MATERIAL CHARACTERIZATION OF HIGH FIBER VOLUME CONTENT LONG FIBER REINFORCED SMC MATERIALS

M. Duhovic[1*], V. Romanenko[2], D. Schommer[1], Joachim Hausmann[1]

[1] *Institut für Verbundwerkstoffe GmbH, Erwin-Schrödinger-Str., Gebäude 58, 67663 Kaiserslautern, Germany.*
[2] *BMW Group, Ohmstraße 2, 84030 Landshut, Germany.*
*Corresponding author (miro.duhovic@ivw.uni-kl.de)

Keywords: *Material characterization; Sheet molding compounds (SMCs); Modelling and simulation.*

Introduction

The compression molding of sheet molding compounds (SMCs) is typically thought of as a fluid mechanics problem. Recently however, the use of carbon fiber based SMC materials (C-SMCs) with high fiber volume content (up to 50%) and very long carbon fibers; (up to 50 mm long) has challenged this point of view. These materials have allowed the manufacture of parts with much better structural properties than ordinary glass fiber based SMC materials. However, the rheological behavior of these types of materials cannot be characterized using standard rheometry equipment. In this work, the material characterization of two types of C-SMC materials has been carried out. The characterization is conducted using two variations of the "Pressrheometer" experiment which measures the force response of pressed SMC charges. The goal of the characterization is to provide the input data for a solid mechanics based material model to allow the compression molding simulation of C-SMC materials within general purpose finite element analysis codes such as ABAQUS® and LS-DYNA®.

SMC Rheology

Rheology is the study of flow and deformation of materials under applied forces. The most common material parameter is the viscosity, which describes the resistance of a fluid or soft solid to an applied stress. This parameter should be independent of the experimental setup and equipment used for the characterization. For a qualitative and quantitative characterization of viscosity, viscometers or rheometers are used. However, many of the shear based rheometers are not suitable for long-fiber-reinforced plastics, due to the presence of the fibers [1]. A summary of the most common procedures used to characterize the rheology of long fiber reinforced compounds is presented in Table 1. The first row shows experimental setups which can be characterized by their "squeeze flow". These types of so-called "press- rheometers" differ by inducing either a 1D or 2D flow of the material. In the second row, the plate to plate rheometer, a special type of rotational rheometer and the spiral rheometer developed by Rabinovich [2] are two further possibilities.

Table 1: *Schematic overview of procedures used for the characterization of long fiber reinforced molding compounds.*

Circular (open)	*Plate open (single/double sided)*	*Plate (closed)*

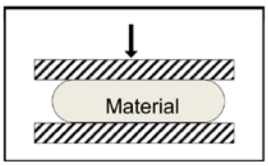
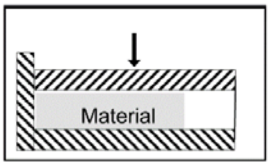
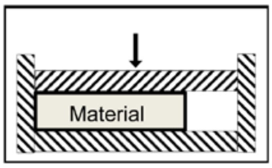
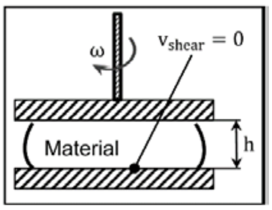
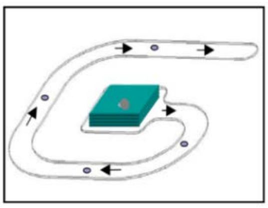

		

Plate-Plate	*Spiral*	
		

The simplest of all these test set-ups is the open circular plate arrangement, whereby the material is positioned in the middle of the plates and flows out laterally unhindered when pressed. The upper plate moves at a defined speed or force. This set-up is based on the basic work done by Lee et al. [3]. Two different configurations allow the pressing to be performed at either a constant cross-sectional area [4] or at constant volume [5]. At constant volume, flow fronts of the individual layers can be visualized [6, 7] by separately coloring the layers prior to pressing [8]. The samples may be circular or rectangular. Using a constant cross-sectional area, material models for press simulation are better calibrated. In addition, pressure sensors can be incorporated along the radius of the tooling [4, 9], which allow the strain and shear flow characteristics of the SMC material to be characterized. Compared with the other press rheometers, this variant has the advantage that the flow processes can be documented during the pressing process via video or photo recordings. Engmann et al. [10] give a good overview of the mathematical description of the squeeze-flow in the press rheometer for different rheological model assumptions.

Sample Press Rheometry Results

Figure 1 (left) shows the characterization results from an open circular plate constant volume press rheometry experiment for a structural C-SMC material (6 layers) at typical part processing conditions. The material is placed into the press at room temperature (20°C) and is pressed between tooling plates heated to 145°C. A press closing speed of 3 mm/s and decreasing plate closing distances (short shots) are used. The dashed square in the center shows the initial stack position. The markers represent the outlines of the average of 3 flow front experiments for each short shot. Together with the press force curves of the constant area press rheometry experiments, Figure 1 (right), the necessary material model data can be extracted and also validated.

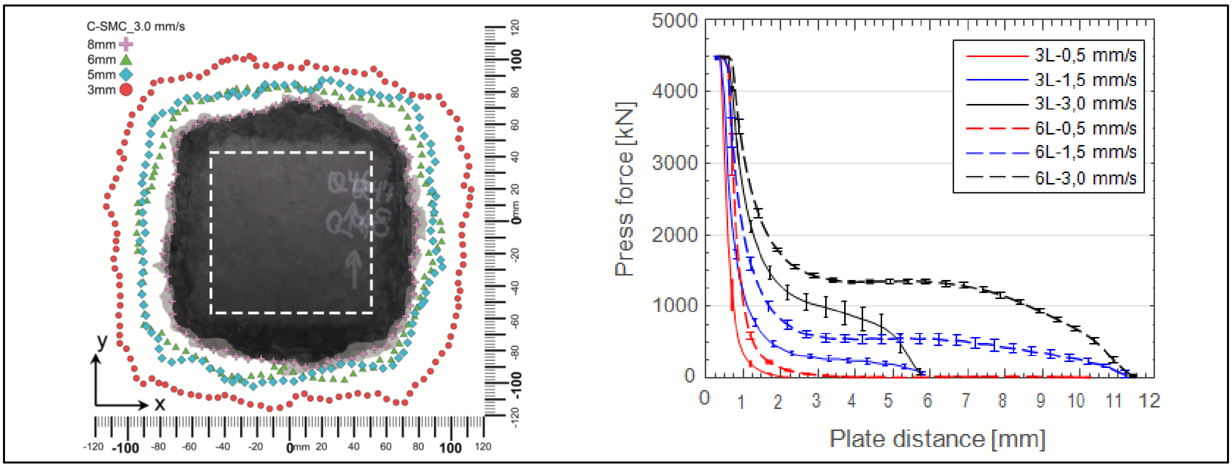


Figure 1: *Averaged flow front profiles for different tool closing distances (8, 6, 5 and 3mm) during pressing at 3mm / s (left) and corresponding constant area press force vs. closing distance curves(3 & 6 layers) at different closing speeds (right) .*

References

[1] Orgéas, L., P. Dumont, L. Nicolais [2011]: Sheet Molding Compounds. In Wiley Encyclopedia of Composites.

[2] Rabinovich, M., K. L. Olsavsky, B. Leach, M. Cabrera-Rios, J. M. Castro [2008]: Sheet molding compound characterization using spiral flow. Journal of Applied Polymer Science, 109(4): 2465–2471.

[3] Lee, L. J., L. F. Marker, R. M. Griffith [1981]: The rheology and mold flow of polyester sheet molding compound. Polymer Composites, 2(4): 209–218.

[4] Kotsikos, G., A. G. Gibson [1998]: Investigation of the squeeze flow behaviour of Sheet Moulding Compounds (SMC). Composites Part A: Applied Science and Manufacturing, 29(12): 1569–1577.

[5] Barone, M. R., D. A. Caulk [1985]: Kinematics of flow in sheet molding compounds. Polymer Comp., 6(2): 105–109.

[6] Le Corre, S., L. Orgéas, D. Favier, A.. Tourabi, A. Maauouz, C. Venet [2002]: Shear and compression behaviour of sheet moulding compounds. Composites Science and Technology, 62(4): 571–577.

[7] Dumont, P., L. Orgéas, S. Le Corre, D. Favier [2003]: Anisotropic viscous behavior of sheet molding compounds (SMC) during compression molding. International Journal of Plasticity, (19): 625–646.

[8] Olsson, N. E. J., T. S. Lundström, K. Olofsson [2009]: Design of experiment study of compression moulding of SMC. Plastics, Rubber and Composites, 38(9-10): 426–431.

[9] Guiraud, O., P. Dumont, L. Orgéas, D. Favier [2012]: Rheometry of compression moulded fibre-reinforced polymer composites: Rheology, compressibility, and friction forces with mould surfaces. Composites Part A: Applied Science and Manufacturing, 43(11): 2107– 2119.

[10] Engmann, Jan, Colin Servais, Adam S. Burbidge [2005]: Squeeze flow theory and applications to rheometry: A review. Journal of Non-Newtonian Fluid Mechanics, 132(1-3): 1–27.