EXPERIMENTAL STUDY OF THE INFLUENCE OF RUBBER PROPERTIES ON SLIDING FRICTION IN DRY CONTACT

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Abstract: This study is devoted to experimental research of rubber friction in sliding contact with rough surface. Influence of pressure, bulk temperature and sliding velocity on friction coefficient in dry conditions is analysed for two rubber compounds with different viscoelastic properties. Grosch method of master curves construction is used for analysing of friction measurements. Such analysis is performed for different temperatures and velocities at constant normal load. The obtained friction master curves are combined into a single friction map. The friction maps demonstrate the influence of viscoelastic properties of rubber on friction coefficient in dry rough contact. Also friction maps show the influence of adhesion and hysteresis contributions into friction coefficient for different rubber compounds.

Keywords: Rubber friction, master curve, 3D friction map, tread compounds.

1. INTRODUCTION

Improving frictional and wear properties of rubber compounds is used in such products as tires, and still remains important problem for industrial production. It is possible to make a better driving of a car during cornering or braking by means of control of friction forces between wheel and road. Meanwhile, it is necessary to combine such different characteristics as low wear and high tire traction. Moreover, it is often need to reach necessary functional properties: tires with low rolling resistance, specified noise level, ecological safety used in tire materials. Thus, improving tribological properties of rubber materials for tires is a challenging and actual problem.

From a large number of experimental studies devoted to rubber friction, in this paper we would like to point out two works of Grosch [1, 2] and Moore [3]. Grosch has shown that in the process of sliding friction of rubber on a smooth hard surface the coefficient of friction increases with the sliding velocity to a maximum value and then decreases, i.e. has one maximum. There are two peaks of the friction force obtained for the sliding contact between rubber sample and rough surface. As it was found, the velocities corresponding to second maximum of friction agree fairly with the frequencies at which the maxima of the loss factor occur. Thus, it was [1] proposed that these peaks arise from two basic mechanism of friction. The first originates from interracial adhesion and the second is due to ploughing or deformation of the rubber surface.

Later Moor [3] showed correlation between adhesion and hysteresis components of rubber friction with wear mechanisms in rubber-like materials. Also, it was pointed out that the division of rubber friction into adhesion and hysteresis components is a convenient method of identifying features and properties of the frictional mechanism as a whole.

The aim of the research is to define the coefficient of friction of two types of tread rubbers with various viscoelastic properties in sliding rough contact; estimate the influence of the normal load and the sliding velocity on the value of the coefficient of friction in dry test conditions.

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2. EXPERIMENTAL

The friction experiments were carried out between flat surfaces. One was a ring of rubber and the other was a disc of silicon carbide paper (particle size 120 µm). For experimental research was chosen two types of rubber compounds. The rubber samples for first friction pair was made from a highway steering tire tread, mainly consisting of a low temperature glass (Tg = –50 °C) compound natural rubber and synthetic cis-butadiene rubber filled with carbon black and other required additives. The rubber samples for second pair of friction was made from a summer low rolling tire tread, mainly consisting of a high temperature glass (Tg = –20 °C) compound solution styrene butadiene rubber and synthetic cis-butadiene rubber filled with silicon dioxide (silica) and other required additives. The exact composition rubber compounds are not known.

The friction tests have been carried out on tribometer mod. UMT–2 (Bruker (ex. CETR), USA) that realized the scheme of rotation of rubber ring against the nominally flat disc surface (figure 1). A ring rubber sample 1 is fixed on specimen stage 2, which is rotated by electric motor 3 through reducer 4. Counterbody 5 is fixed on face-plate which is placed on spherical hinge 8 and is kept from rotation by system stop pins 7. The spherical hinge is to eliminate skewing of specimens during tests. The load is transferred to the contact through elastic element 9 by screw gear 10 which is moved by electric motor 12 through reducer 11. Elastic element 9 includes a 6-component sensor for measuring all forces (F_x, F_y, and F_z) and torques (T_x, T_y, and T_z) acting on a specimen. In particular, TH–100 model is designed for measuring the friction torque T_z within the range 100 to 20000 Nmm and normal load F_z within the range 10 to 1160 N. The lead nut of the screw gear is moving in guides 13. The friction pair is placed in heat termochamber 15 with cover 14. Negative temperature in the zone of frictional interaction is produced by blowing chamber 15 with air from the compressor, which has been passed through the chiller. In this measuring system, the process of frictional interaction is characterized by the friction torque and friction coefficient.

Figure 1. Principle scheme of the tribometer.

Before test, a rubber specimen is rubbed in contact with sandpaper until characteristic wear tracks appear on the entire surface of the specimen. After this, specimens were cleaned and weighted on an analytical balance with an error not exceeding 0.0001 g. Then a specimen was placed in the heat chamber of UMT–2 device, in which it was kept at a prescribed temperature of test (TC) for a period not shorter than one hour. Controlling the given temperature, the tribometer operates in the automatic regime and performs a cycle with constant contact temperature. The full test of a specimen consists of 9 cycles corresponding to the nine contact temperatures varied in the range from –25 to 80 °C. In each
cycle, the test is performed for three different pressures: 0.1, 0.25 and 0.4 MPa. These tests form 3 sequences, in each sequence the contact pressure is constant. A sequence of tests is carried out for 12 different sliding velocities varied from 1 to 200 mm/s. The angle of rotation of a specimen with respect to the counterbody was \( \pi/2 \) for each experiment. At each step, the values of the friction force, load, and sliding velocity are continuously registered.

After the end of a cycle of tests, the rubber specimens were taken from the thermo chamber and cleaned from wear particles by soap solution in water. In the experiment three specimens are tested for each type of rubber compounds. Thus, full single tests of one type of rubber consists of 324 experiments. In results of the treatment of an experiment was obtained average mean of friction coefficient on sliding distance with the steady state friction.

3. RESULTS AND DISCUSSION

Typical friction measurements are presented in figure 2 as the dependences of the coefficient of friction \( \mu \) on the sliding velocity \( V \) obtained for a summer low rolling tire tread rubber under various pressures \( P \) of 0.1…0.4 MPa and temperatures of \(-25…80\) °C. All results were obtained for dry friction conditions and the rough sandpaper. Each experimental point on graphs was obtained as an averaged value of three measurements, with error less than 10%.

![Figure 2](image_url)

**Figure 2.** Dependences of the coefficient of friction on the sliding velocity for a summer low rolling tire tread rubber for various pressure and temperature, measured in dry friction conditions.
Analysis of the results show that, in the diapason from room temperature to +80 °C, the coefficient of friction increases with sliding velocity in the studied range. At decreasing of temperature shift of the maximum of the coefficient of friction in the lower sliding velocity range, is observed. The coefficient of friction reaches a plateau at low temperature (15…5 °C) and there is a second weak maximum at high sliding velocities at lowest temperature (−25 °C). Shifting of the maximums of the coefficient of friction in direction of low sliding velocities are mainly related to changes of the relaxation properties of rubber material due to decreasing of temperature. Meanwhile, due to cyclic deformations of the rubber by asperities of sandpaper in the process of sliding friction a second weak maximum of the coefficient of friction, is observed [3, 4]. In fact, one of the authors of this work has shown [5] that, a second weak maximum at friction of rubber against smooth well-polished steel in the same testing conditions, was not observed. From the results (figure 2) it is evident that normal pressure has a strong influence on the coefficient of friction. The coefficient of friction decreases with load. It was pointed out [6] that, such load dependence is mainly related to the adhesion contribution.

Friction master curves are shown in figure 3 for a highway steering tire tread and a summer low rolling tire tread, respectively. They were obtained from the method of Grosch [1]. For construction of the master curve the WLF equation was used [7]:

$$\lg \alpha_f = \frac{-8.86(T - T_s)}{101.6 + T - T_s}$$

(1)

where \(T_s\) – reference temperature, which, as shown [7] for a wide class of elastomers is approximately equal to \(T_g + 50\), where \(T_g\) is a glass temperature. In present investigation the glass temperature for a highway steering tire tread and a summer low rolling tire tread are equal to −20 and −50 °C, respectively.

![Figure 3](image)

**Figure 3.** Friction master curves for a highway steering tire tread (a) and summer low rolling tire tread (b) at different load levels: 0.1 MPa (1) and 0.4 MPa (2).

3D friction maps are shown in figure 4 for a highway steering tire tread and a summer low rolling tire tread, respectively. For their construction the polynomial function of the 6th order, which approximates well the experimental measurements, was used. For seeking the parameters of the approximation function the method of least squares, was used.

The 3D friction maps constructed on the basis of the measurements are illustrating the influence of normal pressure, sliding velocity and temperatures on the coefficient of friction. Meanwhile, these dependences show relation not from rubber properties only, but also from a surface which characterized by specified shape of asperities and distance between them.
Figure 4. 3D friction map for a highway steering tire tread (left) and summer low rolling tire tread (right).

From analysis of 3D friction maps we can conclude. First of all, the coefficient of friction is nonmonotonic function of the sliding velocity; it can have one or two peaks depended from rubber properties and roughness of the surface. Secondly, the coefficient of friction depends from normal pressure. The coefficient of friction decreases and a main maximum shifts to higher velocities with increasing of normal load.

4. CONCLUSION

The influence of the sliding velocity, normal pressure and temperature on the coefficient of friction for two rubber compounds in dry rough contact, is described. The 3D friction maps show the influence of the different rubber properties on the coefficient of friction. It is shown that for a summer low rolling rubber compound in the studied test conditions a main maximum of the coefficient of friction, which appears in general due to adhesion mechanism and a second weak maximum at higher sliding velocities due to the additional contribution of hysteresis mechanism, are observed. A second weak maximum for another rubber compounds is not observed. This can be due to the difference in the relaxation properties that leads to the shift of the weak maximum to higher velocities. The friction measurements showed that in the studied test conditions the coefficient of friction decreases with increasing load for both rubber compounds independently of velocity and temperature.

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REFERENCES