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Resistance of Asphalt Concrete to Plastic Rutting Depending on Shear Resistance of Binders

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ABSTRACT

The paper substantiates the relevance of studying the process of plastic rutting on roads with asphalt concrete pavements. It is hypothesised that the existing approach to monitoring quality indicators at the stage of production of asphalt concrete mixtures, including the components included in its composition, namely, monitoring the required resistance to plastic rutting of the resulting asphalt concrete pavements, has a significant drawback. The indicated drawback is that assessment of the possibility of using a specific batch of binder for preparation of asphalt concrete mixture is currently carried out only based on incoming quality control of the binder, by comparing the actual values of physical and mechanical characteristics obtained in the laboratory with the minimum standard values stated for the grade of binder material adopted in the design documentation, without taking into account the actual values of the quality characteristics of the binder used at the stage of laboratory selection of the mixture composition. This drawback, in some cases, can lead to failure to ensure the resistance of the asphalt concrete mixture to plastic rutting at the stage of its production.

The study contains the results of testing the shear resistance of batches of binders of one performance grade and the resistance of asphalt concretes prepared using these binders to plastic rutting. The results of the study confirm the hypothesis put forward by the authors; the dependence of the «average rut depth» indicator on the shear resistance of the binder aged by the RTFOT method is obtained and statistically substantiated.

Keywords: motor transport, asphalt concrete, binders, plastic rutting, shear resistance, resistance to rutting, average rut depth.

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BACKGROUND

One of the main regulatory requirements for the operating condition of motorways in terms of ensuring road traffic safety is limitation of the maximum rut depth on the road surface. At the same time, at present, up to 35 % of all identified cases of substandard transport and operating condition of motorways are due to the presence of ruts on the surfaces with a depth exceeding the established maximum values [1].

The rutting on asphalt concrete surfaces is caused by both plastic deformations of the surface material (plastic ruts) and abrasion of the surface material (abrasive ruts). Plastic rutting, in turn, can be either superficial [mix rutting], associated with the discrepancy between the actual shear resistance of the surface layer material (asphalt concrete) and specific operating conditions, or deep [subgrade rutting], the appearance of which is caused by shear deformations of the underlying layers of the road surface and the subgrade [1–3]. This study examines plastic surface rutting, visually distinguished by the presence of uplift (shearing) [1], i.e. lateral uplifts of asphalt concrete along the boundaries of the track (wheel path) (Pic. 1).

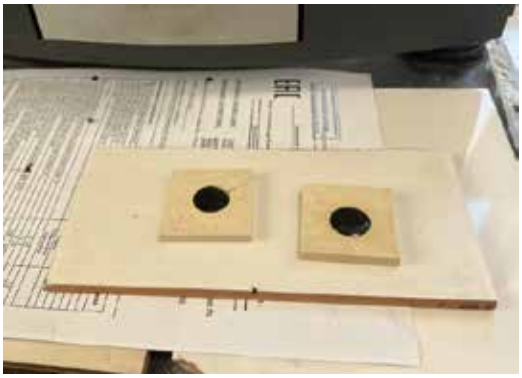
Surface plastic rutting on asphalt concrete pavements develops during the hottest time of the year and has, mainly, a cumulative effect – it is formed under the influence of the load from passing vehicles. In accordance with the current regulatory documentation, the resistance of asphalt concrete to this type of rutting is assessed by the values of the «average rut depth» indicator obtained during the corresponding tests in laboratory conditions. The essence of the method lies in the cyclic effect of the load (20000 passes of the loaded wheel) on the control sample of asphalt concrete at a given temperature, followed by determining the average rut depth based on the results of two parallel tests [4].

The target values of the «average rut depth» indicator are established in the regulatory documentation for asphalt concrete mixtures of various types, depending on the operating conditions of specific sections of motorways. Achieving these target indicators in laboratory conditions is mandatory for approving the composition of the asphalt concrete mixture for production of works. Additionally, quality control of the asphalt concrete mixture for this parameter is provided at the stage of its production with a frequency of once every 15 days.

The fact of a significant influence of the properties of the binder included in the asphalt concrete mixtures on the properties of asphalt concrete, including resistance to plastic rutting, is noted in the works of many authors [1, 3, 5–15]. The assessment of the possibility of using a specific batch of binder for preparation of asphalt concrete mixture is currently carried out on the basis of incoming quality control of this material, by comparing the actual values of physical and mechanical characteristics obtained in the laboratory with the minimum standard values established for the grade of binder adopted in the design documentation, without taking into account the actual values of the quality characteristics of the binder used at the stage of laboratory selection of the composition. The implementation of this approach, which consists only in confirming the required grade of binder when assessing the possibility of its use, without considering the actual values of its characteristics, can lead to failure to ensure the resistance of the asphalt concrete mixture to plastic rutting at the stage of its production.

To test this hypothesis and develop a new approach to assessing the possibility of using

Pic. 1. Ridge of the uplift of the asphalt concrete pavement with a surface plastic rut [photos by the authors].



a)

b)

Pic. 2. Preparation of control plate samples (a) with testing on a dynamic shear rheometer (b) [photos by the authors].

batches of binders entering production, the authors conducted studies aimed at identifying the dependence of the resistance of asphalt concrete to plastic rutting on the properties of binders.

RESULTS

The parameters characterising the efficiency of the binder at positive temperatures are the shear resistance of the original binder and the shear resistance of the binder aged by the *RTFOT* method. The *RTFOT* method allows us to evaluate the changes in the properties of the binder (the term «aging» is used in the regulatory documentation) that occur during preparation of hot asphalt concrete mixtures.

The laboratory conducted studies of samples of binders of the *PG [Performance Grade] 64–40* produced by four manufacturers – hereinafter samples № 1 – № 4. The choice of the bitumen binder performance grade is due to the climatic conditions of operation of motorways in Novosibirsk region.

To determine the value of the shear resistance of the bitumen binder in accordance with the regulatory methodology, control samples with a diameter of 25 mm (Pic. 2a) were made from each binder with their subsequent testing with a dynamic shear rheometer (Pic. 2b).

The results of testing the shear resistance of the original binder and the shear resistance of the binder aged by the *RTFOT* method for all samples are shown in Pic. 3. The level of the horizontal red line in Pic. 3 corresponds to the requirements for the shear resistance values of the binder *PG 64-Y* grade at a test temperature of 64^0C.

The obtained results confirm that all tested binders meet the requirements for the *PG* 64-Y grade, while for the different tested samples of the original binder the values of shear resistance differ by more than 5 times, and the values of shear resistance of the binder aged by the *RTFOT* method by more than 2 times.

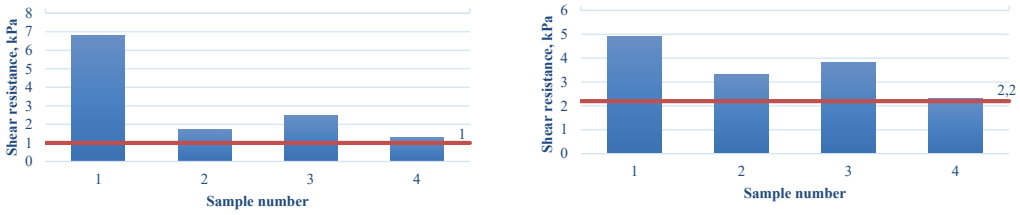
To determine the effect of shear resistance of the bitumen binder on plastic rutting, the stone mastic asphalt concrete mixture *SMA*-16, used in Novosibirsk region, was chosen as the test material. The composition of the mixture, given in Table 1, was selected by the authors as part of the work on construction control of road construction projects.

At the stage of selecting the specified composition in laboratory conditions, the value of the «average rut depth» indicator was obtained

Table 1

Composition of the SMA-16 mixture [performed by the authors]

Name of the material		Content in the mixture, %
Mineral part of the mixture by fractions	fr. 0–4 mm	16,5
fr. 4–11,2 mm		44,3
	fr. 11,2–16,0 mm	25,1
	Mineral powder MP-1	8,5
Stabilising additive SD-3		0,4 (in 100 %)
Organic binder PG 64–40		5,2 (in 100 %)



a) b)

Pic. 3. Results of testing the shear resistance of the original binder (a) and the binder aged by the RTFOT method (b) at a test temperature of 640C [performed by the authors].

a) b)

Pic. 4. Preparation of control sample slabs (a) with testing on a load wheel rolling tester (b) [performed by the authors].

equal to 3,30 mm with the values of shear resistance of the used bitumen binder *PG* 64–40 at a test temperature of 64^{0}C: for initial bitumen binder –1,3 kPa; for bitumen binder aged by the *RTFOT* method – 3,0 kPa.

As part of the study, 4 samples of stone mastic asphalt concrete mixture *SMA*-16 were prepared in laboratory conditions using the previously studied *PG* 64–40 binders.

To determine the values of the «average rut depth» indicator, control slabs (Pic. 4a) were prepared on a sector compactor using respectively each prepared sample of stone mastic asphalt concrete mixture *SMA*-16, with their subsequent testing on a load wheel rolling tester unit (Pic. 4b).

The results of determining the values of the «average rut depth» indicator, obtained at the stage of selecting the composition and the stage of conducting testing, are shown in Table 2.

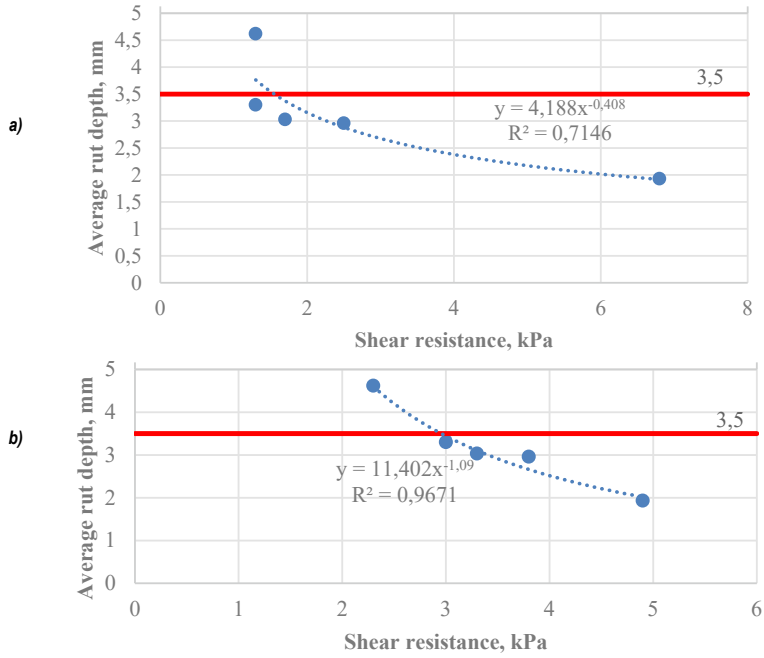
Analysing the results of the tests, it should be noted that for sample No. 4, corresponding to the *PG* 64–40 binder grade in terms of shear resistance, the value of the «average rut depth» indicator was obtained that does not correspond to the requirements of the regulatory documentation established for the *SMA*-16 stone mastic asphalt concrete mixture (no more than 3,5 mm). This fact confirms the correctness of the hypothesis put forward by the authors.

To develop a new approach to assessing the possibility of using batches of binders supplied to production site, the authors conducted a regression analysis of the obtained data, based on the results of which functional dependencies were established for the value of the «average rut depth» indicator on the value of the shear resistance of the binder for the *SMA*-16 asphalt concrete mixture of the composition under study (Pic. 5).

Table 2

Results of determining the values of the «average rut depth» indicator [performed by the authors]

Parameter	Meas. unit	Value of the parameter				
		at the stage of selecting the composition of the mixture	for the sample №			
			1	2	3	4
Average rut depth	mm	3,30	1,93	3,03	2,96	4,62



Pic. 5. Dependence of the value of the «average rut depth» indicator on the shear resistance of the original binder (a) and the binder aged using the RTFOT method (b) [performed by the authors].

Table 3

Results of testing the significance of dependencies using the F-criterion [performed by the authors]

№ of the dependence	n	m	R^2	F_{fact}	F_{tabl}	
					α = 0,05	α = 0,01
1	5	1	0,7146	7,51	10,13	34,12
2	5	1	0,9671	88,19	10,13	34,12

The obtained dependencies are of the following types:

$$RD = 4{,}188 \cdot \left(\frac{G^*}{\sin\delta}\right)^{-0{,}408}, \quad (1)$$

$$RD = 11{,}402 \cdot \left(\frac{G^*}{\sin\delta}\right)^{-1{,}09}, \quad (2)$$

where RD is average rut depth, mm;

G^* – complex shear modulus, kPa;

δ – phase angle, rad;

G^*/δ – shear resistance of the original binder (1) or of the binder aged by the *RTFOT* method (2), kPa.

The results of significance test of the obtained dependencies (regression equations) using the Fisher's exact criterion (F-criterion) are given in Table 3.

The data presented in Table 3 confirm the possibility of using dependence (2) when calculating the predicted values of the «average rut depth» indicator through the values of the shear resistance of binders aged using the *RTFOT* method.

CONCLUSION

Based on the results of the conducted research, the authors have confirmed the hypothesis about the presence of a significant drawback in the existing approach to production of asphalt concrete mixtures, which consists in

confirming only the required grade of binder when assessing the possibility of its use, without taking into account the actual values of its characteristics. It is shown that this drawback in some cases can lead to failure to ensure the resistance of the asphalt concrete mixture to plastic rutting. The relationship between the resistance of asphalt concrete to formation of plastic rutting and the shear resistance of binders included in the asphalt concrete was established, and a functional dependence of the value of the «average rut depth» indicator on the value of the shear resistance indicator of the binder aged by the *RTFOT* method for the *SMA*-16 asphalt concrete mixture of the composition under study was obtained. The use of this functional dependence will allow determining the predicted value of the «average rut depth» indicator at the stage of incoming inspection of binders, and consequently significant reduction in the likelihood of producing asphalt concrete mixture that does not meet the requirements of regulatory documentation for resistance to surface plastic rutting.

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