CHARACTERISTICS OF SHEAR VISCOSITY DURING EXTRUSION OF RUBBER BLENDS

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1. Introduction

During rubber profile extrusion unvulcanized rubber blends are pressed through a jet with specified geometry. For that purpose the raw material is melted and homogenized in a screw extrusion press due to heating and internal friction. Before the extrusion tool is reached the melt is heated within an injection head onto the desired temperature. The production speed of this continuous process is controlled by increasing the revolutions of the screw press. After the heated rubber material leaves the extrusion tool the shape of the produced profile is guaranteed by an assembly line whose speed is insignificantly higher as the speed of the extruder. The vulcanization process is completed in a salt bath. More details about the different parts of an extrusion line can be found in MICHAELI [2].

Due to the viscoelastic behavior heated rubber melts expand upon exiting from capillary tubes and extrusion tools, respectively. This swelling of the extrudate on emerging from a die is typical for such materials. Thus, the shape of extrusion tools for the fabrication of rubber profiles has to consider the respective swelling phenomenon inversely. Up to now extrusion tools are designed on the basis of empirical knowledge of the non-linear viscoelastic flow behavior. Therefore, the injection heads were designed for every specific rubber blend. Thus, the geometry of the sealing profile is obtained by empirical adaptation of the extrusion die. Thus, in rubber profile extrusion there is an increasing interest in predicting the deformation of profile shapes after leaving the tool of the extrusion line by means of numerical simulations. Usage of finite element software allows drastic reduction of the time-consuming adaptation process for the design of extrusion tools. For this task, the influence of an extrusion process on the shear strain rate dependent viscosity $\eta(\dot{\gamma})$ has to be determined. This knowledge cannot be identified adequately by means of standard experiments, such as capillary and torsional rheometry.

2. Materials and experimental setup

The tested materials are non-vulcanized rubber blends used in industry, containing mainly EPDM (ethylene-propylene-diene-monomer) and carbon black and chalk as filler material. Such materials are used for window sealings, pipeline constructions, bridge dilatations and various parts of cars.

In order to identify the influence of an extrusion process on the viscosity η an extrusion rheometer is used. It consists of a vertical extruder (see Figure 1(a) and (b)) and a specified extrusion tool (see Figure 1(c)).

In order to avoid the disadvantages of capillary viscometry [3], an extrusion tool with a circular cross-section has been built. Thus, determination of the viscosity function $\eta(\dot{\gamma})$ is possible under usage of characterization methods [3] which are standardly applicable for capillary experiments.

The diameter of the cylinder is 14 mm, therefore positioning of pressure transducers within the cylinder is possible. The length of the cylinder is 130 mm, it allows arrangement of three pressure transducers and two temperature sensors.

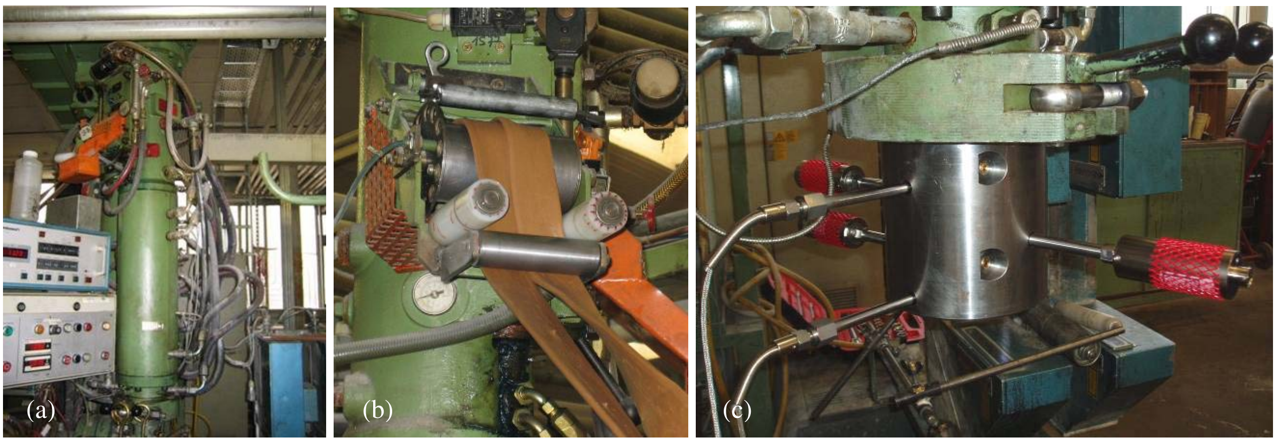

Fig. 1: Extrusion rheometer: (a) vertical extruder, (b) band supply, (c) extrusion tool with pressure transducers.

3. Determination of viscosity function

As for capillary viscometry, during one experiment the investigation of different working points is possible, varying the speed of the screw press. The latter cannot be used as quantity for the melt velocity and the shear strain rate, respectively. Therefore, the extruded material has been weighted after three minutes for each working point. Using the melt density of the raw material the melt velocity for each working point is applied.

The melt pressures and temperatures for every working point are the mean values over three minutes operating time. As regards pressure and temperature measurements, the operating time starts after reaching a steady state.

With increasing screw speed the melt temperature increases, too. Therefore, the desired temperature for a single experiment is never reached. This energy dissipation has to be considered in the framework of material characterization. Therefore, the temperature law after ARRHENIUS according to [2] is used. A detailed description of the thermodynamic behavior of rubber blends can be found in MENGES & TARGIEL [1].

RÖTHEMEYER [4] explains the interaction between rheological properties of rubber blends and the temperature within an extruder. To investigate the influence of temperature on the viscosity function of rubber blends extrusion rheometer tests at different tool temperatures were performed. Temperatures of screw press and injection head were always constant.

Figure 2 shows the results of one experiment with the extrusion rheometer. In the diagram both, the measured and the corrected pressure-velocity curves are shown. After consideration of energy dissipation a linear correlation of melt pressure and velocity in a double logarithmic scale is identified. This linear correlation is valid for a specified temperature, which also have been determined for rubber blends using capillary viscometry. Applying corresponding evaluation methods allow transformation of pressure-velocity curves into a relationship between viscosity η and shear strain rate $\dot{\gamma}$ [3].

For the description of the nonlinear correlation between viscosity and shear rate (see Figure 3) the power law after OSTWALD and DE WAELE is used, introducing two constants, consistency factor k and viscosity exponent n.

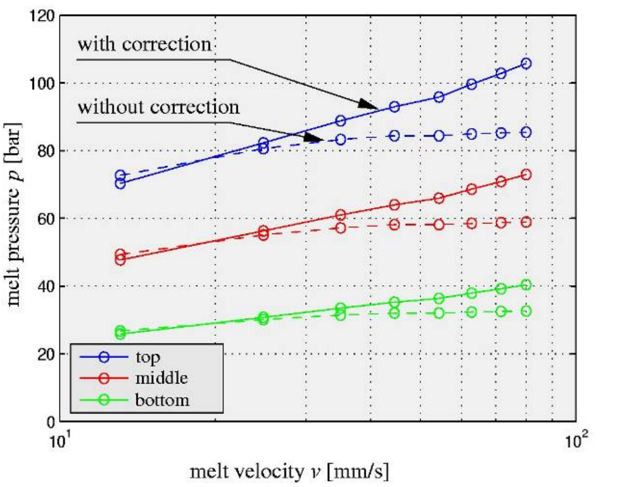

Fig. 2: Pressure measurements during one experiment with the extrusion rheometer and consideration of energy dissipation due to rising temperature.

4. Conclusions

Extrusion rheometer tests complete the program for the experimental investigation of the viscosity function of rubber blends. Together with capillary experiments with raw and extruded material, the following conclusions can be drawn. They will be discussed in more detail during the poster presentation.

- *influence of extrusion process:* The viscosity of extruded materials decrease for all investigated shear strain rates in comparison with raw materials. Thus, this influence cannot be neglected and have to be considered in the framework of numerical simulations of extrusion tools.
- *numerical validation of extrusion rheometer:* The identified viscosity function is used as material information for a numerical simulation of the extrusion rheometer. Comparison of measured and calculated melt pressures shows a good agreement. Thus, material characterization for capillary experiments can be used for evaluation of extrusion rheometer tests with rubber blends.
- *geometry dependence of viscosity function:* A correlation between consistency factor k and diameter D of capillary experiments (0.5, 1.0 and 2.0 mm) as well as of extrusion tool (14 mm) has been identified. This fact is valid for both, raw and extruded rubber blends [3].

5. References

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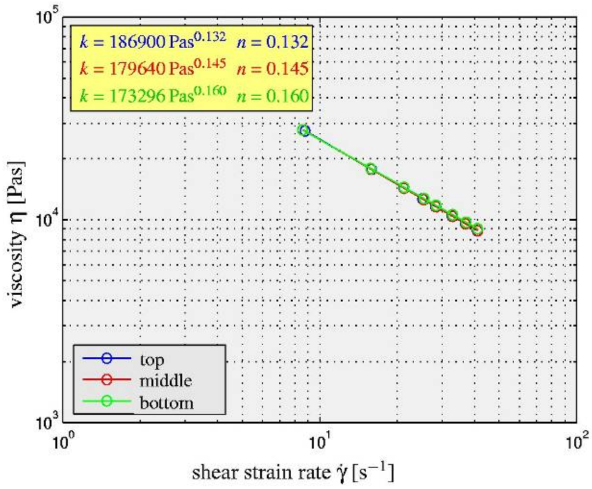

Fig. 3: Viscosity functions of one experiment with the extrusion rheometer for all pressure measurements at a temperature of 70 °C.