Constitutive Characterization of Extruded Rubber Blends by means of an Extrusion Rheometer

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Overview

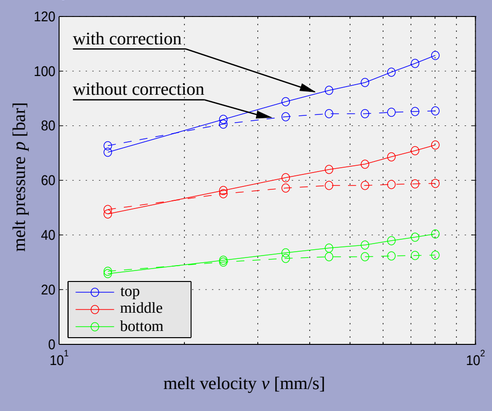
The influence of an extrusion process on the viscosity function of rubber blends is identified. This knowledge is required for performance of realistic numerical simulations of injection heads and extrusion tools for rubber profile production. The experimental basis of this investigation are tests with both, capillary and extrusion rheometer. The latter is a combination of an industrial extruder and a circular cross-sectional extrusion tool, allowing the application of material characterization methods used for capillary experiments. Thus, determination of the viscosity function of extruded rubber blends is possible. Additional capillary experiments allow an identification of the influence of extrusion on the viscosity of rubber blends. For the material characterization a nonlinear iteration scheme is used, which is proven to be applicable for rubber compounds and rubber blends. Successful verification of extrusion rheometer tests are performed with numerical back-calculation of the corresponding pressure measurements.

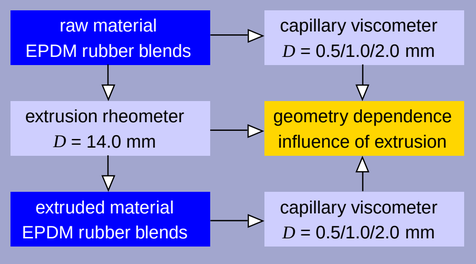
Literature:

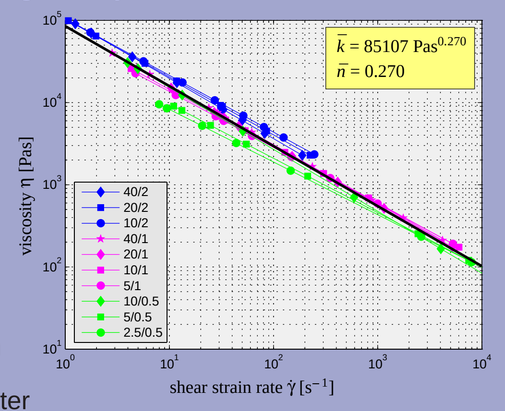
[1] S. Arrhenius: Über die Dissociationswärme und den Einfluss der Temperatur auf den Dissociationsgrad der Elektrolyte. Zeitschrift für physikalische Chemie, 4 (1889): 96-116.
[2] M. Klüppel, R. Badura, R.H. Schuster: Thermodynamik und Rheologie weichgemachter Nitrilkautschuke – Kapillarrheologische Korrekturen. Kautschuk Gummi Kunststoffe 45 (1992): 614-619.
[3] A. Limper, D. Schramm, M. Glabisch: Praktische Erprobung eines Extrusionsrheometers zur schnellen Beurteilung von Verarbeitungseigenschaften. Kautschuk Gummi Kunststoffe 52 (1999): 644-651.
[4] H.W. Müllner, J. Eberhardsteiner, P. Mackenzie-Helnwein: Constitutive Characterization of Rubber Blends by Means of Capillary-Viscometry, Journal of Non-Newtonian Fluid Mechanics, 141 (2007): submitted.

Material Characterization of Extruded Rubber Blends

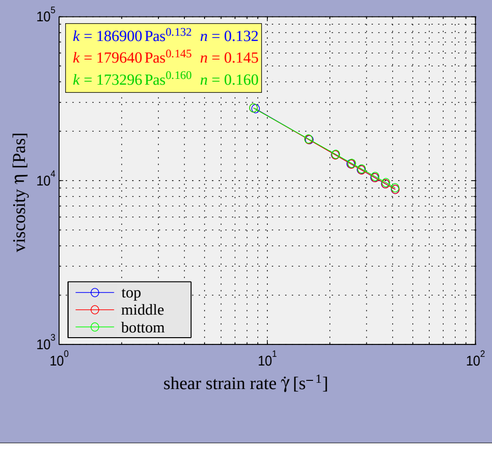
The determination of viscoelastic properties of rubber blends by capillary viscometry is characterized by different viscosity functions due to different geometries of capillary dies. According to Klüppel et al. [2] the occurrence of wall slippage is one possibility for this phenomenon. Due to different diameters of capillary dies (D = 0.5, 1.0, 2.0 mm) and extrusion tool (D = 14 mm) the viscosity functions cannot be compared. The investigation of extruded materials under usage of capillary viscometry allows verification of interaction between extrusion process and viscosity as well as geometry dependence of viscosity functions. Because of usage of circular geometries for both experiments, capillary and extrusion rheometer tests, the consistency factors of different experiments can be compared. For raw and extruded rubber blends a clear relation between viscosity and geometry of the extrusion tool is identified.

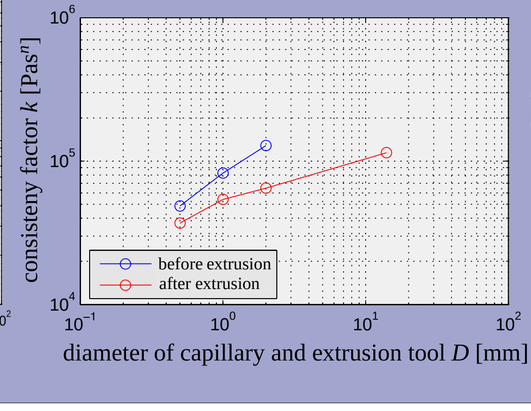


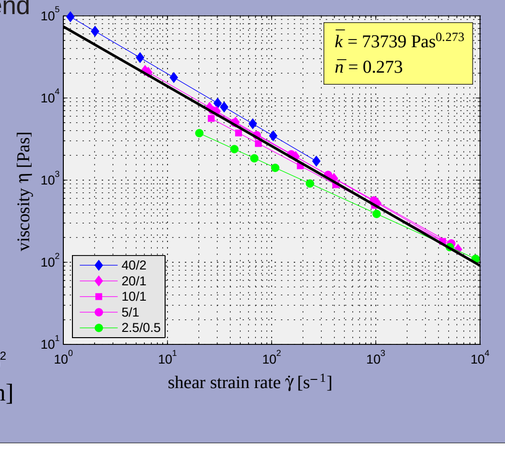




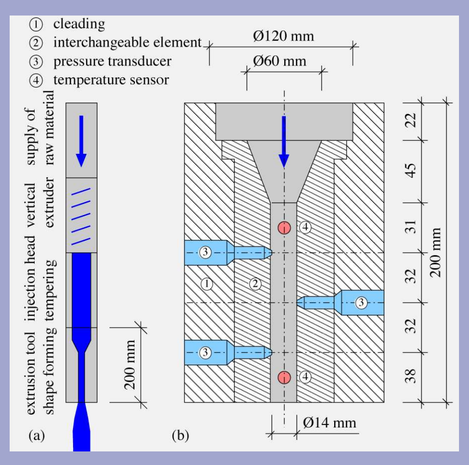
Top left: consideration of energy dissipation
Top right: viscosity of raw rubber blend
Bottom left: viscosity with extrusion rheometer
Bottum right: viscosity of extruded rubber blend



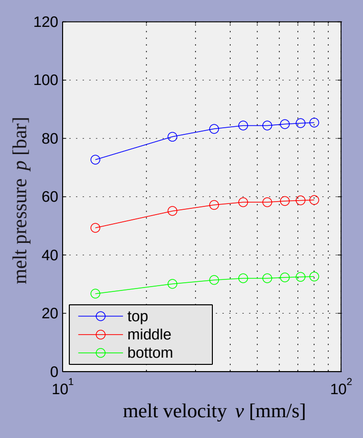


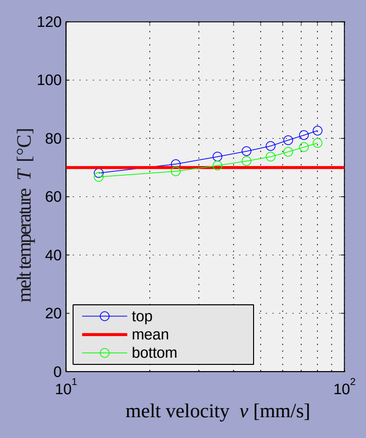


Experimental Investigations



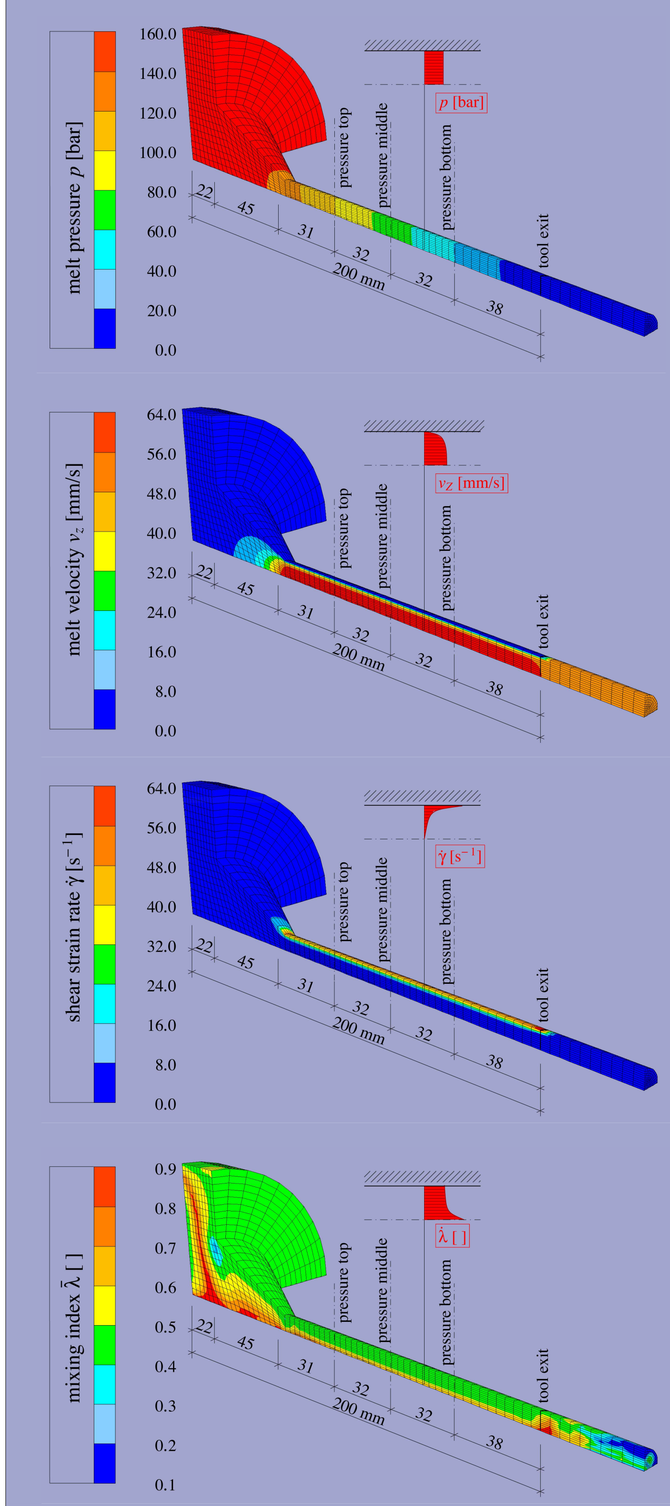
In order to identify the influence of an extrusion process on the viscosity more precisely, an extrusion rheometer is used [3]. It consists of a vertical extruder and a specified extrusion tool. In order to avoid the disadvantages of capillary viscometry, an extrusion tool with a circular cross-section has been built. Thus, determination of the viscosity is possible under usage of characterization methods, which are standardly applicable for capillary experiments with rubber blends.
The influence of salt bath vulcanization on the profile shape is not relevant, therefore is it not investigated. The diameter of the cylinder is 14 mm, therefore positioning of pressure transducers within the cylinder is possible. The length of the cylinder is 133 mm. This length allows arrangement of three pressure transducers and two temperature sensors. The distances of the pressure transducers avoid significant flow interaction.





top left: extrusion tool
top right: dimensions of tool
middle left: vertical extruder
middle right: supply of raw material
bottom left: melt pressure
bottom right: melt temperature

Numerical Validation



A numerical simulation of an extrusion rheometer test is performed using the computational fluid dynamics software POLYFLOW Version 3.92 (by Fluent Inc., Belgium). A working point at a tool temperature of 70 °C and a screw speed of 20 rpm is considered. Therefore, a comparison between experiment and simulation allows a validation of the present material characterization according to Müllner et al. [4].
For the simulation wall adhesion is considered. The consideration of wall slippage in the framework of numerical simulations is still in progress. Due to symmetry reasons a quarter of the extrusion rheometer is considered. As material description the power law with parameters according to the measurements of the extrusion rheometer is used (values of middle pressure transducer). The distributions of various state variables are shown. In addition, the positions of the pressure transducers are indicated. A verification of pressure measurements is possible, which is collected in the table situated under this text.
The obtained numerical results show a good agreement with experimental data under consideration of energy dissipation according to Arrhenius [1]. Therefore, a satisfactory validation for the material characterization method according to Müllner et al. [4] has been achieved.
However, the influence of an extrusion process on the viscosity function has not been identified. For this task, additional capillary experiments with raw and extruded material are required.

position	experiment
injection head	136.0 bar
pressure top	84.4 bar
pressure middle	58.1 bar
pressure bottom	32.0 bar
correction	simulation
149.7 bar	149.8 bar
92.9 bar	94.1 bar
64.0 bar	62.4 bar
35.3 bar	38.5 bar