PROCESS SIMULATION OF SHEET MOULDING COMPOUND (SMC) USING AN EXTENSIONAL VISCOSITY MODEL

M. Hohberg[1*], L. Kärger[1], A. Hrymak[2], F. Henning[1,3]

[1] *Karlsruhe Institute of Technology (KIT), Institute of Vehicle System Technology, Karlsruhe, Germany*
[2] *Western University – Chemical and Biochemical Engineering, London, Canada*
[3] *Fraunhofer Institute for Chemical Technology (ICT), Polymer Engineering, Pfinztal, Germany*
*Corresponding author (martin.hohberg@kit.edu)

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Introduction

The flow of Sheet Moulding Compound (SMC) is different compared to most other composite materials. The flow dynamic is driven by the hot mould surface and the cold initial charge material. Due to the low thermal conductivity of the compound material and the resulting temperature gradient at the mould surface, a resin-rich lubrication layer with a low viscosity arises. This lubrication layer leads to homogeneous stresses over the material thickness in the core area, resulting in typical SMC bulk flow.

Model description

To develop a model, which can describe the typical flow behaviour of the SMC flow, the lubrication layer and the deformation rate dependent core region need to be considered. For the core region, a Non-Newtonian approach is used in which the elongational and the shear viscosity are calculated separately. The elongational viscosity dominates the flow behaviour and is modelled by a power-law approach depending on the deformation rate [1] combined with an Arrhenius function to consider the thermal shear-thinning:

$$\eta_{elong}(\boldsymbol{D},T) = \eta_{ps}\left(\frac{\|\boldsymbol{D}\|}{D_0}\right)^{n-1} exp\left(-b\left(\frac{1}{T_0}-\frac{1}{T}\right)\right), \tag{1}$$

where η_{ps} represents the elongational viscosity under plane strain, **D** the deformation rate tensor, D_0 the reference deformation rate, n a power-law coefficient, and *b* a fitting parameter of the Arrhenius function. The rheological parameters were characterized by using an in-line rheological tool [2, 3]. For the subordinate shear viscosity, the Castro-Macosko model [4] is used to consider the shear and temperature dependency.

Beside the rheological stresses, the hydrostatic fluid pressure **p** needs to be considered. This pressure is calculated based on the hyperelastic specific deformation energy w_0. The pressure is a non-constitutive variable, which has to fulfill the constraint of the deformation gradient tensor **F**, with det(**F**) ≡ 1. Therefore, the hydrostatic pressure can be expressed as

$$\boldsymbol{p} = \frac{K}{2}\ln(det(\boldsymbol{F}))\,\boldsymbol{b}^{-1}, \tag{2}$$

where K is the bulk modulus and **b** the Left-Cauchy-Green tensor, which is defined as

$$\boldsymbol{b} = \boldsymbol{F}\cdot\boldsymbol{F}^T. \tag{3}$$

In this first approach, the lubrication layer is neglected and replaced by a slip boundary condition. This leads to the same velocity field, but not to the correct pressure prediction. The negligence of the hydrodynamic friction stresses can be accepted as long as simple 1D flows are calculated. For more complex flows, like in ribs, a model considering the lubrication layer by a friction approach is under development and will be presented in the future.

Since this model is describing the SMC as a one-phase fluid, an extra model for the fibre orientation is necessary. Therefore, the ARD-RSC model [5] is used to describe the fibre reorientation of long fibres (1 inch, approx. 25 mm) with a high fibre volume content (20 % - 45 %).

To implement this models and methods, the commercial simulation tool Abaqus is used. By using the Coupled-Eulerian-Lagrangian (CEL) approach [6], the fluid-structure interaction as well as large deformations can be described. In this CEL approach, the increment is divided into two steps: In the Lagrangian step, the material deformation due to the resulting stresses is calculated. In the Eulerian step, the initial mesh is restored and the material fraction is mapped onto the undeformed mesh. Therefore, the interaction between the SMC material and the tool as well as the interaction between the SMC and possible inserts or reinforcements can be predicted during the Lagrangian step.

Within the CEL method, a user defined material subroutine is used to implement the previous defined models. By using the available state variables, also the fibre orientation can be considered within this subroutine.

Simulation results

With the new developed simulation method, a reference structure is simulated. This reference structure has outer dimensions of 230 mm x 180 mm and a 15 mm high beading in the centre. The flank angles of the beading are between 40 ° and 60 °. The initial charge is placed as a preformed sheet over the whole length into the mould (cf. Figure 1 a). The fibre orientation is defined as quasi-isotropic in the initial charge plane. At the beginning of the moulding process, the material is slightly compressed before a flow occurs. While the material is flowing, the typical plug-flow can be observed with no velocity gradient through the thickness, although the mesh has several elements over the thickness (cf. Figure 1 b).

The resulting fibre orientation from the ARD-RSC model is plotted in Figure 1 on the surface of the reference structure. Due to the interpolation of the surface, the orientation distribution is slightly more inhomogeneous than in the core region. Nevertheless, the fibre orientation shows the expected reduction of the component perpendicular to the flow direction (A_{xx}) due to the flow in y-direction. As significant process-induced input, the final fibre orientation is then mapped and homogenized for structural simulation [7, 8].

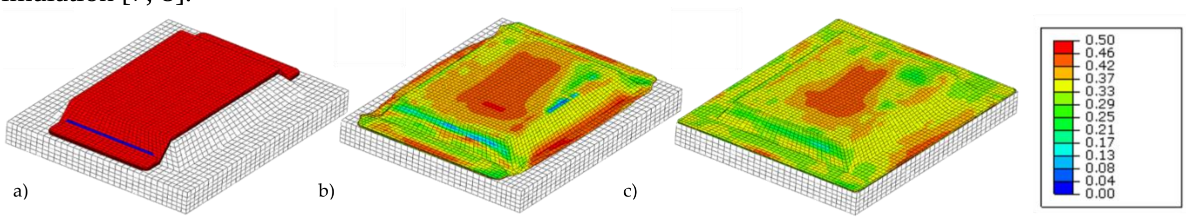

Figure 1: *SMC compression moulding of a beading geometry with the evolution of the fibre orientation component A_{xx} (a: t = 0.0 s, b: t = 2.0 s, c: t = 2.7 s)*

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