AN ATTEMPT FOR CORRELATION BETWEEN MOONEY VISCOSITY AND RHEOLOGICAL PROPERTIES OF FILLED RUBBER COMPOUNDS

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ABSTRACT

For the characterization of rubber compounds from the point of view of their processing capability in the rubber industry is widely used a technological indicator – the Mooney viscosity. The Mooney viscosity obtained gives information just for one point of the flow curve of the respective rubber or rubber compound. This is the reason that no full rheological characteristics of the elastomeric material are obtained.

The aim of this study is to find a correlation between the Mooney viscosity and the torque on a Plasticorder for rubber compounds.

A correlation was settled between the Mooney viscosity ML and the torque M and the corresponding equations for this dependency were derived for rubber compounds based on SBR (styrene-butadiene rubber) containing different types of carbon black and for compounds with one and the same type of carbon black, but of different level of filling.

Keywords: rheology, rubber compounds, Mooney viscosity, torque, correlation.

INTRODUCTION

In order to describe rubber compounds from the point of view of their processing capability different methods are used [1]. In this respect full characterization is achieved by analyzing the flow curves of rubbers and rubber compounds [2]. The flow curves can be obtained by different viscometers. In the rubber industry is widely used (over 100 years) a technological indicator – the Mooney viscosity. It serves for a comparison and control. It is measured relatively quickly with the respective viscometer according to the International standard ISO 289-1:2002 [3]. The Mooney viscosity obtained gives information just for one point of the flow curve of the rubber or rubber compound and this is the reason that no full rheological characteristics of the elastomeric material are obtained [4]. In order to describe the processing capability of rubber compounds by means of Brabender Plasticorder, the measurements are usually performed at relatively high rotation speed – at about 20 min⁻¹. When these revolutions are retained the shear conditions during the production process are mostly similar to the processing conditions, but are very different from the shear conditions during the measurement of the Mooney viscosity.

Our previous investigations were carried out on a Plasticorder [5] at low rotor revolutions of 1, 2, 5 and 10 min⁻¹. This investigation includes an attempt to calculate the average shear rate \( \dot{\gamma} \) based on the experimentally obtained data at different rotor revolutions. It was found through extrapolation of the linear relationship shear rate \( \dot{\gamma} \) v/s rotor speed, that \( \dot{\gamma} \) values in the range 1-2 s⁻¹ correspond to the rotor revolutions 1 to 5 min⁻¹. Taking into account that \( \dot{\gamma} \) in the Mooney viscometer is at about 1-1.5 s⁻¹, we tried to find out a correlation between the values of the Mooney viscosity and the results from the measurements carried out on the Plasticorder.

In [6] a correlation between the Mooney viscosity and the effective viscosity, obtained by means of a capillary viscometer, is found. The investigations were carried out on the both rheometers with 6 types of rubbers, namely NR crepe sheets (natural rubber), SMR-20 (Standard Malaysian Rubber, i.e. type natural rubber),...
SBR (styrene-butadiene rubber), NBR (acrylonitrile-butadiene rubber), MQ (silicone rubber), IIR 268 R (butyl rubber) and their compounds. Following equation is obtained:

\[ PL = 10 \ (\lg \eta + t) \]

where is:

- \( PL \) – Mooney viscosity, Mooney units;
- \( \eta \) – effective viscosity, Pa.s;
- \( t \) – duration for flow out of material in capillary viscometer, s.

According to the authors [6], the error does not exceed 2 %.

Other researchers [7] found a correlation between rheological behavior of filled rubber blends and their properties/structure. They suggested that a thorough understanding of the characteristic rheological response to the morphology/structure evolution of multiphase/multi-component polymers facilitates researchers’ optimizing the morphology/structure and ultimate mechanical properties of polymer materials.

Similar investigations aimed to find out a correlation between the Mooney viscosity and the torque were carried out for NR (natural rubber) and BR (butadiene rubber) compounds on a Plasticorder in the monography [8]. According to the author, the deformation conditions strongly influence the compounds structure, respectively their effective viscosity. This is the reason to find just qualitative dependences property/composition.

The aim of the present study is to find a correlation between the Mooney viscosity and the torque on a Plasticorder Brabender for rubber compounds based on SBR (styrene-butadiene rubber), filled with different types of carbon black or with one type of carbon black with different filling degree.

**EXPERIMENTAL**

**Objects of investigation**

Styrene-butadiene rubber SBR (Bulex 1500) with molecular weight ~ 200000 and density \( \rho=0,93 \) g/cm\(^3\).

**Carbon black**

The properties of carbon black used are listed in Table 1 [9].

**Composition of rubber compounds**

Investigated rubber compounds have following composition:

- SBR/Bulex 1500/100 phr,
- Carbon black 50 phr,
- ZnO 5 phr,
- Stearic acid 1,5 phr.

**Methods for investigation**

- **Mooney viscosity – ISO 289-1:2002 [3].**
- **Determination of the torque by Brabender Plasticorder**

  The investigated rubber sample is loaded in the Plasticorder camera at low rotors revolutions (i.e. 1-2 min\(^{-1}\)). After filling the camera revolutions increase to 30 min\(^{-1}\). The temperature of the compound is followed until it reaches 100°C. Then the rotors revolutions are reduced

![Table 1. Characteristics of investigated types of carbon black.](image-url)
to 2, 3 or 4 min\(^{-1}\) and the torque values are read at the respective temperature. A diagram “torque vs. temperature” is plotted and the experimental points define a band of this dependence. Torque at 100°C is determined by interpolation in the middle of the band obtained for this temperature.

RESULTS AND DISCUSSION

Influence of the type of carbon black on the correlation between the Mooney viscosity and the torque on a Plasticorder Brabender of a rubber compound

Experimental results of the dependence “torque \(M_B\) vs. temperature” of the investigated compounds at given revolutions of the rotors are shown in figures 1÷3. In these figures are presented the bands lining between the curves of highest and lowest torque values resulting from multiple measurements for each of the compounds. For each of the revolutions defined at 100°C the average torque value of the corresponding compound is defined as “\(x\)”. In some cases this band is quite wide (Fig. 1a), in others it is reduced almost to one curve (Fig. 2a). However it is impossible to establish any conformity neither with the dependence from the type of the carbon black, nor from the number of the rotor revolutions.

Fig. 4 presents the diagrams of Mooney viscosity values and of torque values, for compounds containing different types of carbon black at different rotors revolutions.

As it can be seen, the Mooney viscosity increases with increasing the activity of the investigated carbon black. The tendency of changing of the torque \(M_B\) is different in dependence on the activity of carbon black. The better coincidence between the torque and the Mooney viscosity, by their absolute values, is observed at rotor revolutions of 3 min\(^{-1}\) for carbon black PM-15, PGM-33 and N-550, the coincidence for type carbon black N-330 occurs at 2 min\(^{-1}\), and the dispersing is the highest for carbon black N-220.

![Fig. 1. Dependence of the torque \(M_B\) on the temperature for the SBR compound filled with 50 phr carbon black PM-15 at different rotors revolutions on Plasticorder.](image)

![Fig. 2. Dependence of the torque \(M_B\) on the temperature for the SBR compound filled with 50 phr carbon black PGM-33 at 2 min\(^{-1}\) (a) and carbon black N-550 at 3 min\(^{-1}\) (b).](image)
Influence of the filling level of rubber compounds containing the same type of carbon black on the correlation between Mooney viscosity and the torque

Fig. 5 shows the dependence of the Mooney viscosity on the carbon black N-550 content in rubber compounds, respectively 30, 40, 50, 60 and 70 phr carbon black.

Fig. 6 and Fig. 7 demonstrate the experimental data for the dependence of the torque vs. temperature of the investigated compounds at different rotors revolutions of the plasticorder.
In Fig. 6 and Fig. 7 are depleted the bands lining between the curves of highest and lowest torque values obtained for each of the revolutions defined at 100°C. It is clear that at low level of filling the band width is smaller (Fig. 6a) and at high filling level it is greater (Fig. 7a, b).

Following the results obtained for the torque at 100°C and Mooney viscosity in dependence on the carbon black content in the rubber compounds are shown in Fig. 8.

It is settled that for carbon black contents of 30, 40 and 50 phr the Mooney viscosity is lower in comparison with the respective torque values, and at 60 and 70 phr the Mooney viscosity values are close to the highest torque values.

Fig. 9 shows the correlation between Mooney viscosity $ML$ and torque $M_B$ at different rotors revolutions.

vice versa the Mooney viscosity could be calculated if the torque is available for the investigated compounds. Such calculation could be of practical importance if it serves as a base for obtaining of at least approximated values for rheological properties of carbon black filled SBR compounds. This very useful taking into account the following: The Ostwald de Waele equation is stating [2,4], that the effective viscosity of polymers can be calculated, if the consistency index $K$ and the rheological flow index $n$ are available. The rheology stated that, if $K$ in the exponential rheological equation represents the shear stress at shear rates of $\gamma=1$, i.e. the torque occurs just during these conditions. Furthermore, it is known that the flow index $n$ for filled rubber compounds is usually between 0,2 to 0,4 and, it is possible to calculate approximately the effective viscosity of the investigated rubber compounds on the base of the results obtained. Thus, starting with measurements of the Mooney viscosity, it becomes possible to obtain the very useful from practical point of view results concerning the rheological properties of carbon black filled SBR rubber compounds. As concerning the reliability of the results mentioned
above it is necessary to do the same measurements with a capillary viscometer which will be an object of our further investigation.

**CONCLUSIONS**

The hypothesis that it is possible to investigate the torque $M_B$ for rubber compounds at a given temperature without preliminary tempering of the mixing chamber is confirmed.

A method for torque measurements of rubber compounds by means of a Plasticorder Brabender at minimal rotor revolutions in the mixing camera is developed.

The correlation between Mooney viscosity $ML$ and torque $M_B$ by means of a Plasticorder is settled, and this correlation is revealed by a complete coincidence of their values for rubber compounds containing 50 phr carbon black of the types PM-15, PGM-33 and N-550 at 3 min$^{-1}$, and for N-330 at 2 min$^{-1}$. Concerning N-220 carbon black no correlation can be founded.

A correlation is revealed between $ML$ and $M_B$ for SBR rubber compounds with N-550 carbon black at the levels of 30, 40, 50, 60 and 70 phr and an equation for this dependency is worked out:

\[ ML = 1.8 \ M_B - 45.2 \]

or

\[ M_B = (ML + 45.2)/1.8. \]

**REFERENCES**