# USING OPENFOAM FOR SIMULATION OF REACTIVE INJECTION MOLDING AS A NON-ISOTHERMAL COMPRESSIBLE MULTIPHASE FLOW

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## Introduction

Reactive injection molding is one of the most important processes for manufacturing dis-continuous fiber reinforced thermosets [1]. The process of mold filling significantly influences the mechanical, thermal and optical properties of the final part. Hence it is indispensable to have good process controls to achieve the high quality standards of automotive industry. To reach this standards in an early stage of development, process simulation is required. Although thermoset materials show a more complex flow behaviour, commercial software often focuses on thermoplastic injection molding and uses similar models for thermosets [1-3]. Furthermore, Commercial Software often use a Finite-Element (FE) approach, modelling a single-phase flow to reduce the calculation time by neglecting the air in the mold. The state of research therefore includes multiphase solvers modelling thermoplastic injection molding isothermal and incompressible [4].

This work presents a recently published Finite-Volume (FV) based multiphase solver, simulating polymer and air as a compressible and non-isothermal continuum [5]. The solver is implemented in the Computational-Fluid-Dynamics (CFD) toolbox OpenFOAM 4.1 and validated with experimental injection molding trials of a glass fiber reinforced phenolic resin.

## Implementations

Well known curing kinetics and viscosity models are implemented in the OpenFOAM framework to model rheological behaviour of the thermoset material [5]. To predict the fiber orientation, the work of Heinen [6] is modified to simulate multiphase flows. For modelling of multiphase flows, the Volume-of-Fluid Method (VoF) is used, where the VoF-factor $\alpha$=1 represents a Finite Volume (FV) filled with polymer and $\alpha$=0 represents a FV filled with air.

To enable mold filling, a phase-depending boundary condition (BC) for the velocity vector $\boldsymbol{U}$ is implemented, using the third party tool SWAK4FOAM. This BC allows the air to leave the system at the outlet boundary face, but acts like a wall towards the polymer. Therefore, the BC is an interpolation between a Neumann BC (for air) and a Dirichlet BC (for polymer) as function of the VoF-factor:

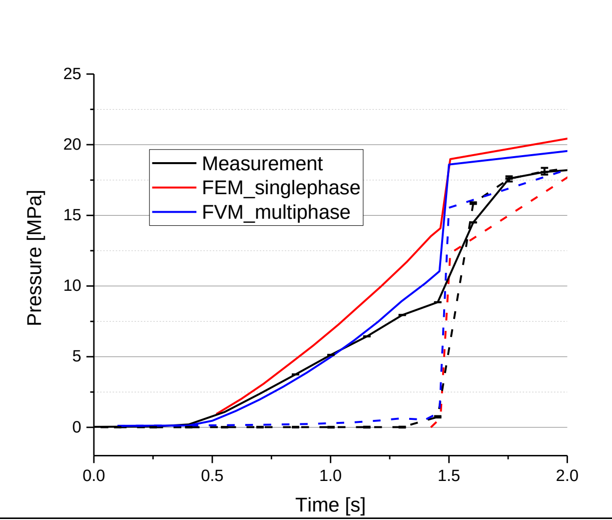
$$BC = \propto \cdot DirichletBC + (1-\alpha)\cdot NeumannBC \tag{1}$$

$$DirichletBC \overset{\text{def}}{=} \boldsymbol{U} = \begin{pmatrix}0\\0\\0\end{pmatrix} \text{ and } NeumannBC \overset{\text{def}}{=} \frac{d\boldsymbol{U}}{dt} = \begin{pmatrix}0\\0\\0\end{pmatrix}. \tag{2}$$

## Results

The developed solver is compared to experimental trials and to the commercial FE-software Moldflow 2018.1 (Figure 1). For pressure measurement, two sensors are positioned in the mold, sensor 1 right after the film gate (beginning of flow) and sensor 2 at the end of the cavity (end of flow). Detailed information about the trials, cavity, process conditions and additional trials are given in [5].

To validate the fiber orientation model, the FV-solver is compared to Moldflow 2018.1 using the Moldflow standard model (Moldflow-rotation-diffusion) on a fictitious geometry (Figure 2).



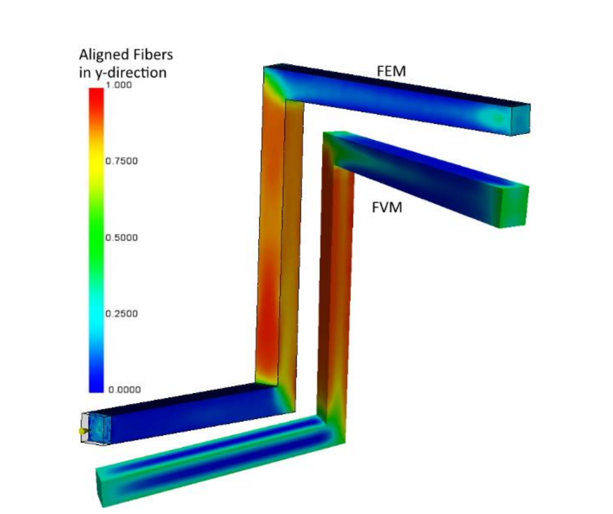




**Figure 1:** *Pressure over time for a filling speed of 137.5 cm³/s and a mold temperature of 170 °C. Comparing measurement (black), FEM (red) and FVM (blue) at sensor position 1 (solid line) and 2 (dotted line) [5].*

**Figure 2:** *Comparison of predicted fiber orientation between FEM and FVM in y-direction [5].*

Figure 1 shows the comparison of pressure data. The FV multiphase solver predicts the pressure at sensor position 1 accurately during the mold filling process (< 1.5 s). The predicted pressure rise at sensor position 2 is too fast in the FVM simulation, but fits again to the measurement shortly after 1.5 s. The FEM simulation predicts a too high pressure at position 1 in general and needs 0.5 s longer than the FV-solver until the pressure at sensor 2 fits to the measurement.

Figure 2 compares the predicted fiber orientation in y-direction. The results of the FE and FV simulation fit well to each other. In the FE simulation, the fibers align faster in the transition area.

## Discussion and Conclusions

An FV-based solver for simulation of reinforced reactive injection molding is presented. The solver can predict the pressure during mold filling, which leads to an accurate modelling of curing kinetics and hence viscosity. Furthermore, the solver predicts fiber orientation on the level of commercial software.

The open source structure of OpenFOAM offers a high potential for further investigations. Anisotropic viscosity models can be implemented in combination with viscoelastic stress modelling to achieve a better flow modelling, which is a key aspect for accurate mold filling simulation of discontinuous fiber reinforced thermoset materials.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