# Dynamics of rutting because of road surface wear

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**Abstract.** The results of the road surface wear observations in different periods of the year on one of the highways are considered in the paper. Reducing the rate of wear of road surfaces by car tires is an urgent task for the Russian Federation, since the state incurs huge losses owing to this. A set of measures is necessary to reduce the wear of road surfaces, especially during the period when studded tires are used on the cars. Additional researches related to the specifics of our country are required for developing such activities. Foreign measures cannot be applied without significant modification, since each country has its own approach to solving this issue. It is necessary to fulfill a research of wear mechanisms in the "car tire – road surface" system and obtain quantitative dependences of the wear rate on some external factors to substantiate organizational and technical measures aimed at reducing road surface wear. The article presents the results of observations of the rate of increase in the track and the road surface roughness degradation are presented in the paper. The following quantitative indicators were determined as a result of observations: the rate of change in rut depth due to the road surface wear; spectral density of the microprofile of road surface roughness during its wear. Preliminary conclusions were drawn about the mechanism of road surface wear and proposals were formulated for the trend of further researches based on the results of field studies.

**Keywords:** Wear of the road surface, roughness, wear mechanism of the road surface, track on the road surface, microprofile of the road surface.

## 1 Introduction

There has been a significant increase in the wear of road surfaces in recent years due to a significant increase in the intensity and speed of traffic flows on the roads of the Russian Federation. The wide use of tires with antiskid studs by road users in winter causes additional destructive effects on the road surface. This leads to the formation of ruts with a

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depth exceeding the permissible value already in the second or third year after the commencement of road surface operation.

The state incurs huge losses in the Russian Federation as a result of the wear and tear of road surfaces. Thus, they reach 220 billion rubles in year according to the Federal Road Transport Agency (Rosavtodor). About 400,000 tons of road surfaces are worn out in one year in Moscow alone according to the Institute of Transport Economics and Transport Policy. Along with material damage, the wear of the road surface leads to significant negative environmental consequences due to the appearance of fine dust (pm 10 particles) in the air, which causes severe respiratory diseases when ingested by the human body [1-3].

The papers of many scientists are devoted to studying the problem of increased wear of road surfaces both in Russia [4-14] and abroad. Besides, the causes of wear of road surfaces and developing measures for reducing their wear are being actively studied abroad [15-21]. Foreign scientists pay much attention to environmental aspects related to the wear of road surfaces and the formation of fine dust [1-3, 21]. However, it has not been possible to fully solve the problem of road surface wear until the present time.

There has been established by the previous studies that the intensity of wear of road surfaces, accompanied by the formation of ruts on them, varies in different periods of the year [2, 6, 7]. This is due to various external factors, the main of which are as follows: the speed of traffic flow, ambient temperature, the degree of road surface moisturization, the presence or absence of deicing agents, and the use of different types of tires on the vehicles. Additional researches are required for developing urgent technical and organizational measures to reduce the wear of road surfaces especially during the period of use of studded tires on the cars. To substantiate them, it is necessary to perform a study of wear mechanisms in the “car tire – road surface” system and obtain quantitative dependences of the rate of wear on some external factors. Foreign measures cannot be applied without significant modification, since each country has its own approach to solving this issue due to climatic features, the use of various road construction materials and traffic conditions.

The following tasks were set and solved in this paper in order to establish quantitative indicators of road surface wear in various periods of the year:

1. develop a methodology for monitoring the rate of rutting and degradation of road surface roughness;
2. obtain quantitative indicators characterizing the wear of the road surface;
3. draw preliminary conclusions about the wear mechanism of road surfaces.

Observations were fulfilled on the inside traffic lane of the Moscow Ring Road. As a result of observations, the following were determined: the rate of change in rut depth due to the road surface wear; the main geometric parameters of the road surface roughness and the spectral densities of the road surface roughness during its wear (in a rut).

Quantitative dependences of the wear rate of road surfaces in different periods of the year were obtained and preliminary conclusions were drawn about the mechanism of road surface wear based on the performed field studies.

## 2 Materials and methods

A methodology was developed to study the dynamics of rut formation during the operation of a highway for solving the assigned tasks. This methodology provides for monitoring changes in rut depth in marked sections of the Moscow Ring Road via periodically measuring its depth and the roughness of the road surface. The rut depth was determined using a 3-meter rod in accordance with [22]. The measurement of the road surface roughness parameters was determined based on microprofiles of its surface obtained using a precision profilometer. This device is designed to operate under stationary conditions, so it was decided to monitor changes in the roughness of the road surface using removable

core samples installed in it. The technology for their manufacture, installation and removal is described below.

Experimental measurements were performed from October 2016 to June 2018 at the sections with approximately the same traffic conditions and different pavement service lives. The studies were fulfilled on 12 sections of the Moscow Ring Road. The results obtained in the following three sections are presented in this paper due to limitations on the paper volume:

- Outer side of the Moscow Ring Road – km 77 (sample No. 3);
- Inner side of the Moscow Ring Road – km 58 (sample No. 11);
- Inner side of the Moscow Ring Road – km 74 (sample No. 5);

The observations covered surfaces of various years of laying and materials. Thus, sample No. 3 was selected from an asphalt concrete layer on a construction bitumen (BND) with a gabbro filler (fraction 20 mm) laid in 2015, sample No. 5 consists of dense asphalt concrete A-1 with granite filler (fraction 15 mm) laid in 2016, No. 11 – from crushed stone mastic asphalt concrete (ShchMA-15) 2014 on a bitumen with styrene-butadiene-styrene (SBS) polymers and a granite filler. The observations were interrupted due to the fact that repair works began at the experimental sites.

The sections of the roadway wherein measurements were taken were precisely determined to compare the results of periodic observations. In order to facilitate the search for the sections where measurements were taken and samples were installed, these areas were selected so that they were located next to the lighting masts or opposite the joints between the road fence blocks. Besides, marks were made with a white paint on the road fence and the edge of the roadway. Twelve road surface samples were totally installed. However, five of them became unserviceable prematurely during the operation of the road, so seven samples located in pairs at a distance of 10-15 m from each other (except for sample No. 5) were used for the entire observation period. In this case, one sample was placed on one type of a road surface, and the other one was placed on the next one. This installation scheme creates identical operating conditions for the samples and made it possible to obtain relative wear rates of different materials when exposed to the same factors as a result.

To observe the samples, special steel cylindrical forms (sleeves) were designed and manufactured, whereinto asphalt concrete pavement samples drilled with a core sampler were placed (Fig. 1). Reliable fixation of the samples in the sleeves was provided via organic mastic.

The major challenge was the task of ensuring that the samples were installed in their previous place so that the upper plane of the sample coincided with the plane of the road surface. The position of each sample was adjusted in two steps for this purpose. It was adjusted using special gaskets in the laboratory at the first stage and on the road at the second stage. The developed measures made it possible to install the samples height along with an accuracy of + 0.5 mm.

After placing into the recess, the samples were fixed to prevent their radial movement when driven by car wheels, as well as to prevent water from getting between the sample and the hole walls. To do this, fixing rubber rings were installed on the generatrices of the samples, and the gap between the sample and the hole wall was sealed with a quick-hardening sealant. Special slots were provided in the sleeves and local milling (inclined recesses) were made in the road surface clearly seen in Fig. 1 in order to ensure subsequent removal of the sample from the recess in the road surface. The appearance of the sample after placing in its previous position is shown in Fig. 2.

**Fig. 1.** Sample No. 5 before placing into a recess on the roadway.

**Fig. 2.** Sample No. 2 after placing and sealing.

Laboratory studies of the samples consisted of scanning their surface along 4 sections located symmetrically relative to the diameter at a distance of 10 and 20 mm in each direction. Scanning was performed to obtain a microprofile of the road surface roughness.

We used a high-precision profilometer, the external appearance of which is shown in Fig. 3 for this purpose. This device makes it possible to determine the coordinates of elevation marks with an accuracy of 10 μm with a scanning pitch of 50 μm. To perform laboratory studies, asphalt concrete samples were removed from the pavement, delivered to the measurement site and returned to the site no later than in 24 hours.

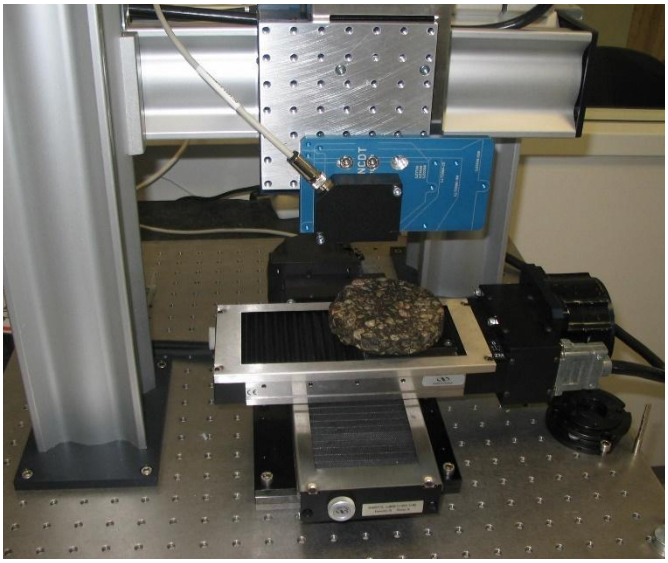

**Fig. 3.** External appearance of the plant for researching the surface roughness of the samples being studied.

The time moment of measuring the rut depth is shown in Fig. 4.

**Fig. 4.** Determining a rut depth using a rod.

Due to the high labor intensity of the work on measuring the sample surface microprofile, three measurements of this parameter were made over the entire observation period during the implementation of this work. The rut depth was measured 6 times during this period.

The results of studying the literature and analyzing the results obtained in this study made it possible to establish that the rut develops unevenly throughout the year. The rut depth changes slightly in the warm period of the year (April-October months) and a progressive increase in the rut depth is observed in the cold period of the year.

## 3 Results

The obtained results (Tables 1 and 2) indicate that the rate of increase in rut depth is 0.2 mm/month on average during the warm period. The average rates of increase in rut depth are about 1.6 mm/month during the winter period. That is, in winter, the wear rate of the road surface is 8 times greater than in the warm season. This may be due to several factors. As far as is known, the main ones will be the temperature of the road surface, the presence of aggressive solutions of deicing reagents, as well as the use of car tires with antiskid studs and high vehicle speeds [5]. The low temperature of the road surface material leads to increase in its fragility, which, in combination with deicing reagents, will inevitably lead to more intensive wear of the binder and chipping of the mineral filler. Many researchers have paid attention to the increase in wear with decreasing temperature, for example, [8, 23].

**Table 1.** Rut depth.

| **Sample No.** | **Rut depth, mm according to measurement dates** | | | | | |
|---|---|---|---|---|---|---|
| | **October 15, 2015** | **March 24, 2016** | **October 26, 2016** | **March 15, 2017** | **October 16, 2017** | **March 27, 2018** |
| 3 | 17.0 | 25.2 | 26.4 | 34.5 | 36.6 | 46.6 |
| 5 | 1.4 | 6.2 | 7.0 | 12.1 | 13.7 | 21.7 |
| 11 | 25.0 | 34.3 | 37.0 | 43.0 | 45.1 | 57.1 |

**Table 2.** Rut depth increment (wear rate), mm/month.

| **Sample No.** | **Periodical rut depth increment, mm** | | | | |
|---|---|---|---|---|---|
| | **October 15, 2015-March 24, 2016** | **March 24, 2015-October 26, 2016** | **October 26, 2016-March 15, 2017** | **March 15, 2017-October 16, 2017** | **October 16, 2017-March 27, 2018** |
| 3 (2015) | 1.64 | 0.17 | 1.62 | 0.30 | 2.00 |
| 5 (2016) | 0.96 | 0.11 | 1.02 | 0.23 | 1.60 |
| 11 (2014) | 1.86 | 0.38 | 1.20 | 0.30 | 2.40 |

The thickness of the top layer of asphalt concrete should be less than in the middle of the lane at the sections with ruts caused by the road surface wear. This was confirmed when measuring the height of the road surface samples taken at km 46+600m (Fig. 5). According to the obtained measurement results, the thickness of asphalt concrete along the left rut turned out to be 27 mm greater on average. Considering that the depth of the rut at the time of sampling was 28-30 mm and assuming that its thickness was the same across the width of the traffic lane after laying the layer, it can be argued that the rut on this road section was formed as a result of asphalt concrete wear. The difference between the thickness of the road surface samples and the rut depth is due to the fact that during the core sampling process, the top layer of the coating peeled off and it could rotate with it when the core

sampler rotated. In this case, the lower surface of the upper layer has worn out to some extent. This fact can be seen from the figure.

a) b)

**Fig. 5.** Road surface thickness on the samples taken in the middle of the traffic lane (sample on the right) and along the left rut (sample on the left)

Microprofiles of the surface roughness of each road surface sample were obtained and determined in laboratory conditions for an in-depth study of the road surface wear mechanism. To compare the roughness parameters of different samples, the concept of the spectral density average value (spectral power density [24, 25]) within the frequency range Δn was used, which is expressed by the formula:

$$G(\Delta n) = \frac{1}{\Delta n \cdot L} \cdot \int_{\Delta n} \left|\hat{q}(n)\right|^2 dn \tag{1}$$

where n =1/λ – road frequency (the reciprocal of the roughness wavelength λ), $mm^{-1}$;

$\hat{q}$ – Fourier transformation [6] of the microprofile q determined at the interval [0, L].

The Fourier transformation module $\left|\hat{q}\right|$ characterizes the magnitude of the roughness amplitude; therefore $G(\Delta n)$ shows the integral mean of the roughness amplitude square within the frequency range Δn.

Preliminary results of mathematical processing of microprofiles obtained at different times are shown in Fig. 6-8. The curves corresponding to the dates of microprofile measurement performance are indicated in the figure in numbers: 1 – measurement on October 26, 2016; 2 – measurement on March 15, 2017; 3 – measurement on October 16, 2017. Roughness parameters were assessed using quantitative criteria based on graphs of the microprofile spectral densities. Microprofile spectral density curves make it possible to determine which structural elements of the surface are most susceptible to change during the road surface operation.

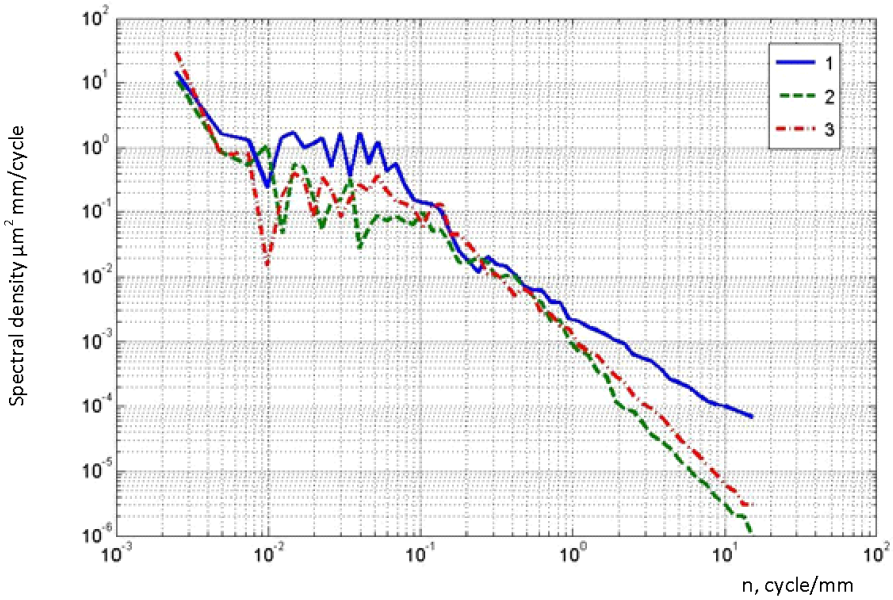


**Fig. 6.** Spectral density of sample No. 3 surface roughness microprofiles**.**

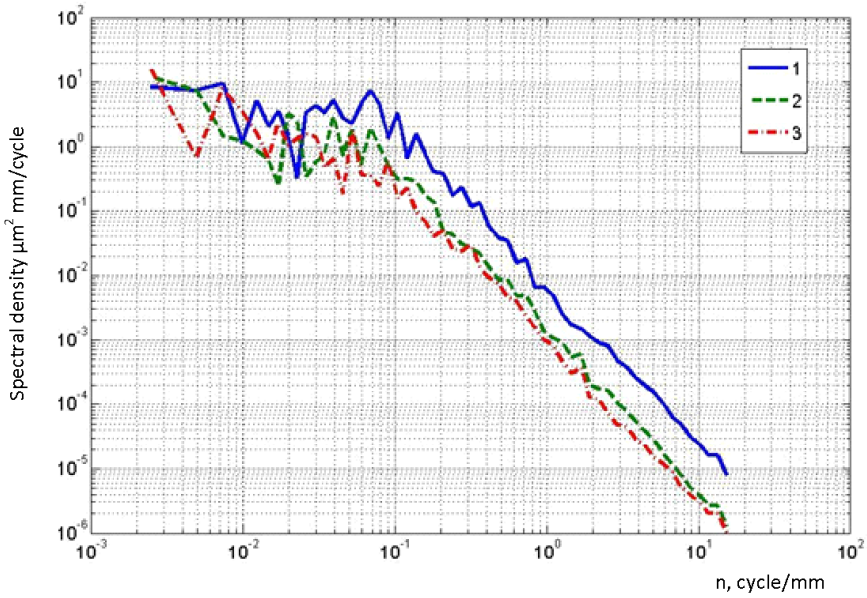


**Fig. 7.** Spectral density of sample No. 5 surface roughness microprofiles.

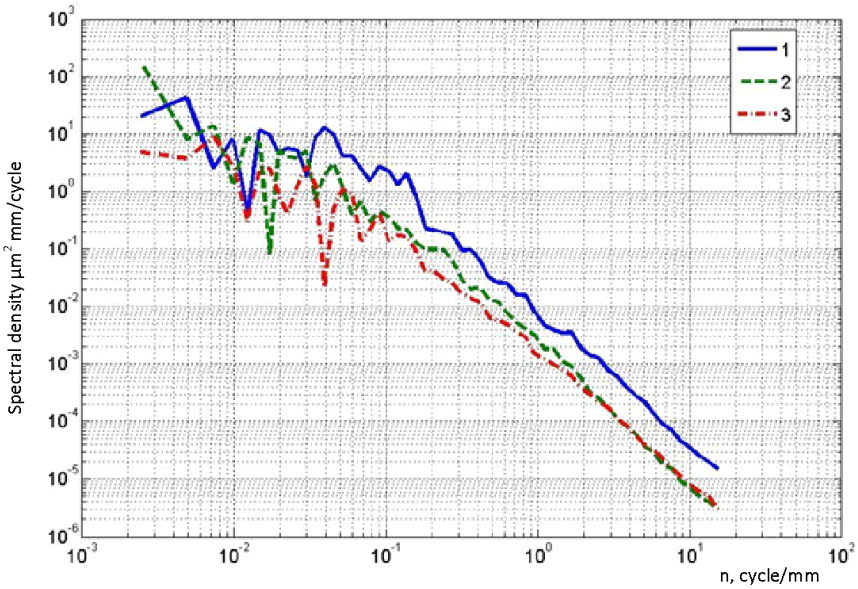


**Fig. 8.** Spectral density of sample No. 11 surface roughness microprofiles.

## 4 Discussion

The analysis of the obtained spectral densities made it possible to establish the following. According to observational data, the rut depth in section No. 3 increased more in winter than in the warm period of the year. The wear of this sample may be due to intense abrasion of the binder and polishing of the grain surface of the crushed stone protrusions, as can be seen in the spectral density graphs: microroughness (λ<1 mm) decreased significantly (curve 1 & curve 2). Macro-roughness (λ>10 mm) corresponding to the size of the used crushed stone 20 mm (cyclic frequency, approximately 0.04-0.05 also decreased. A large gap between curves 1 & 2, especially at λ<1 mm, indicates the micro-roughness wear apparently due to polishing of crushed stone grains. The gabbro mineral is more resistant to chemical erosion than granite due to its denser structure and less moisture absorption, and also has greater strength and better wear resistance. Its abrasion resistance exceeds that of granite with a value of 0.07 g/cm$^2$ (granite abrasion is 1.4 g/cm$^2$) [24]. That is, gabbro better withstands various physical actions, including impacts from antiskid studs, but it is largely susceptible to grinding with antiskid studs in the winter. This conclusion should be considered as preliminary one. It is necessary to conduct special researches to determine the wear resistance of gabbro crushed stone when exposed to studded tires in the presence of chemical reagents using special laboratory testing equipment.

Sample No. 5 was selected from asphalt concrete with a short service life. As a rule, one should expect an increase in a surface roughness due to the binder film wear and exposure of micro- and macro-roughness of the stone material during the initial period of operation of this road surface. The spectral density curves shown in Fig. 8 indicate that the surface roughness of this sample increased throughout the entire observation period over the entire wavelength range. An increase in the coarse surface component, due to the size of the stone material, the wavelength is 10-15 mm on average, indicates advanced wear of the binder accompanied by exposure of crushed stone grains. The increase in macro-roughness in the

winter can be explained by the binder wear, chemical erosion of the material, and exposure to studded tires. The increase in macro-roughness in the warm season is apparently associated with an intense wear of the asphalt binder when exposed to tires in the presence of abrasive, as well as washout of the binder during the rainy season. The road surface is in a wet state [1] and a large number of abrasive particles are observed on the surface of the coating, which increase the intensity of surface polishing about 30% of the time during the warm period of the year.

Analysis of those spectral densities of sample No. 11 (ShchMA-15+SBS) presented in Fig. 8 shows that the macro- and micro-roughness decreased during the cold period of the year, which is associated with the wear of both the stone material itself and the binder, despite the fact that the bitumen was modified with a polymer additive. No noticeable changes were recorded in the microroughness region (wavelength up to 0.5 mm) during the warm period of the year, i.e. the surface microroughness turned out to be stable. This may indicate an equilibrium roughness that self-renews under the influence of natural factors and the impact of car tires in the presence of an abrasive. The surface macro-roughness of this sample increased during the warm period, which may also be due to the asphalt binder wear when exposed to tires in the presence of abrasive and the binder washout during the rainy season, despite the use of modified bitumen. The results obtained on this sample are somewhat unexpected and require additional laboratory studies to research the wear of polymer asphalt binder in comparison with a conventional one.

It is expected that the results obtained during this research can serve as a basis for the development of measures concerning increasing the service life of the road surface. In this regard, the observation of roughness parameters is expected to be continued and supplemented with laboratory studies using special equipment.

## 5 Conclusion

The following conclusions were drawn as a result of the analysis of the data obtained as a part of the performed researches:

- change in roughness in different wavelength ranges occurs differently in various periods of the year as evidenced by different dynamics of change in the geometric parameters of the surface microprofile;
- it was established during the observation period that there is an increase in both macro- and micro-roughness of the coating surface in the winter. No noticeable changes were recorded (with the exception of freshly laid coating) in the medium-wave band. A slight decrease in the medium-wave component of roughness was observed on the ShchMA-15 coating;
- the macro-roughness of the surface of the coatings being researched changed differently during the warm period of the year. It has increased on the freshly laid pavement, it has decreased slightly on ShMA-15, and it has increased on the section with asphalt concrete type A-I, which indicates an advanced wear of the asphalt binder;
- modification of bitumen with SBS polymers has not reduced the wear rates of the coating;
- the formation rate of rutting in winter is 8 times higher than in summer;
- The developed methodology for measuring the roughness parameters of removable road surface samples and their fixation on the track has shown good practical results;
- Spectral density index can be used to analyze the wear mechanism of a road surface.

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