Wear of Asphalt Concrete Pavements and Its Contribution to the Depth of the Rut

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Abstract. The purpose of the article is to determine the contribution of wear of asphalt concrete pavement to the depths of ruts. The method of experimental research is field and laboratory tests. In the course of field work, the thickness of the asphalt concrete pavement in the core taken from the bottom of the rut, between the rut and side bulging of rut, if any, is measured. When performing laboratory work, the indicators of the physical and mechanical properties of asphalt concrete are determined in samples taken from the coating and in reformed samples. Laboratory data make it possible to judge the compliance of asphalt concrete with the requirements of the standard and evaluate its possible compaction by transport during exploitation. The difference in the thickness of the asphalt concrete in the cores taken from different points of the cross-section of the coating allows us to determine the amount of wear and calculate its share in the depth of the rut. As a result, share of the rut depth caused by the wear of the asphalt concrete pavement and the deformation of the structural layers of the pavement and the soil of subgrade were established.

1. Introduction
A rut formed on the surface of the pavement is one of the most common defects of pavement. The problem of the formation of ruts and increasing their depths during the exploitation of the road is relevant worldwide. Currently, works are known whose purpose is to develop methods for predicting the growth of rut from the effects of traffic loads [1–5]. Rut depth is limited by limit values. The authors of the works, the purpose of which is to determine the limit depth of the rut, proceed from the conditions for ensuring safe movement. Moreover, it is considered that during rain water accumulates in the rut, which leads to a decrease in skid resistance [6–8], and in some cases causes the hydroplaning effect [9–11]. Therefore, when determining the limit rut depth, the main goal is to provide the required coefficient of cohesion of the tire with the coating [12]. The second factor taken into account when determining the limit rut depth is the increase in dynamic load when performing an overtaking maneuver. In this case, it is assumed that at the beginning of the overtaking maneuver the wheels leave the rut, and at the end of the overtaking the wheels enter the rut. This is accompanied by a tire hit on the coating, which leads to an increase in dynamic coefficient. Therefore, the rut depth is limited by the limiting value of the dynamic coefficient at the required speed of the overtaking car, the factual modulus of elasticity of the pavement, and the geometric parameters of the rut [13, 14].

Currently, when checking the conditions of road pavement resistance to rutting, a criterion is applied according to which the rut depth RD should not exceed the limiting value RDlim. That is:

\[ RD \leq RD_{lim} \]  \hspace{1cm} (1)
Criterion (1) does not share the rut depth $RD$ into components caused by residual deformation accumulated by the layers of pavement and subgrade, and wear of the coating. Therefore, this criterion does not take into account the causes of rutting. At present, three models of rut formation on asphalt concrete pavements of highways are known [15]. These models are shown in figure 1.

![Figure 1. Models of ruts and surveys of ruts in trenches [15]: a – Structural rutting; b – Instability structure; c – Surface wear; 1 – asphalt concrete pavement; 2 – base from granular material; 3 – subgrade.](image)

Figure 1. Models of ruts and surveys of ruts in trenches [15]: a – Structural rutting; b – Instability structure; c – Surface wear; 1 – asphalt concrete pavement; 2 – base from granular material; 3 – subgrade.

The model shown in figure 1a, illustrates the formation of a rut due to the accumulation of residual deformations in all layers of pavement and subgrade. The depth of such a rut is calculated as the sum of the residual deformations of all layers of pavement and subgrade, and the residual deformation of each layer is described by the corresponding empirical formula [1,16,17].

A model of the second type illustrates the formation of a rut due to shear deformations in asphalt concrete. Such a rut is shown in figure 1b. From the analysis of this figure it follows that a rut of this type is accompanied by side bulging. It is noteworthy that due to the shear of asphalt concrete, the layer thickness in the side bulging increases and at the bottom of the rut it decreases. Between the ruts, the thickness of the coating remains the same as after construction. Note that this type of rut is easy to determine experimentally. To do this, it is enough to take cores from the bottom of the rut and side bulging and measure their thickness, comparing with the thickness of the core taken from the same cross section at the point between the ruts. If in the side bulging the layer thickness is greater than in the cores taken between the ruts, and the coating thickness at the bottom of the ruts is less than the thickness of the layer between the ruts, this means that the cause of the ruts is the shear of asphalt concrete.

Considering the ruts with a side bulging of the asphalt concrete pavement, we note that the formation of the bulge may be due to deformations of shear in the layers underlying the pavement. In this case the core thickness, taken from the bottom of the rut, its side bulging and between the ruts will be identical or almost the same.

As main causes of plastic deformation of asphalt coating are considered high temperature [18] and high bitumen content [19]. These factors lead to deformation of compaction and shear of asphalt concrete, and the rut is the result of a combination of such deformations [20]. In addition, asphalt concrete experiences the effect of fatigue, during which damage progressing. With an increase in damage, indicators of mechanical properties worsening [21–23].

The third rut model illustrates pavement wear that affects only the top asphalt layer. The authors of [24, 25] argue that such a rut is formed in winter as a result of exposure the tires equipped with spikes, as well as anti-icing abrasive materials.

Summing up the review, we note that a rut can be formed due to a combination of all three models shown in figure 1. Depending on the external conditions prevailing cause of rutting can be one of the models shown in figure 1. For example, in places of braking and acceleration of cars with tires equipped with spikes, the main contribution to the rut can be made by the wear of the asphalt concrete coating. In other sections of the road, characterized by constant speeds, wear on the asphalt pavement makes the least contribution to the formation of ruts.
The authors believe that determining the contribution of coating wear to the total rut depth will allow a more reliable prediction of the rut depth. Therefore, criterion (1) can be represented as:

\[ \sum S_i \leq R_{\text{lim}} (1 - k_{\text{SW}}); \quad k_{\text{SW}} = h_{\text{SW}} / R_D, \]

where \( i \) – number of pavement layer including subgrade; \( S_i \) – residual deformation of the surface of the \( i \)-th layer, mm; \( k_{\text{SW}} \) – coefficient characterizing the share of wear of asphalt concrete pavement in the total depth of the rut; \( h_{\text{SW}} \) – value of wear asphalt concrete pavement, mm; \( R_D \) – rut depth on the surface of the coating.

Coefficient \( k_{\text{SW}} \) is a scalar value ranging from 0 to 1. The essence of this variation of the value of the coefficient \( k_{\text{SW}} \) is that at \( k_{\text{SW}} = 0 \), the rut is caused only by residual deformations of \( S_i \), and at \( k_{\text{SW}} = 1 \), only wear \( h_{\text{SW}} \) should be considered for the cause of the rut.

2. Materials and methods

The aim of our work is to determine the coefficient \( k_{\text{SW}} \) on road sections with different traffic conditions. The determination of the coefficient \( k_{\text{SW}} \) is performed experimentally. The experiments were performed in two stages. At the first stage, field researches were performed. During field research, pavement diagnostics were carried out on various streets of Omsk. During the diagnostics, characteristic sections of roads with different traffic conditions were identified on each street. To characteristic sections relate:

– sectors of roads with almost constant speed;
– braking sections near traffic lights, walking crossings and turns on adjacent roads;
– acceleration sections located behind traffic lights, walking crossings and turns onto adjacent streets;
– public transport stops.

On each characteristic sector cross sections perpendicular to the axis of the road were selected. In each cross section, are assigned two or three points of selection core. Three selection points are assigned if the rut has side bulging. In this case, the first selection point is located at the bottom of the rut the second - at the side bulging and the third - between the ruts or near the axis of the road. Two sampling points were assigned in the absence of ruts side bulging.

In each cross section, the depth of the outer and/or inner rut was measured. After that, cores were drilled from the sampling points, which were delivered to the laboratory for measuring thicknesses and performing tests to determine the compaction factor and water saturation, as well as other parameters required to determine the compliance of asphalt concrete and the mixture with the requirements of the standards. The physical and mechanical properties of the asphalt concrete mixture were determined by testing reformed samples.

Illustrations of field work are shown in figure 2.

To determine the wear of the asphalt concrete pavement \( h_{\text{SW}} \), cores taken from cross sections with ruts without side bulging were used. The value of wear of the coating \( h_{\text{SW}} \) was determined by the difference in core thicknesses taken between the rut and from the bottom of the rut. The value of the coefficient \( k_{\text{SW}} \) was calculated by the ratio of the wear of the coating \( h_{\text{SW}} \) to the rut depth \( R_D \).

When testing cores taken from such cross sections, the compaction factor and water saturation were determined. The difference of these indicators in the cores from the bottom of the rut and between the ruts allowed us to state either the fact of compaction of asphalt concrete in the rut, or the development of damage. The conclusion about compaction of asphalt concrete in the rut made if the compaction factor of the core taken from the rut turned out to be greater than the compaction factor of the core taken between the ruts. The fact of compaction of asphalt concrete in the rut was also confirmed when the water saturation of the core taken from the rut turned out to be less than the water saturation of the core taken between the ruts. In cases where the water saturation of the core taken from the rut was greater than the water saturation of the core taken between the ruts, the fact of accumulation of damage in the asphalt concrete was noted.
Figure 2. Field work during the examination of ruts: a – inner rut depth measurement (1st Cheredovaya street) b – coring from the bottom of the outer rut and between the ruts (Demyana Bednogo Street); c – Coring from the bottom of the inner rut and between the ruts (1st Cheredovaya street); d – thickness measurement of asphalt concrete layers in cores (core taken at Internatsionalnaya street).

3. Results
The results of experimental studies are shown in table 1.

| Road name                    | Driving conditions          | Section number | RD, mm | Parameters   | k_{SW} |
|------------------------------|-----------------------------|----------------|--------|--------------|--------|
| Internatsionalnaya street    | Site with a constant speed of movement | 1              | 4,0    | 0,5          | 0,13   |
|                              |                             | 2              | 4,0    | 0,5          | 0,13   |
|                              |                             | 3              | 4,0    | 0,5          | 0,13   |
|                              | Public transport stop       | 1              | 55     | 5            | 0,09   |
|                              |                             | 2              | 72     | 6            | 0,08   |
|                              |                             | 3              | 55     | 4            | 0,07   |
|                              | Site with a constant speed of movement | 1              | 20     | 2            | 0,10   |
|                              |                             | 2              | 20     | 3            | 0,15   |
|                              |                             | 3              | 22     | 4            | 0,18   |
|                              |                             | 4              | 18     | 2            | 0,11   |
|                              |                             | 5              | 21     | 3            | 0,14   |
|                              | Braking site                | 1              | 30     | 13           | 0,43   |
|                              |                             | 2              | 32     | 15           | 0,47   |
|                              |                             | 3              | 35     | 17           | 0,49   |
|                              | Braking site                | 1              | 63     | 50           | 0,79   |
| 1st Cheredovaya street       | Acceleration site           | 1              | 36     | 9            | 0,25   |
|                              |                             | 2              | 34     | 7            | 0,21   |
| 21st Amurskaya street        | Site with a constant speed of movement | 1              | 20     | 3            | 0,15   |
|                              |                             | 2              | 18     | 2            | 0,11   |
|                              |                             | 3              | 19     | 3            | 0,16   |

Table 1. Results of determination of rut depths RD, wear h_{SW} and coefficient k_{SW}. 
4. Discussion

Based on the results of experimental studies, we can draw conclusions about the contribution of coating wear to the depth of the rut:

1. The wear of asphalt concrete pavements develops in winter from the effects of tires with spikes. The greatest contribution of wear to the depth of the rut is in the areas of braking ($k_{SW}=0.4–0.8$). In acceleration areas, wear makes a smaller but significant contribution to the rut depth. ($k_{SW}=0.2–0.4$).

2. At areas with normal driving conditions, that is, in areas with a constant speed, the greatest contribution to the depth of the rut is made by deformations of the layers of pavement and soil of subgrade ($k_{SW}=0.1–0.2$). Moreover, in the places of short-term bus stops, the depth of the ruts caused by the deformation of the layers of pavement and subgrade is significantly higher than the depth ruts in the section with the usual mode of movement ($k_{SW}<0.1$).

3. The set values of the coefficient $k_{SW}$ can be used in criterion (2). In this case, the calculation of the rut depth is calculating the sum of $\sum S_i$ of residual deformations of $S_i$ accumulated by the layers of the pavement and the subgrade. In this case, the calculation is simplified.

5. References

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