SIMULATION OF HEAT TRANSFER IN A CALIBRATOR FOR PROFILE EXTRUSION USING OPENFOAM

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Abstract

A new model is developed to describe the temperature discontinuity between polymer and calibrator in a coupled way using conditional volume averaging of the energy equation. The model is implemented in OpenFOAM. Subsequently, the correct implementation is tested with the Method of Manufactured Solutions (MMS) and the code is validated with various 2D benchmark cases, for which analytical solutions are available. The developed code is then applied to optimize the arrangement of cooling channels of a 3D calibrator for a complex plastic profile. The number and position of the cooling channels are varied and two conflicting objectives are identified. The optimization problem is solved using a multi-objective evolutionary algorithm. All results presented show the advantage of this model compared to uncoupled solution algorithms in terms of computational time.

Introduction

Figure 1 shows a typical extrusion line for the production of thermoplastic profiles, which consists of an extruder, a die, a calibration unit, a haul-off and a saw. The calibration/cooling zone is intended to cool down the polymer below its melting temperature, as fast and uniformly as possible, and to assure the outer-dimensions of the extrudate. However, due to the slip in velocity at the calibrator/polymer interface there is a temperature discontinuity, which can be resembled by an additional contact resistance h for heat transfer, which complicates the model development.

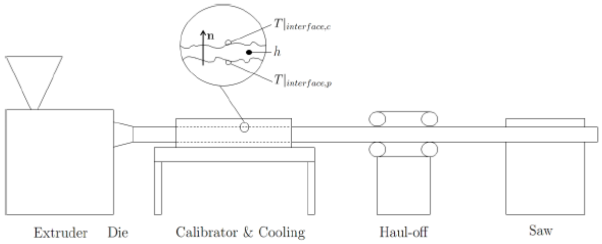

Figure 1. Schematic view of a thermoplastic profile extrusion line.

Model Development

In this work we derived a coupled equation describing the temperature both in the polymer and the calibrator, which was obtained by using conditional volume averaging and subsequent closure modeling:

$$\frac{\partial(\rho_m c_{P,m} T_m)}{\partial t} + \nabla\cdot(\mathbf{U}_m \rho_m c_{P,m} T_m) - \nabla\cdot k_m \nabla T_m = -\nabla\cdot\left[\frac{k_m\nabla\alpha_p - \alpha_p\alpha_c(\bar{k}^p-\bar{k}^c)(\frac{1}{k^p}-\frac{1}{k^c})h\mathbf{n}}{h(\frac{\alpha_p}{k^p}+\frac{\alpha_c}{k^c})+\nabla\alpha_p\cdot\mathbf{n}}\nabla T_m\cdot\mathbf{n}\right] \quad (1)$$

where T_m is temperature in the whole domain, ρ_m is the weighted density, $c_{P,m}$ denotes the weighted heat capacity, k denotes heat conductivity and α is the volume fraction, which is also used for weighing the physical properties

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indexed with a *m*. This equation was implemented in the open-source software OpenFOAM, which is based on the Finite-Volume-Method (FVM).

Validation

The correct implementation of the model is first checked with the Method of Manufactured Solutions (Roy et al., 2004). Next, the model is validated with various 2D problems, for which there are analytical solutions available. One of the results is shown in Figure 2, left. A 2D block consists of two materials with different heat conductivity that are separated by a horizontal interface. At the interface a contact resistance is assumed. The analytical solution is presented in Nóbrega et al. (2004).

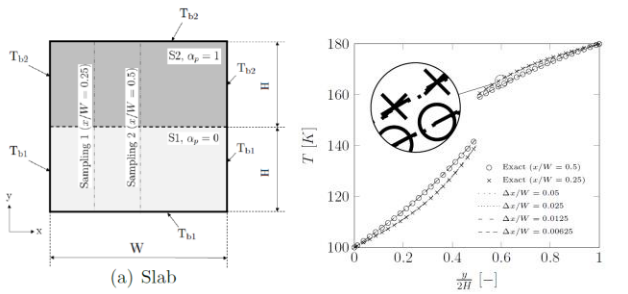

Figure 2. Left: Geometry and boundary conditions for a 2D slab problem; right: Exact and computed results.

In Figure 2, right, the results are presented and we find that we exactly predict the analytical solution. Furthermore, grid convergence is achieved.

Complex profile study

We then examined the heat transfer in a 3D calibrator for a complex profile as sketched in Figure 3.

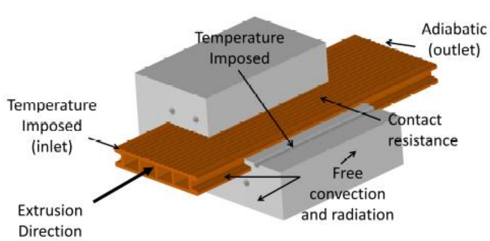

Figure 3. *Complex plastic profile with thermal boundary conditions.*

In the simulations we make use of the symmetry in order to reduce computational costs. The temperature in an axial slice at the outlet of the calibrator is shown in Figure 4 for the specific cooling channel setup shown in Figure 3. As expected, the temperature in the interior of the profile remains high, while the exterior regions are already well cooled.

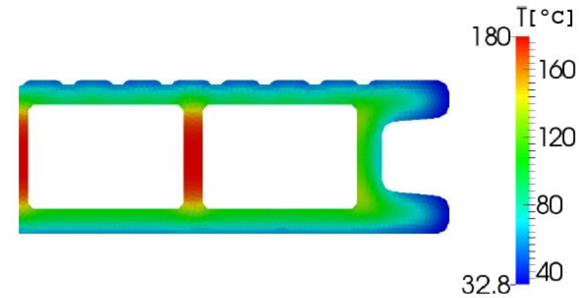

Figure 4. Temperature profile in the plastic after the calibration step.

We find that the developed model outperforms other uncoupled solution methods (Nóbrega et al., 2004) in terms of computational time.

The position and number of the cooling channel were subsequently parametrized and a multi-objective evolutionary algorithm adopted to minimize both the variation in the temperature of the profile as measured by the standard deviation of temperature and the average temperature of the profile at the outlet. We find that the two objectives are conflicting and we finally obtain the pareto-optimal solutions to this optimization problem.

References

Roy, C. J., Nelson, C. C., Smith, T. M., Ober, C. C. (2004). Verification of Euler/Navier-Stokes codes using the method of manufactured solutions. *Int. J. Numer. Meth. Fluids, 44, 599.*

Nóbrega, J. M., Carneiro, O. S., Covas, J. A., Pinho, F. T., Oliveira, P. J. (2004). Design of calibrators for extruded profiles. Part 1: modeling the thermal interchanges. *Polym. Eng. Sci., 44, 2216.*