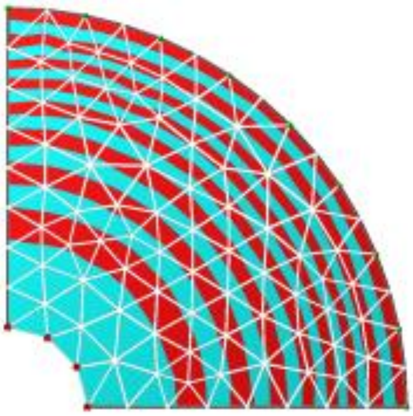
Introduction

The main goal of the development and implementation of flow analysis software is to create a tool for part designers and manufacturers, to design of a robust production method for high quality composite parts that meet structural, visual, and most important, economical requirements. In the particular case of an injection moulding process, this translates into designing an injection strategy and – if applicable – choosing flow aids, that results in a process which guarantees low void content (no dry spots) and has low sensitivity for variations in preforming and process parameters. To meet our user's goals, we implemented software that is extremely fast, very accurate and highly robust.

Modelling the RTM process and implementation in software

At the core of our model for Liquid Injection Moulding of composites is Darcy's Law, extended to three dimensions. Solving this equation is not particularly difficult, and our implementation uses a combined Finite Element/Control Volume Method. As was shown in [1] for 1D linear line elements and 2D linear triangular shell elements, both FEM and CVM formulations are equivalent for the discretisation of the pressure and velocity fields. This result extends to 3D for the linear tetrahedral element. For the progression of the flow front, the VOF method is used, which allows for a very efficient and accurate implementation.

Table 1: *Simulation of injection of a quarter disk (worst case for accuracy) The model (with 167) elements is shown at the left, the table lists the resulting injection times, error compared to the analytical solution (1411 s) and the calculation time on a laptop with Windows 7 64-bit, Intel i7-2640M CPU at 2.8 GHz and 8GB RAM. Model parameters: inner radius 200 mm, outer radius 1000 mm, thickness 1 mm, fibre/volume fraction 50% and permeability 1e-9 m2 (isotropic) [3].*



Elements	*Result*	*Rel. Error*	*Calc. time*
57	1381 s	2.1%	<< 1 s
167	1410 s	0.07%	<< 1 s
696	1409 s	0.14%	< 1 s
1008	1411 s	-	1 s
3868	1411 s	-	4 s

For the calculation of temperature and curing history [2], we use a streamline upwind method for the convection terms. The solver, which exploits the structure of the stiffness matrix, is very fast: non-isothermal calculations with curing typically take only twice as much calculation time as an isothermal run.

Designing injection strategies that work, adding SALT

Any injection strategy consists of one or more of the following types: point injection, edge injection or peripheral injection. Comparing those three basic types [4] leads to the unavoidable conclusion that peripheral injection is preferred because it results in the shortest injection time and the smallest variation in flow front progression speed. In practice however, mould construction limits the possibilities and the designer should be able to compare different strategies in short time to arrive at the best trade-off between complexity, robustness and cost of the manufacturing process. Part of this design process can be automated (sensitivity analysis, location of ports), and we implemented a scripting language to support optimization, called 'SALT', which has multiprocessing as a core capability.

Optimization complements exploration of the possibilities. Injection strategies should not result in dry spots and the major cause (apart from choosing a wrong strategy) is race tracking. Next major cause for voids is stagnation of flow and the opposite is true: ensuring that the resin flows everywhere will minimize void content.

Selecting consumables: flow media and membranes

For the infusion of larger parts like wind turbine blades, boat hulls and bridges, one-sided moulds with a flexible bag are used because a double sided stiff mould becomes impractical. The consequence is that the only way to create a pressure difference is to draw a vacuum which limits the pressure gradient available to drive the resin flow. In addition, if there is a considerable height difference, part of the vacuum is also required to lift the resin. Flow media, like meshes and grooved cores, can assist to speed up the resin flow but practical experience learns that the ratio of the permeability of the reinforcement and flow medium is limited, otherwise there is a high risk for voids and (local) air traps. The other limit is the height of parts which can be infused in a single shot. In theory, vacuum is able to lift a resin column of almost 10 meters, but in practice this limit is about 6 meters because a pressure gradient is required to make the resin flow to the highest point. We eliminated this barrier by designing a 2-step process, which consists of two separate shots under a single bag in continuous reinforcement, and creation of a 'perfect' weld line using VAP membrane and an arrangement of vacuum and feeding lines.

Conclusion and future work

An extension to full 3D, tetrahedral elements that can be freely combined with the shell and line elements, is about to be released. In combination with the very fast RTM-Worx solver and a completely new 3D mesh generator that can generate very coarse meshes, the software will allow fast design of injection strategies. Under the control of SALT, the speed and accuracy is a first requirement to make optimization feasible: one of the target applications is real-time process monitoring, adjusting the model on-the-fly for permeability variations.

References

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