The study of the influence of temperature on the tread wear of all-metal cord heavy-loaded radial tire

A V Morozov¹, I Yu Tsukanov¹ and K N Minkov²

¹ Laboratory of tribology, Ishlinsky Institute for Problems in Mechanics RAS, Moscow, 119526, Russia
² The All-Russian Research Institute for Optical and Physical Measurements Federal State Unitary Enterprise, Moscow, 119361, Russia

E-mail: morozovalexi@mail.ru

Abstract. In the present study, the wear resistance of the new tread rubber of the all-metal cord radial truck tire has been investigated at different temperatures: -25, +20 and +80 °C at a constant normal pressure of 0.7 MPa and a sliding speed of 20 mm / s. The low sliding speed negates the increase in temperature, which appears at higher speeds. In order to assess the effect of temperature on the change in the wear mechanism, the surface of the tested rubber is investigated by the method of non-contact profiling. The paper shows how the wear rate and surface microrelief vary with the volume temperature of the tested rubber.

1. Introduction

Studies related to the minimization of wear of treads working under conditions of frictional interaction are relevant in the manufacture of new rubber in modern tire production. The all-metal cord tire, the protector of which is the subject of this study, is technically more complex and expensive than traditional tires, but such advantages as increased payload, fuel economy, high speed characteristics, extended service life, the possibility of restoring the tread pattern for tire reuse and etc. make this tire economically advantageous, which contributes to reducing transportation costs for freight.

One of the necessary conditions for all-metal tires is the high values of the frictional forces that arise between the wheel and the road, which obviously leads to a significant effect on the tire wear resistance of the tire tread. It should be noted that high friction leads to a significant dissipation of energy, which transforms from mechanical to thermal, thereby heating the tire protector. It is known [1] that the temperature has a significant effect on the wear of rubber. And since the energy is consumed at a very small depth from the contact surface and the heat conductivity of the rubber is low, the temperature rise in the surface layer can become very significant, enhancing thermal and oxidative destruction, thereby multiplying the abrasion of the rubber, resulting from the separation of wear particles with repeated action of sharp asperities of the counterbody surface.

In this paper, we present the results of a study of a new rubber for the tread of an all-metal cord freight tire, obtained using a laboratory tribometer that allows inexpensive comparative studies of the effect of temperature on the wear resistance of the tested rubber. In this study, we give estimates of the change in the microrelief in order to study the influence of temperature on the wear mechanism of rubber.
2. Experimental study
The experimental study consisted of tribological tests consisting of determining the influence of temperature on the wear rate and in the subsequent evaluation of the surface roughness using the method of non-contact three-dimensional profilometry.

2.1. Materials
For research, a tread rubber, used in trunk drive all-metal cord tires and based on a combination of natural rubber and synthetic divinyl rubber. The test sample is an annular sample 1 glued to a steel disc, which in turn is fixed on a self-aligning tribometer holder (figure 1). The rubber ring has an internal diameter of 41 mm, an outer diameter of 55 mm and a height of 7 mm. As a counter sample 2, a disk with a silicon carbide sandpaper having graininess of 120 μm, pasted to its surface, was used. The counter sample is fixed to the rotating sample stage of the tribometer, inside the heat chamber 3.

![Figure 1. Tribometer: 1 - rubber sample, 2 - counterbody (sand paper), 3 - heat chamber.](image)

2.2. Tribological test
Experimental study of tribological properties (in this paper results are given for wear resistance) was carried out on a laboratory tribometer according to the rubber ring-disk contact scheme. The principle of the tribometer operation and a detailed description of the test procedure are presented in [2], below are the main features.

The sample stage of the device (Fig. 1), with fixed sandpaper, can rotate with a given constant angular velocity in the range 0.001…90 rpm. The indicators of the process of frictional interaction in the measuring system of the device are continuous recording of the normal load, the friction torque and the number of executed revolutions.

Testing of rubber samples is carried out according to the program specified by the operator in an automatic mode, while during the test the normal load $P = 740$ N and the slip velocity $V = 20$ mm / s are kept constant. In this study, three temperatures (+80, 20 and -25 ° C) were chosen to estimate the wear rate of rubber samples. Before the test begins, the test friction pair is held in the tribometer heat chamber for two hours, after which the sample is rubbed on the friction path of 0.4 m. It should be noted that the rubber samples are run in at a given temperature. After the tests, the samples are thermostated at room temperature and then weighed. The weight of the samples before and after the test determines the wear rate.

2.3. 3D profile measurements
Measurement of the microgeometry of the elastomer surfaces was carried out on the optical confocal profilometer DCM 3D from Leica (Germany), a 530 nm LED radiation source was used. To measure the size of particles formed during the wear process, a 10x magnification lens was used. To assess the parameters of roughness, a 5x lens was chosen with a numerical aperture of 0.15. Data processing was carried out in the free software Gwyddion [3]. Parametric and statistical estimates of waviness and
roughness heights were made in accordance ISO 4287-1997. The dimensions of the measured area were 1.9 x 2.5 mm.

For the parametric estimation, the parameters Wa and Ra were used in the longitudinal and transverse directions, as well as the arithmetic mean deviation of the texture Sa. One-dimensional parameters were estimated in five sections. In the statistical analysis, the distribution functions of the heights of the asperities and the spectral power densities were used. The spectral power density is determined by the Fourier transform of the autocorrelation function of the coordinates of the rough surface points.

3. Results

The geometric characteristics of the wear particles formed during the tribological tests were evaluated using an optical non-contact profilometer. The profilometer is not equipped with the function of stitching adjacent frames, therefore figure 2 presents images of fragments of typical wear particles obtained at three different temperatures: -25, 22 and 85 °C. We note that wear particles in the process of friction slide into rollers, and their diameter decreases with increasing bulk temperature at which the samples are tested.

![Figure 2](image)

Figure 2. Typical size of wear particles, which were obtained at different temperatures: -25 (a), 22 (b) and +85 °C (c).

After the test is completed at the specified temperature, all wear particles are removed from the rubber sample, and its surface is examined with a non-contact profilometer. Table 1 presents the averaged parameters of the topography of the investigated surfaces of rubber samples, and the three-dimensional images of their microgeometry are shown on figure 3. The results in the table show that all the controlled height parameters of roughness increased with the increase in the bulk temperature of the tests. Thus, analyzing the data of table 1 and figure 3, we can conclude that changes in the geometric characteristics of both the rubber surface and its wear particles are observed with a change in temperature, but there is no change in the wear mechanism.

| Bulk temperature, (°C) | Wa lateral (μm) | Wa longitud. (μm) | Ra lateral (μm) | Ra longitud. (μm) | Sa (μm) |
|-----------------------|----------------|------------------|----------------|------------------|--------|
| -25                   | 4.26           | 4.07             | 7.94           | 10.70            | 14.80  |
| 20                    | 6.07           | 8.05             | 13.60          | 7.60             | 18.90  |
| 80                    | 8.40           | 8.70             | 18.00          | 14.30            | 26.70  |

![Figure 3](image)

Figure 3. Topographies of the worn-out surfaces which were observed at -25 (a), 22 (b) and +85 °C (c).
All the curves of the surface texture height distribution corresponded to the normal distribution with different values of the characteristics - standard deviation, asymmetry and kurtosis. With increasing bulk temperature, the standard deviation of the height of the texture increased. This result also corresponds to the parametric evaluation of the surface texture. A clear relationship between the values of asymmetry, kurtosis and bulk temperature of the samples during the tests was not revealed.

The power density spectra of the samples surface roughness $C(q)$ in logarithmic coordinates are shown in Fig. 4, from the analysis of which it follows that the bulk temperature of the test affects mainly the low-frequency and high-frequency harmonics of the spectra. In this case, the ratio of amplitudes and frequencies in the region of medium frequencies is practically independent of the bulk temperature. The overall increase in the amplitudes of the harmonics with increasing bulk temperature corresponds to parametric and statistical analysis. In the region of medium frequencies, the surface texture has self-affinity (fractal properties). The graph in this area is a straight line, the slope of which allows us to determine the fractal dimension of the structure. The influence of the bulk temperature on the fractal dimension is insignificant, but with its increase the self-affine properties of the texture are found in a wider frequency range.

![Figure 4](image)

**Figure 4.** Power density spectra of sample surfaces at various bulk temperatures of the test

Figure 5 presents the results of an estimate of the wear rate of rubber, calculated on the basis of weight loss measurements from three experiments, for three bulk temperatures: -25, 22 and +80 °C. All the results presented are obtained under conditions of dry friction and a certain roughness of the rough ground paper. Analysis of the data presented shows that an increase in wear resistance is observed with increasing temperature of the samples. It should be noted that the nature of this behavior is mainly related to the change in the viscoelastic properties of elastomers due to temperature.

Investigation of the surfaces of elastomers using the method of non-contact (confocal) profilometry with subsequent mathematical analysis makes it possible to distinguish their features depending on the bulk temperature, despite the visually apparent proximity of worn surfaces. A comparison of the obtained data about rubber wear and microgeometry of its surface showed that an increase in wear with increasing temperature leads to an increase in the height parameters of the asperities, but on the whole it does not change the geometric structure of the surface, which may indicate the preservation of the wear mechanism when the temperature changes.
4. Conclusions
It was found that the wear rate of the test tread rubber increases with decreasing bulk temperature. In this case, the wear mechanism in the selected friction pair rubber-sandpaper has a mechanical (abrasive) character and does not change over the whole investigated temperature range. The analysis of wear particles and roughness of the rubber surface allows not only to judge qualitatively about the mechanism of wear, but also quantitatively determine the parameters characterizing it: the geometry and size of the wear particles, the parametric and spectral properties of the surface roughness. It should be noted that the spectral estimation of the roughness of rubber revealed a self-affinity (fractal properties) of the microgeometry of the rubber surface after friction, regardless of the temperature of the test. It should be added that in this paper sandpaper is used as a counterbody, allowing testing in some idealized limiting mode. This circumstance makes it possible in the foreseeable future to study the influence of fillers on the abrasion resistance of rubber, and also to assess the influence of temperature on the speed of this process.

Acknowledgments
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5. References
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