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INCREASING PERFORMANCE OF ROAD LAYERS FROM POROUS ASPHALT

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Statement of the problem. Studies of the degree of influence of the content of polymer-modified bitumen, adhesive additives and mineral materials of various rocks on the physic-mechanical and operational properties of draining asphalt have been conducted.
Results. The results of the mathematical planning of a three-factor experiment are presented in the process of studying the operational properties of porous asphalt.
Conclusions. The composition of the draining asphalt mix on mineral materials of various types and types of rocks and polymer-modified bitumen PMB 50/70 with an adhesive additive that provides an increase in the abrasion service life, reaction rate and water resistance has been developed and justified.

Keywords: draining asphalt, porous asphalt mix, upper layer, polymer-modified bitumen, water permeability.

Introduction. Drainage asphalt concrete pavements are conducive to high performance characteristics of highways [1, 6, 5, 19]. A high porosity of asphalt concrete contributes to an increase in water permeability, which reduces the amount of surface water and, thus, reduces the formation of splashes during rainy weather [11, 12, 15]. This reduces the risk of aquaplaning and improves visibility on the roads and ultimately safety. Additionally, a special texture of the surface of the draining asphalt concrete (Fig. 1) helps to reduce noise that occurs when a tire interacts with a surface.

Drainage asphalt concrete when applied in the upper layers of the pavement is exposed to external factors, particularly abrasion from car studded tires, surface contamination from agricultural machinery. The experience of overseas countries shows that the life cycle of surfacing made of highly porous asphalt concrete mixtures with open granulometry is no longer than 2–4 years largely due to premature peeling and chipping [15].

Fig. 1 Texture of the surface of asphalt concrete samples:
a) crushed stone-mastic asphalt concrete CSMAC-15;
b) draining asphalt concrete DA-15

The scientific novelty of the study is due to the fact that new criteria are suggested for assessing the quality of draining asphalt concrete in terms of "water resistance based on the Lottman method", "abrasion based on the Prall Test method" and rutting resistance which unlike the existing methods, allow one to predict the service life of the top layer of the surfacing, identify the degree of influence of studded tires and weather and climatic factors on the wear-and-tear layers of draining asphalt concrete. In addition, some solutions are proposed for improving the quality of draining asphalt concrete by optimizing its composition using a complex binder based on polymer-modified bitumen and an adhesive additive.

1. Selection of the draining asphalt concrete mixture by the method of granulometric curves. For selecting the composition of a draining asphalt concrete mixture according to STO AVTODOR 2.15-2016, crushed stone of various rocks (granite, gabbro and sandstone) fractions of 5—10 and 10—15 mm were employed (grain compositions are shown in Table 1), sand from crushing screenings, activated mineral powder, stabilizing — additive SD-3 and polymer-modified bitumen grade PMB 50/70 [2, 16].

Based on the analysis of the manufacturer's regulatory and technical documentation, the content of the stabilizing additive is 0.4 % of the mass of mineral materials (STO 77142802-003-2011).

Polymer-modified bitumen SBS PMB "DDS" 50/70 72-22 manufactured by JSC "SMU-Dondorstroy" was employed as an organic binder.

All the components of the asphalt concrete mixture complied with the requirements of the current regulatory and technical documentation.

Table1

Grain composition of mineral materials

Name	Grain size, smaller, mass %										
	40	20	15	10	5	2.5	1.25	0.63	0.315	0.16	0.071
Crushed sandstone fraction of 10—15 mm	100.0	100.0	92.71	2.03	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Crushed sandstone fraction of 5—10 mm	100.0	100.0	100.0	98.20	8.97	0.0	0.0	0.0	0.0	0.0	0.0
Crushed granite fraction of 10—15 mm	100.0	100.0	91.36	3.08	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Crushed granite fraction of 5—10 mm	100.0	100.0	100.0	97.33	8.24	0.0	0.0	0.0	0.0	0.0	0.0
Crushed stone gabbro-daibaz fraction of 10—15 mm	100.0	100.0	93.55	2.58	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Crushed stone gabbro-daibaz fraction of 5—10 mm	100.0	100.0	100.0	98.11	7.75	0.0	0.0	0.0	0.0	0.0	0.0
Sand from sandstone crushing screening	100.0	100.0	100.0	100.0	99.30	74.28	56.32	43.14	33.53	23.17	14.40
Sand from screenings of crushing granite	100.0	100.0	100.0	100.0	99.08	73.52	57.41	41.72	30.37	24.12	12.27
Sand from gabbro crushing screenings	100.0	100.0	100.0	100.0	98.72	70.57	58.67	46.04	35.17	27.48	15.37
Mineral powder	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.92	99.43	96.88	83.44

The optimal content of mineral materials and organic binder was selected according to the physical and mechanical properties, i.e., residual porosity, average density, resistance to delamination in terms of binder runoff, frost resistance coefficient and filtration rate.

In order to identify the relationship between the amounts of inert materials and organic binder, experimental studies were performed with varying contents of the crushed stone component of the asphalt concrete mixture and polymer-modified bitumen.

The curves of the granulometric composition of the DA-15 drainage asphalt concrete mixture are presented in Fig. 2.

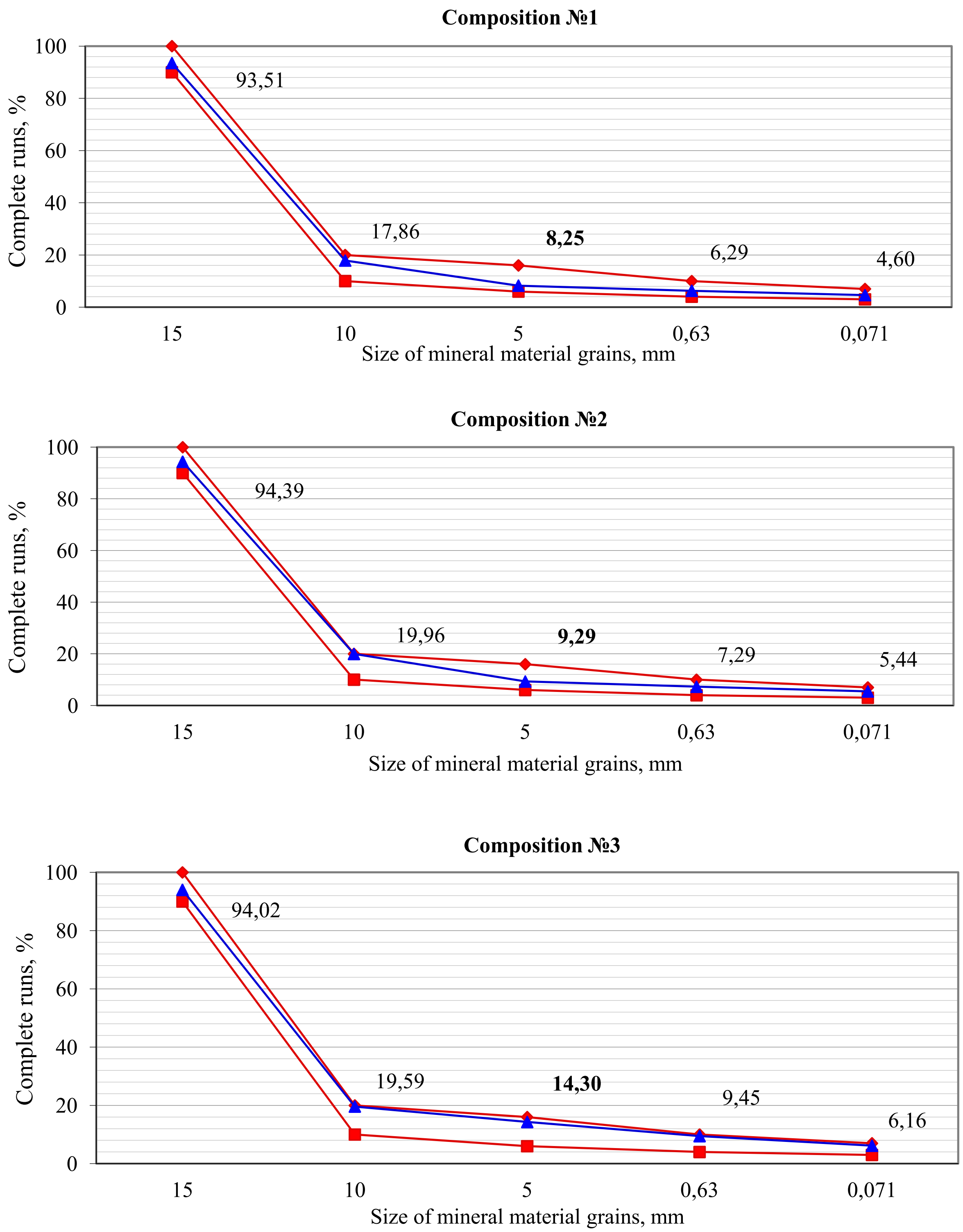

Fig 2. Curves of the granulometric composition: composition №1 with a crushed stone content of 91.75 %; composition № 2 with a crushed stone content of 90.71 % and composition № 3 with a crushed stone content of 85.7 %

The test results of the developed formulations with a varying content of an organic binder are presented in Fig. 3.

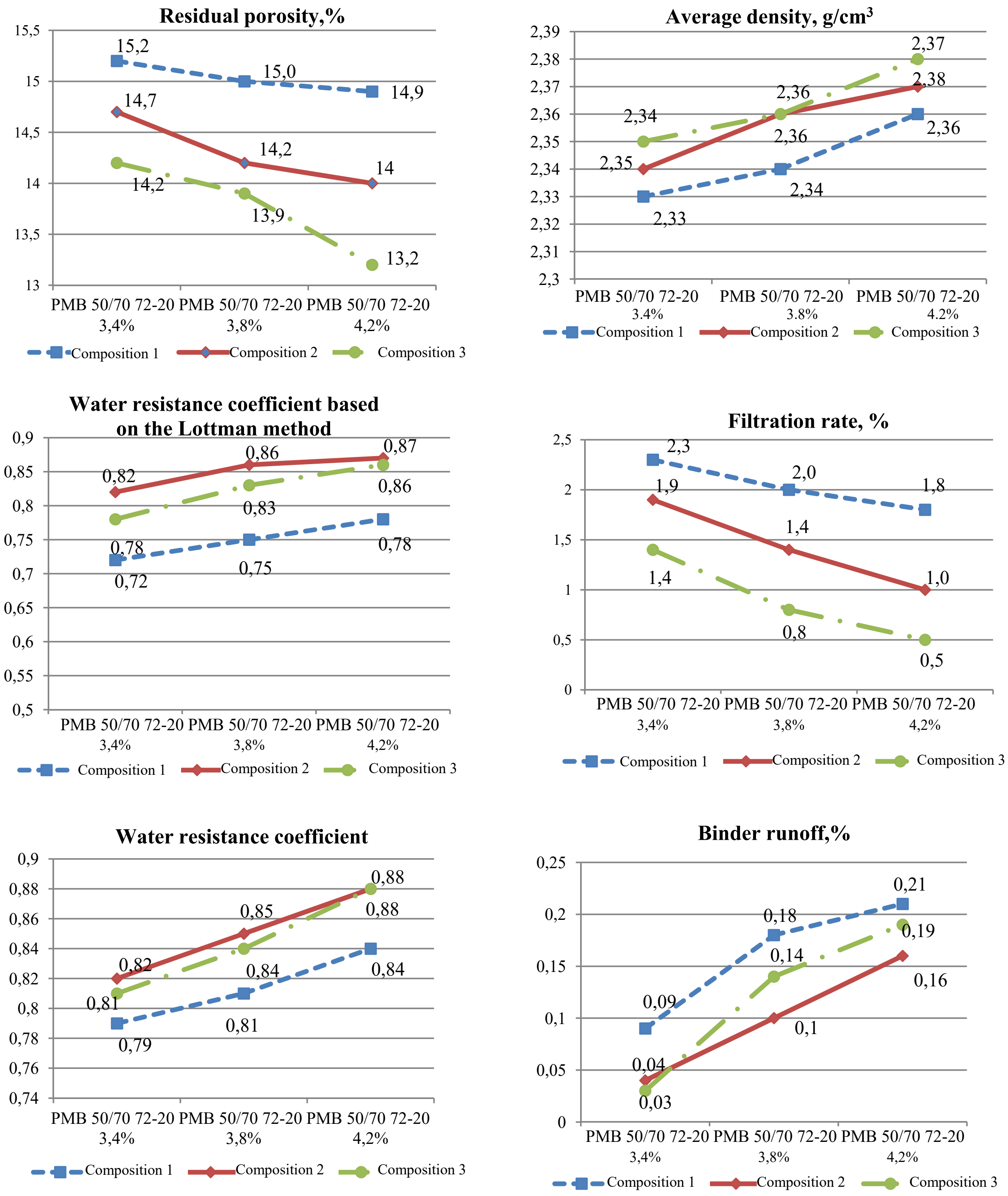

Fig. 3. Results of the tests of draining asphalt concrete DA-15 (PMB — Polymer-modified bitumen)

According to the data in Fig. 3, as the percentage of the binder decreases and the crushed stone part of the mixture increases, a rise in the residual porosity takes place and thus a decrease in the density of asphalt concrete. However, it should be noted that all the results for the residual porosity are within regulatory limits. Based on the obtained results, the most optimal properties are found in the mixtures of composition № 2 with the amount of PMB of 3.8 %. An increase in the bitumen content leads to a considerable decrease in the filtration rate by 40 % and an increase in the binder runoff by 30 %. Draining asphalt concrete based on polymer-bitumen binders have low values in terms of the “coefficient of water resistance based on the Lottman method” and “coefficient of water resistance” according to GOST (ГОСТ) 12801-98 “Materials Based on Organic Binders for Road and Airfield Construction. Test Methods”, which indicates that in the composition of asphalt concrete mixtures it is essential to increase the thickness of the bitumen film through the use of an adhesive additive.

2. Development of mathematical dependences of physical, mechanical and operational characteristics on the type of rock, amount of polymer-modified bitumen and an adhesive additive. The influence of the content of polymer-modified bitumen, adhesive additives and mineral materials of various rocks on the physical, mechanical and operational properties of draining asphalt concrete was investigated by means of the mathematical planning of a three-factor experiment [6, 17, 20, 21]. In the process of experimental studies, tests were performed according to the indicators “water resistance coefficient”, “filtration rate” and “abrasion”.

In order to assess the effect of an adhesive additive and mineral materials of a basic and acidic rock composition on the physical, mechanical and operational properties of draining asphalt concrete, composition № 2 was taken and optimized in compliance with the grain size composition of the used mineral materials. The experimental compositions are shown in Table 2.

Table 2

Compositions of draining asphalt concrete mixtures depending on the rock of the mineral material

Road construction materials	Compositions of DA-15 depending on the rock of the mineral material		
	Gabbro	Granite	Sandstone
1. Crushed stone of fraction of 10—15 mm	79.66	80.10	80.00
2. Crushed stone of fraction of 5—10 mm	10.66	10.19	10.26
3. Sand from sandstone crushing screening	3.32	3.35	3.38
4. Mineral powder	5.96	5.97	5.97
5. Stabilizing additive 3	0.39	0.39	0.39
Total:	100.00	100.00	100.00

The investigated indicators of the properties of draining asphalt concrete in a three-factor experiment were filtration rate, coefficient of water resistance based on the Lottman method and abrasion by means of the Prall-test method [4, 8, 11].

During the experimental studies, 9 samples were produced for each point of the plan. The samples were designed in compliance with Preliminary National Standard ПНСТ 115-2016.

The following factors were selected as variable values in the three-factor experiment: X_1 is the rock of mineral materials; X_2 is the content of the AMDOR-20T adhesive additive; X_3 is the content of polymer-modified bitumen PMB 50/70. "Abrasion", Y_1; "Filtration Rate" Y_2, "Water Resistance Coefficient" Y_3.

In the theory of experiment planning these values Y_i are called response functions.

The experimental design and the intervals for varying factors were identified based on the preliminary test results. The investigated factors and the ranges of their variation are shown in Table 3.

Table 3

Investigated factors and variation intervals in the experiment plan

Characteristics	Code value	Investigated factors		
		X_1 Rock	X_2 Content of the adhesive additive,%	X_3 Content of the polymer-modified bitumen,%
Main level (X_{oi})	0	granite	0.3	3.8
Variation interval Λ_i	X	—	0.1	0.2
Upper level (X_i^{max})	$X_i = +1$	gabbro	0.4	4.0
Lower level (X_i^{min})	$X_i = -1$	sandstone	0.2	3.6

The experimental design and the natural values of the studied factors at each point are shown in Table 4.

The relationship between the studied variables and performance properties of the draining asphalt concrete were identified with the regression equation:

$$y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_{11}X_{11} + B_{22}X_{22} + B_{33}X_{32} + B_{12}X_1X_2 + B_{13}X_1X_3 + B_{23}X_2X_3,$$

where B_i is the regression coefficient; X_i is the number of the variables; Y_i is the response function.

Table 4

Experiment plan and natural values of the variables

Plan number	Experiment plan			Natural values of the variables		
	X_1	X_2	X_3	X_1 Rock	X_2 Content of the adhesive additive,%	X_3 Content of the polymer-modified bitumen, %
1	1	–1	–1	Gabbro	0.2	3.6
2	1	–1	1	Gabbro	0.2	4.0
3	–1	–1	1	Sandstone	0.2	4.0
4	–1	–1	–1	Sandstone	0.2	3.6
5	0	–1	0	Granite	0.2	3.8
6	0	0	–1	Granite	0.3	3.6
7	–1	0	0	Sandstone	0.3	3.8
8	0	0	1	Granite	0.3	4.0
9	1	0	0	Gabbro	0.3	3.8
10*	0	0	0	Granite	0.3	3.8
11	1	1	–1	Gabbro	0.4	3.6
12	1	1	1	Gabbro	0.4	4.0
13	–1	1	1	Sandstone	0.2	4.0
14	–1	1	–1	Sandstone	0.2	3.6
15	0	1	0	Granite	0.3	3.8
16*	0	0	0	Granite	0.3	3.8
17*	0	0	0	Granite	0.3	3.8

Based on the results of a three-factor experiment, mathematical models were obtained that sufficiently describe the response functions from variable factors, rational ranges of their values were identified in order to predict the degree of influence on the indicators of physical, mechanical and operational properties of draining asphalt concrete [1].

The isosurfaces of the main investigated indicators are shown in Fig. 4.

According to the analysis of the isosurfaces in Fig. 4, the following basic principles of the influence of the investigated factors on the operational properties of draining asphalt concrete can be identified:

— draining asphalt-concrete mixtures prepared using mineral materials from gabbro and diabase or granite are 46% more resistant to abrasion according to the Prall-test method than those prepared using sandstone mineral materials;

— as the binder content increases and the concentration of an adhesive additive is at its maximum, draining asphalt concrete mixtures are more stable in terms of abrasion according to the Prall-test method than with low concentrations of a binder and adhesive additive, which is largely due to an increase in adhesive and cohesive bonds;

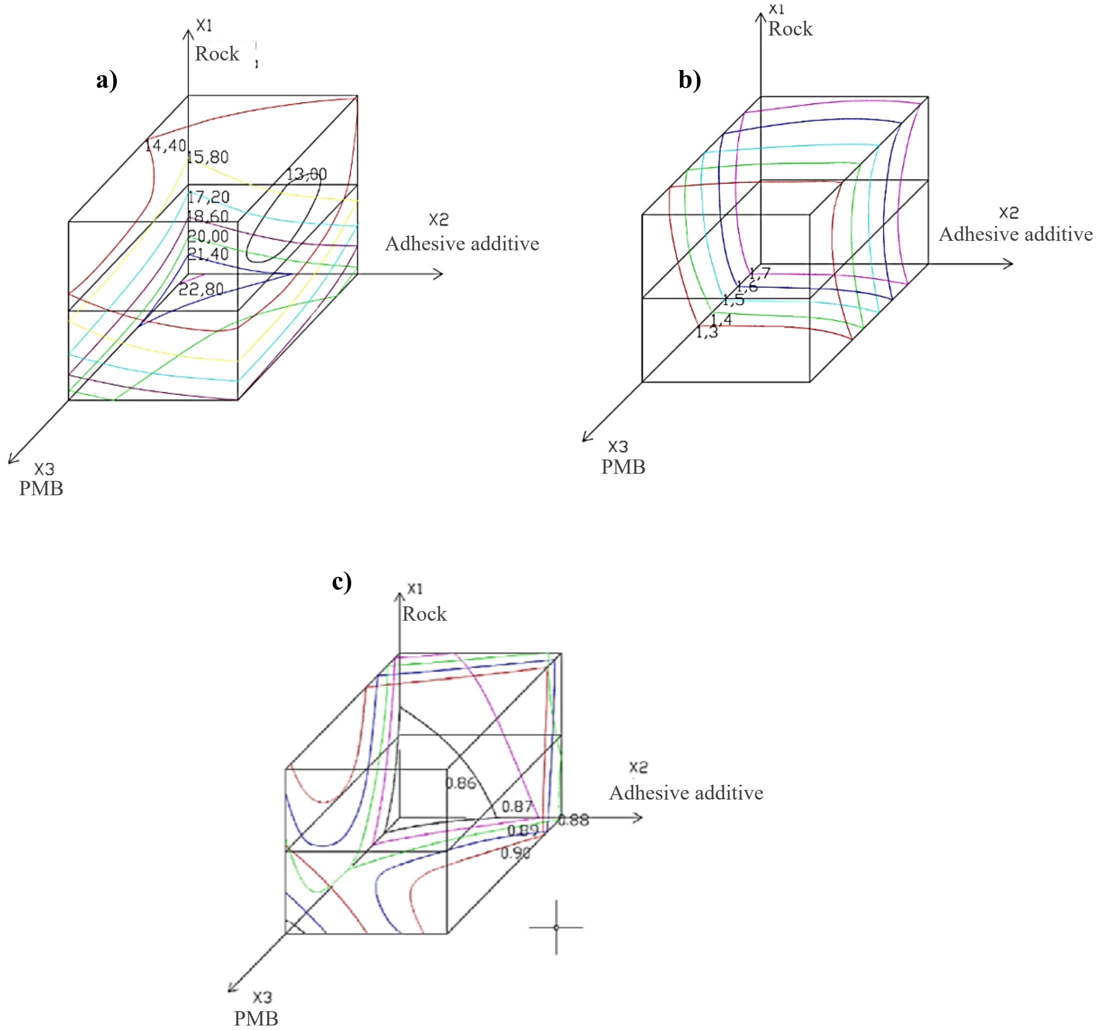

Fig 4. Isosurfaces of the investigated indicators where (a) is the abrasion based on the Prall-test; (b) is the filtration rate ; (c) is the water resistance coefficient based on the Lottman method

— an increase in the concentration of an adhesive additive in all the investigated mixtures regardless of the type of rock and the percentage of binder has the major influence of the coefficient of water resistance based on the Lottman method;

— the rate of filtration largely subject decreases as the percentage of binder rises, which is associated with a decrease in the number of pores in asphalt concrete.

Hence based on the data of the experimental studies, it was found that for the preparation of draining asphalt concrete mixtures with high physical, mechanical and operational properties, mineral materials using gabbro-diabase are recommended, and the binder content should be 3.7 % with an adhesive additive concentration of at least 0.4 % by weight of organic binder and 3.8 % at a concentration of adhesive additives of 0.3 % of the mass of the organic binder.

3. Predicting the life cycle of the upper surfacing layer. In order to predict the life cycle of the draining asphalt concrete, tests were conducted on the optimized composition of the draining asphalt concrete on mineral material using gabbro-diabase and an organic binder content of 3.7 % with an adhesive additive for rutting resistance.

The preparation of slab specimens for rutting tests was performed on a sector compactor simulating the process of compaction of the asphalt concrete mixture with rollers in production conditions [17, 20].

Prior to the testing, plate specimens were thermostated in a climatic chamber at a temperature of (60±1) °C for 4 hours and then exposed to the action of a wheel for a certain number of cycles [15]. The test results are in Figure 5.

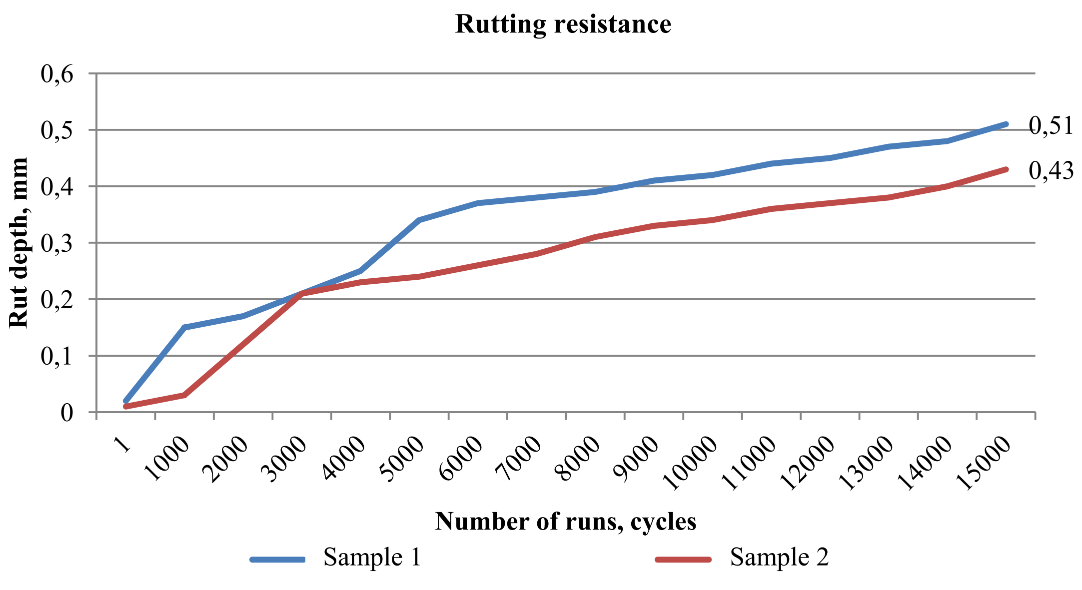

Fig 5. Graph of the rutting resistance of draining asphalt concrete using PMB 50/70 with the adhesive additive AMDOR 20T

The analysis of the research results showed that with the optimal composition of all the components of the draining asphalt concrete mixture, the actual value based on "rutting resistance" averages 0.47 mm.

When predicting the life cycle of the draining asphalt concrete pavement using the maximum permissible rutting value (2 cm) in compliance with the current regulatory and technical documentation, its operation is possible for more than 7 years without the formation of plastic deformations (see Fig. 6).

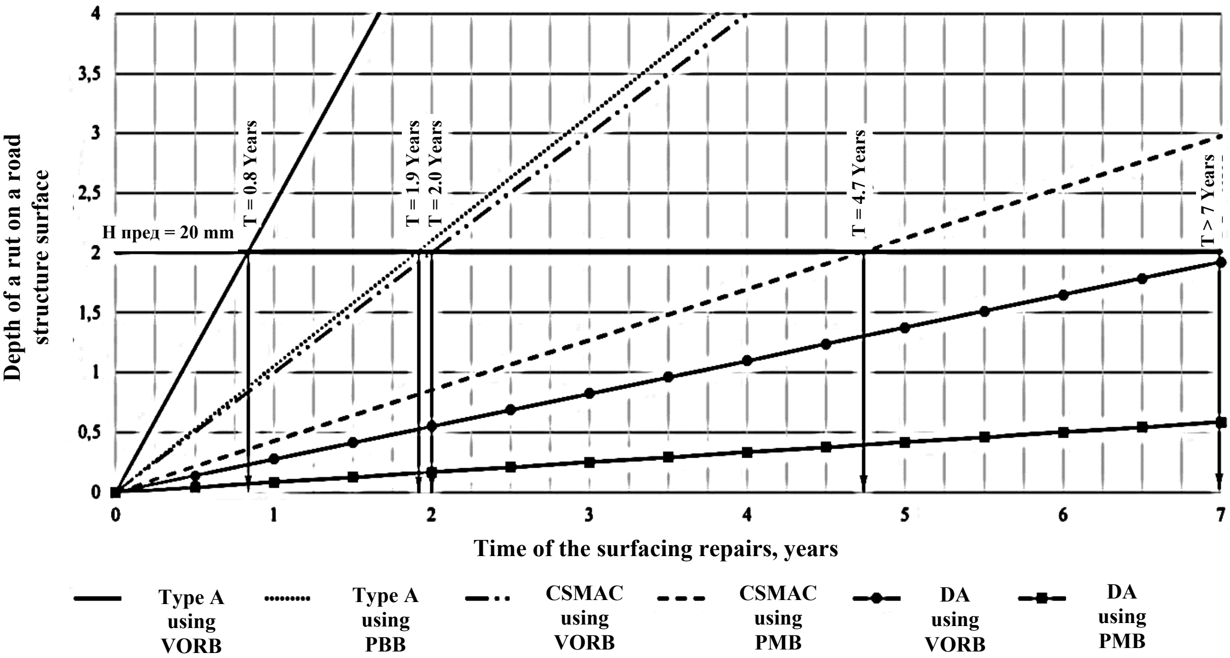

Fig. 6. Predicted depth of a rut on a road surfacing depending on the type of asphalt concrete: Нпред is a maximum permissible number for the rutting resistance; T is the life cycle of a surfacing; Type A is a fine-grained dense Type A asphalt; CSMAC is crushed stone mastic asphalt concrete CSMAC-15; DA is draining asphalt concrete DA-15; VORB; PMB is polymer-modified bitumen

Conclusions. The use of an adhesive additive makes it possible to increase the water resistance index based on the Lottman method by increasing the bitumen film on the surface of mineral materials, which in turn leads to an increase in resistance to cracking. In order to increase the resistance of draining asphalt concrete to climatic factors, the content of the adhesive additive should be at least 0.4 %.

The newly developed compositions of draining asphalt concrete with a complex modified binder provide the required performance characteristics, i.e., abrasion, filtration rate and water resistance, during the entire life cycle of the top layer of the coating. The developed compositions increase the life cycle of the upper surfacing layer and the turnaround time from 3—4 years to 5—7 years.

The study has shown that application of drainage asphalt concrete on mineral materials using gabbro-diabase or granite is less susceptible to abrasion under the influence of studded tires, which in turn improves the durability of a pavement.

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