MOLD FILLING SIMULATION OF A PRESSURE CONTROLLED RESIN TRANSFER MOLDING (PC-RTM) PROCESS – METHOD AND APPLICATION

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Introduction

Structural components made of continuous fiber reinforced plastics are increasingly demanded by the automotive industry. To produce those parts economically, a fast, robust and highly automated process is needed. Because of their high automation potential, Compression Resin Transfer Molding (CRTM) processes are increasingly investigated. In a CRTM process, foam cores can be embedded into the preform before resin infiltration. In this case, the cavity pressure must not exceed a specific limit to avoid infiltration or crushing of the core material [1]. This limit can be assured by a pressure-controlled-RTM (PC-RTM) process, where the pressure is controlled by adjusting the cavity height allowing a significant increase of permeability while the resin infiltrates the preform with a high constant resin mass flow during injection. Pressure control in RTM was introduced before [2, 3] and allows a fast manufacturing with defined cavity pressure in contrast to traditional high-pressure RTM processes.

Method

Figure 1 shows the three relevant PC-RTM process steps. In step 1, resin is injected at a constant flow rate and as a result the cavity pressure increases continuously until the predefined pressure limit is reached. Subsequently, in step 2, the press opens the mold gap to increase the preform permeability to keep the cavity pressure constant until injection end. During the pressure-controlled compression (step 3), the mold gap is closed by the press to fully impregnate the preform and obtain the part thickness. PC-RTM allows the use of cost-efficient but pressure sensitive foam cores in large, complex FRPs. The process combines short cycle times with controlled processing conditions to prevent foam damage by resin pressure.

Numerical mold filling simulations can predict the infiltration behavior and avoid expensive experimental investigations. As there is no state-of-the-art method available to model PC-RTM, a method to simulate conventional RTM mold filling using a three-dimensional finite-volume formulation [4] was extended to allow for a moving mesh to account for the change of cavity height during the process. Depending on the cavity height, fiber volume fraction and therefore permeability changes during the process, which is also implemented in the simulation model. Finally, the fluid pressure in the cavity is controlled by implementing a pressure-dependent formulation of the position of the upper mold boundary using a virtual PID element.

Verification and application

Figure 2 shows the result of a verification by comparing the simulation results to an analytical solution of a one-dimensional Darcy-flow. The simulation shows a good agreement with the analytical solution, only showing the influence of the PID-controlling.

Furthermore, an application example of a complex geometry is presented to demonstrate the numerical capability of the simulation method. Figure 3 shows the complex part geometry with inlet and outlet boundary conditions (left). The result of the evolution of the pressure at the inlet boundary and the resulting mold gap of the mold filling simulation are also shown in Figure 3 (right). At the beginning of the simulation, a mold gap of 0.5 mm is set and the pressure limit is set to 20 bar. Upon reaching the pressure limit after ca. 15 sec, the cavity starts to further open. When the injection stops after 29 sec, the pressure is held at 20 bar while the cavity closes until the part is fully infiltrated at 48 sec. The simulation method was successfully tested for this complex geometry and therefore further numerical studies to optimize the process can be conducted in future.

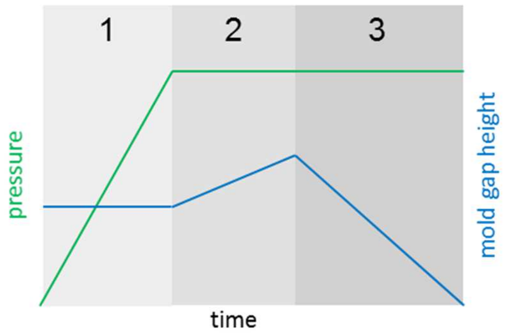

Figure 1: *Schematic representation of inlet pressure and gap height of a PC-RTM process with three stages; 1: Injection with constant mold gap; 2: Injection with a pressure controlled increase of the mold gap; 3: Pressure controlled compression to final part thickness.*

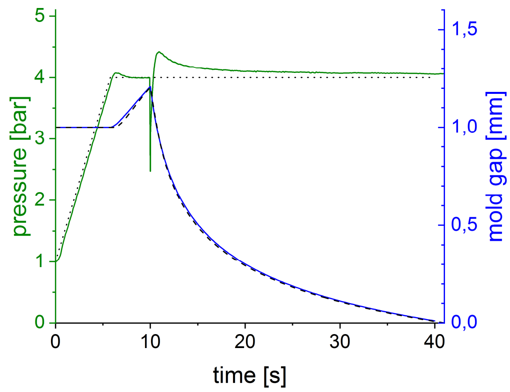

Figure 2: *Comparison of a PC-RTM simulation (continuous lines) with an analytical solution of a one-dimensional Darcy-equation (dots).*

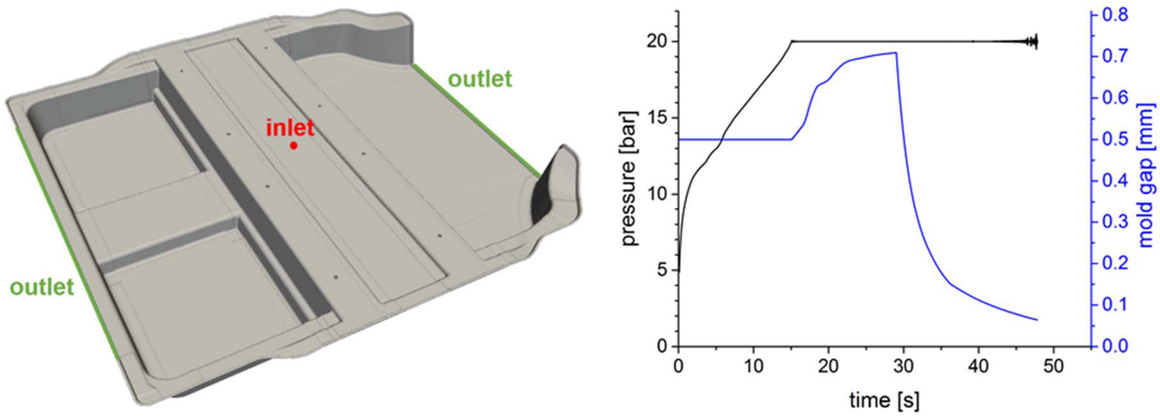

Figure 3: *Left: geometry of the application example; Right: Simulation results of pressure and mold gap during mold filling; mold gap at the beginning 0.5 mm; injection time 29 sec; maximum pressure 20 bar.*

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