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Experimental study of asphalt concrete as the optimal material for lining irrigation canals

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ABSTRACT

Introduction. The main losses of water in irrigation systems occur due to filtration, determined by the properties of the soil in which the canal passes. Loss due to filtration in irrigation systems amounts up to 50% of the water taken for irrigation. In addition to the physical and chemical properties of the soil, the size of the wetted perimeter, the water horizon in the canal, the groundwater level and other factors are also of great importance. **Methods and materials.** The selection of asphalt concrete proportioning was carried out by laboratory method and Tsiat curves. The study was carried out on the chemical and physical properties of Shymkent bitumen and their mixtures with Aktau bitumen; loess aggregate, limestone and Shymkent cement were used. Micro- and nanostructural analysis of the resulting asphalt concrete was carried out by scanning electron microscope (SEM). **Results and discussion.** Asphalt concrete prepared with cement has shown a decrease in temporary compressive strength at 50°C by 70–38%, prepared with limestone – by 47–33%, and prepared with loess – by 66–20%. **Conclusion.** Ground limestone turned out to be the best aggregate for asphalt concrete, as it produces higher quality asphalt concrete than other aggregates. Ground limestone gives a particularly dramatic increase in the quality of asphalt concrete in fine-grained asphalt concrete. An increase in temperature from 20 to 50°C sharply reduces the temporary compressive strength of asphalt concrete and less sharply with an increase from 50 to 70°C.

KEYWORDS: asphalt concrete, irrigation canals, lining, bitumen, nanostructured microfillers, mineral mixture.

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INTRODUCTION

One of the main tasks of irrigation is the rational use of available water resources for irrigation, i.e., their distribution throughout the irrigation network without large losses along the way. Loss due to filtration in irrigation systems amounts to up to 50% of the water taken for irrigation and is the main reason for the unfavorable balance of groundwater in the irrigated area, causing waterlogging and, as a consequence, salinization of areas. Therefore, the issue of lining canals with appropriate materials is of great importance in irrigation [1–3].

Modern researchers (Petrusevich V.V., Garbuz A.Yu., Talalaeva V.F., etc.) are actively developing various hydrophobic coatings for hydraulic structures. Mainly considering the influence of compositions of water-repellent agents on the physical and mechanical properties of asphalt concrete pavements [1, 3]; technologies for repairing concrete lining of canals [4–6]; optimization of the location of expansion joints in concrete lining of canals, etc. [7–10].

Asphalt concrete, as a material for lining irrigation canals, has the following advantages compared to other materials [1–5]:

1. It is waterproof, which cannot be said about cement concrete;
2. Compared to cement concrete, it has some plasticity, i.e. the ability to deform. This gives it the opportunity, to a certain extent, to follow the deformations of the bottom and side surfaces of the canal, without much loss of its waterproof properties;
3. It has the ability to harden quickly (2–3 days), which makes it possible to quickly put canals into operation, which cannot be achieved when lining canals with cement concrete;
4. Asphalt concrete lining, in the event of cracks and local damage, can be easily and quickly repaired. In addition, the material of old clothing can be reused with the addition of some new bitumen;
5. Asphalt concrete is practically not exposed to mineral groundwater and waste water;
6. Asphalt concrete is frost-resistant.

The above properties of asphalt concrete attracted attention and prompted us to study the issue of using asphalt concrete for lining irrigation canals using local materials.

Today, Austrian and German construction companies are actively using hydrophobic asphalt concrete coatings for lining irrigation canals (Fig. 1).

The Kazakh Main Academy of Architecture and Construction (KazGASA) has been engaged in such research for a number of years. Their continuation is this work, which began in the second half of 2022 [2, 5, 7]. Its tasks included resolving the following issues:

1. Study of the chemical and physical properties of Shymkent bitumen and their mixtures with Aktau bitumen;
2. Study of loess, limestone and Shymkent cement aggregates;
3. Research of inert materials;
4. Selection of asphalt concrete recipes using the laboratory method and Tsiat curves with the above aggregates. The purpose of this was to determine the best method for selecting asphalt concrete;
5. Study of the influence of various aggregates on the quality of asphalt concrete and the possibility of using loess as a filler;
6. Study of the influence of Shymkent bitumen and their mixture with Aktau bitumen on the quality of asphalt concrete and the possibility of using them in asphalt concrete;
7. Study of the influence of temperature on the quality of asphalt concrete.

Let's move on to consider the results of these studies.

MATERIALS AND METHODS

Properties of bitumen

Aktau and Shymkent bitumens, as well as their mixtures, were used as a binder in asphalt concrete. Aktau bitumen was used in the design of recipes and in studying the influence of various aggregates on the quality of asphalt concrete.

To select the appropriate grade of Aktau bitumen, a study of the physical properties of available bitumen was carried out (Table 1).

Bitumen penetration was determined with a Lintel PN-20 automatic penetrometer. Ductility was determined with a digital ductilometer (Fig. 2).

From Table 1 it can be seen that the most suitable for asphalt concrete is the bitumen of barrel No. 3, which was chosen for the work.

To study Shymkent bitumen and their mixture with Aktau bitumen for the quality of asphalt concrete, bitumen grade BND 60/90, delivered from Bitumen Plant LLP (Shymkent city, Republic of Kazakhstan) were tested (Table 2).

As can be seen from Table 2, Shymkent bitumens have high penetration and low ductility, so that according to technical conditions they should be considered unsuitable for asphalt concrete. The best bitumen from the above

Fig. 1. **Irrigation canals lined with asphalt concrete:** a – Alz Canal, Germany; b – Canal of Saint Pantaleon, Austria

Table 1
Physical properties of bitumen

Physical properties of bitumen	No. of bitumen barrels					
	1	2	3	4	5	6
Penetration at 25°C	84	15	41	109	25.5	13.5
Ductility at 25°C	>100	3.8	39.5	58.7	3.0	4.2
Softening temperature for ring and ball	47°C	80.5°C	57°C	42.5°C	68°C	80.5°C

Fig. 2. **Determination of penetration and ductility of bitumen:** a — Automatic penetrometer — Lintel PN-20; b — Digital ductilometer, 1500 mm

Table 2
Physical properties of bitumen

Physical properties of bitumen	No. of bitumen barrels										
	1	2	3	4	5	6	7	8	9	10	11
Penetration at 25°C	92	90	92.6	27.3	–	101	100	12.5	102.7	22.5	23.1
Ductility at 25°C	2.8	2.4	7.2	2.3	–	2.7	2.7	1	2.4	2.1	1.9
Softening temperature of the ring and ball in degrees, °C	79.5	87	49	90	37	82	82	>100	93.5	>100	>100

Shymkent bitumens is the bitumen of barrel 3, which was chosen to study the influence of the available Shymkent bitumen on the quality of asphalt concrete.

To improve the quality of Shymkent bitumen, Aktau bitumen was added to it in various proportions, and the mixtures thus obtained were studied for physical properties.

Based on the experience of previous works [3–8], Shymkent bitumen No. 11 was mixed with Aktau bitumen No. 3 and Shymkent bitumen No. 11 with Aktau bitumen No. 1. The results of studies of these mixtures are summarized in Table 3.

A mixture of bitumens No. 5 turned out to be suitable for asphalt concrete, i.e. a mixture with a ratio of 25 to 75% Shymkent to Aktau bitumen, which must be recognized as economically unprofitable.

To study the mixture of Shymkent and Aktau bitumen for the quality of asphalt concrete, mixture No. 5 was chosen.

Based on this, it follows that Shymkent bitumen of the above quality does not meet the technical conditions, so it must be considered unsuitable for asphalt concrete. The quality of Shymkent bitumen can be improved by adding a relatively large amount of Aktau bitumen. But economically this is of little benefit.

Aggregates and inert materials used for asphalt concrete

For asphalt concrete, materials were used that were available at the asphalt concrete plant in Almaty, namely:

1. Granite crushed stone, 17–6 mm in size;
2. Granite fines, 6–0 mm in size;
3. Kaskelen sand;
4. Shymkent cement as a filler;
5. Ground limestone as aggregate.

In addition, ground loess taken from the territory of KazGASA was used as a micro-aggregate.

Table 3
Physical properties of bitumen mixtures

Mix no.	Mixture composition	Penetration at 25°C	Ductility at 25°C	Softening temperature of the ring and ball in degrees, °C
1	Shymkent No. 11-30% +Aktau No. 3-70%	41.5	7	63
2	Shymkent No. 11-90% +Aktau No. 1-10%	32	2.2	100
3	Shymkent No. 11-75% +Aktau No. 3-25%	33	2.9	87
4	Shymkent No. 11-50% +Aktau No. 3-50%	41.1	6.1	65
5	Shymkent No. 11-25% +Aktau No. 3-75%	55	31.5	55

The granulometric composition of the above materials is summarized in Table 4.

The specific gravity of the materials was determined by the Le Chatelier-Candlot flask [9–11]. The volumetric weight of the materials was determined by shaking the material with a volume of 1000 cm^3 to a constant weight using a Tettmyer shaking apparatus (Tetmyer pestle – Vicat device). It was necessary to abandon the determination of volumetric weight by the compaction method on a Baumé pile driver, since different materials require different and large numbers of blows to obtain a constant volumetric weight (Fig. 3).

From Table 4 it is clear that in terms of granulometric composition, Shymkent cement, limestone and loess basically meet the requirements for aggregates, i.e., more than 60% passes through a sieve with a hole of 0.066 mm and on a sieve with a hole of 0.5 mm, no more than 2% remains (according to Tsiat's technical specifications, it is

Table 4
Granulometric composition of materials

Name of materials	Particle size analysis in %									Specific gravity	Volume weight
	6–4 mm	4–2 mm	2–1.0 mm	1.0–0.49 mm	0.49–0.20 mm	0.20–0.12 mm	0.12–0.06 mm	<0.06 mm	Spraying		
1. Granite fines 6–0 mm in size	46.6 43.76	19.8 22.17	7.3 7.64	8.00 8.40	9.0 7.3	3.2 2.83	4.7 2.41	1.2 5.2	0.20 0.20	2.72	1.89 1.91
2. Kaskelen sand	– –	2.83 2.87	1.38 1.75	9.26 8.80	54.3 53.95	18.40 18.50	8.87 9.85	0.50 4.20	4.46 0.08	2.67 2.68	1.72 1.73
3. Shymkent cement	– –	0.81 0.96	0.29 0.28	0.63 0.73	2.56 2.68	6.71 7.01	23.24 23.08	65.36 65.02	0.40 1.24	3.13 3.16	1.87 1.88
4. Limestone filler	–	–	0.18	1.04	8.25	11.85	14.97	62.25	1.46	2.68	–
5. Loess grinding No. 1 grinding No. 2 grinding No. 3 grinding No. 4	– – – –	0.13 – – –	0.72 0.18 0.10 –	1.59 1.01 2.02 2.36	14.73 8.25 16.43 16.76	11.97 11.85 8.33 9.66	10.16 14.97 8.65 6.9	58.92 62.25 63.59 61.28	1.78 1.46 0.48 0.83	2.65	1.60 1.61
6. Crushed stone size 17–6 mm	–	–	–	–	–	–	–	–	–	2.72	1.42 1.42

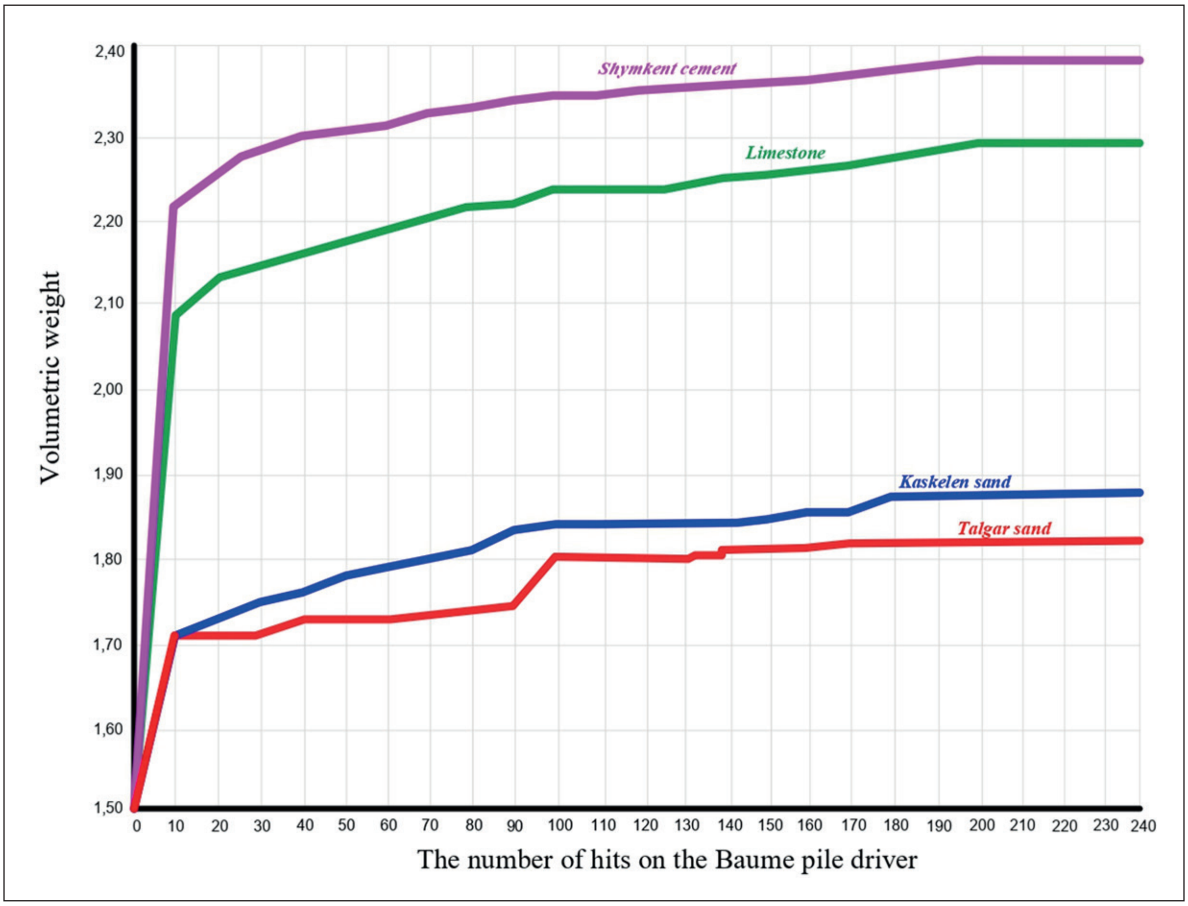


Fig. 3. **Specific gravity of materials**

required that at least 65% pass through a sieve with a hole of 0.088 mm and at least 100% pass through a sieve with a hole of 0.5 mm) [12, 13–15]. The chemical analysis of the above aggregates is as follows (Table 5).

Selection of asphalt concrete recipes

From the available materials, mineral mixtures of asphalt concrete recipes were selected using two methods: the laboratory selection method and the Tsiat curve method [16, 17]. For each of these methods, two recipes were selected with each aggregate, namely, one recipe for fine-grained asphalt concrete and one recipe for medium-grained asphalt concrete [18–22].

The selection of mineral mixtures of recipes according to the laboratory method was carried out in a cubic form with compaction on a Baume pile driver [23]. Using this method, the following mixtures were selected (Table 6).

Table 5
Chemical analysis of aggregates

No.	Name of elements of chemical analysis	Shymkent cement in %	Ground limestone %	Loess in %
1	Hygroscopic water	0.48	0.18	1.75
2	Ignition loss	2.78	38.96	14.24
3	Silica SiO_2	21.70	4.18	51.11
4	Sulfuric anhydride SO_3	1.55	0.63	0.97
5	Calcium oxide CaO	59.60	51.40	12.32
6	Magnesium oxide MgO	3.52	1.38	1.72
7	Sum of oxides $Te_2O_3 \div Al_2O_3$	10.05	3.75	17.81

Table 6
Selection of mineral mixtures

Recipe no.	Composition of recipes in %						
	Crushed stone size 17-6 mm	Granite fines size 6–0 mm	Kaskelen sand	Shymkent cement	Ground limestone	Loess	Total
1	–	58.82	23.52	17.66	–	–	100
1-a	–	55.55	22.23	–	22.22	–	100
1-b	–	58.82	23.53	–	–	17.65	100
2	35.71	25.00	17.86	21.43	–	–	100
2-a	35.71	25.00	17.86	–	21.43	–	100
2-b	35.71	25.00	17.86	–	–	21.43	100

Mineral mixtures selected according to the Tsiat curves and the resulting curves are shown in the graphs (Fig. 4 and 5). To select the amount of bitumen for the above mineral mixtures of the recipes, the specific gravity, volumetric gravity and their porosity were determined [20–24].

The specific gravity of mineral mixtures was determined by the formula [13]:

$$D_n = \frac{100}{\frac{P_1}{D_1} + \frac{P_2}{D_2} + \frac{P_3}{D_3} + \frac{P_4}{D_4}},$$

where P_1, P_2, P_3, P_4 is the amount of crushed stone, granite fines, sand and filler in the mineral mixture in %, D_1, D_2, D_3, D_4 are the specific gravities of crushed stone, granite fines, sand and filler.

Volumetric weight was determined by shaking a mineral mixture with a volume of 1000 cm^3 to a constant weight [13, 14].

The porosity of mineral mixtures was determined using the formula [14]:

$$A_n = 100\left(1 - \frac{R_n}{D_n}\right),$$

where R_n is the volumetric weight of the mineral mixture.

The approximate amount of bitumen for recipes was determined by the formula [14, 15]:

$$\tilde{O} = 100\left(\frac{A_n * a}{R_n}\right),$$

where *a* is the coefficient assumed to be equal to 0.85 for hot and dry climates.

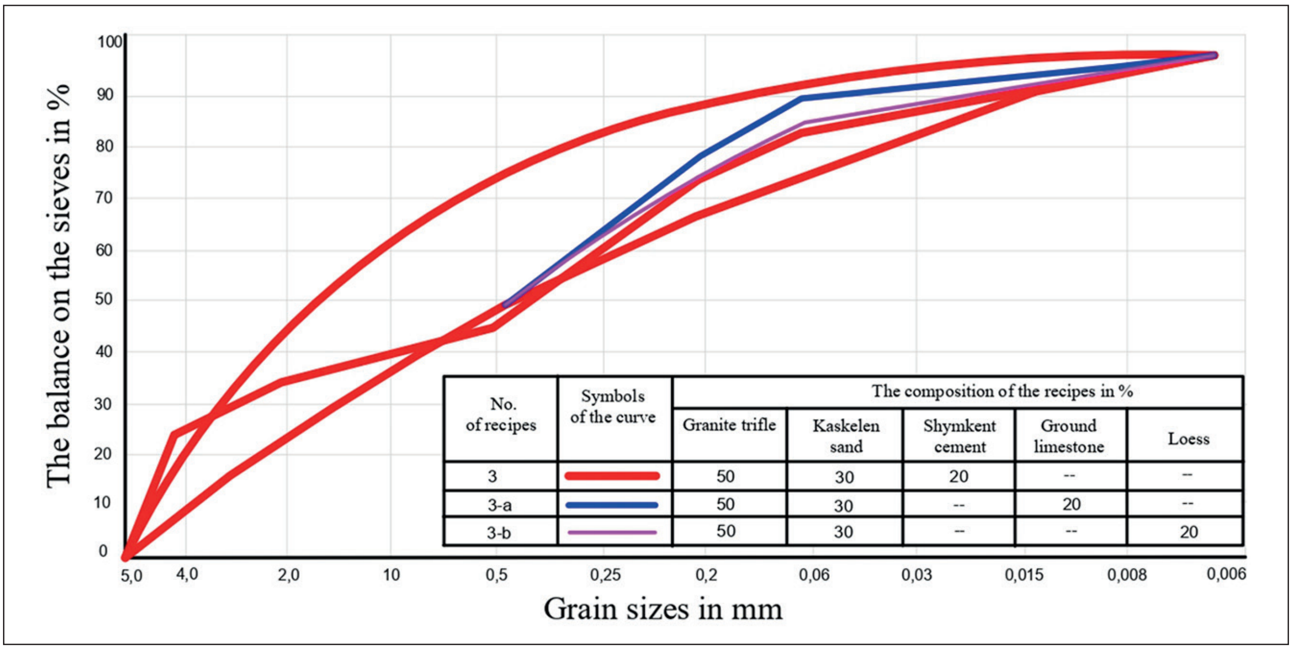


Fig. 4. **Mineral mixtures recipes**

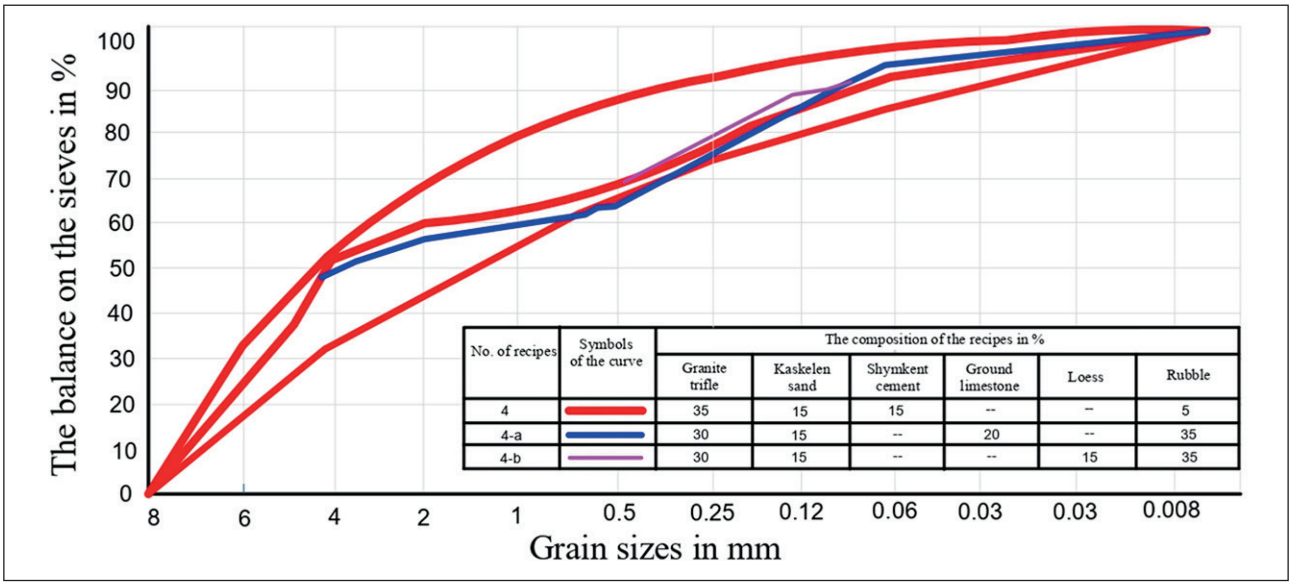


Fig. 5. **Mineral mixtures recipes**

The results obtained are summarized in Table 7.

To finally determine the amount of bitumen for each recipe, several batches of asphalt concrete mixtures were prepared with different amounts of bitumen.

The asphalt concrete mixture was prepared in a paddle mixer as follows: a mineral mixture was prepared according to a specific recipe and heated to a temperature of 175°C, at the same time the bitumen was heated to 175°C [14]. After heating, the mineral mixture and bitumen were placed in a mixer and mixed thoroughly for 5 minutes, while maintaining 240 revolutions of the mixer shaft the entire time. From the mixture prepared in this way, 6 cubes measuring 7×7×7 cm were made for testing temporary compressive strength at temperatures of 20 and 50 or 70°C and 1 sample measuring 20×20×2.5 cm for testing water permeability (Fig. 6).

After preparing and cooling the samples, they were measured, weighed, and their specific gravity, volumetric gravity, and residual porosity were determined [14–16].

The specific gravity of the samples was determined by the formula [13]:

$$D_a = \frac{(n + 100)D_n}{100\Delta + nD_n},$$

where n is the percentage of bitumen in the mixture, and Δ is its specific gravity.

The volumetric weight of the samples was determined by dividing the weight by the volume [13, 14].

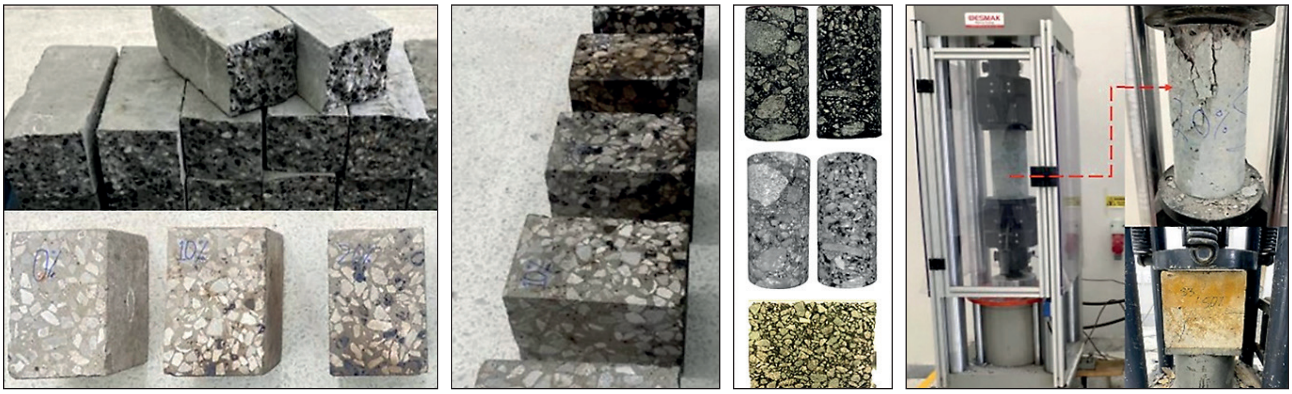
Residual porosity was determined using the formula [13]:

$$A_a = 100\left(1 - \frac{R_a}{D_a}\right).$$

Before testing for temporary compressive strength, samples were kept for 4 hours in a thermostat at a certain

Table 7
Comparative table of mineral mixtures

Name	Recipe no.											
	1	1-a	1-b	2	2-a	2-b	3	3-a	3-b	4	4-a	4-b
Selection method	Laboratory						According to the Tsiat curves					
Specific gravity of mineral mixture	2.78	2.70	2.70	2.76	2.70	2.70	2.78	2.70	2.70	2.78	2.70	2.70
Volumetric weight of the mineral mixture	2.14	2.10	2.05	2.25	2.13	2.13	2.11	2.10	2.03	2.23	2.14	2.11
Porosity of mineral mixture	23.00	22.2	24.10	18.5	21.10	21.10	24.10	22.2	24.80	19.80	20.20	21.80
Approximate amount of bitumen	9.14	8.99	9.99	6.99	8.42	8.42	9.71	8.99	10.38	7.55	8.07	8.78



Pic. 6. **Testing of asphalt concrete samples for temporary compressive strength**

temperature, and then tested on a hydraulic press (Fig. 6) [17–20].

The water permeability test was carried out on the VIP-1 device as follows: first, the sample was exposed to a water pressure of 0.5 atm. for 1 hour, and then every hour the pressure increased by 0.5 atmospheres until it reached 2.0 atmospheres [22, 23].

RESULTS AND DISCUSSIONS

Considering the test results for temporary compressive strength and water permeability in Table 8, we find the optimal amounts of bitumen for each recipe. The test results are summarized in Table 8.

Comparing recipes selected by the laboratory method (Nos. 1, 2, 1-a, 1-b and 2-b) with recipes selected according to the Tsiat curves (3, 4, 3-a, 4-a, 3-b and 4-b), the following conclusions can be drawn:

1. Fine-grained asphalt mixtures selected according to the Tsiat curves (recipes No. 3, 3-a and 3-b) with various aggregates turned out to be of higher quality than similar mixtures selected using the laboratory method (recipes No. 1, 1-a and 1-b).

2. Medium-grained asphalt concrete mixtures selected by the laboratory method with various aggregates (recipes No. 2 and 2-b) turned out to be of higher quality than similar mixtures selected according to Tsiat curves (recipes No. 4 and 4-b). An exception to this is recipe

Table 8

Test results of recipes for temporary compressive strength and water permeability

Recipe no.	Amount of bitumen in %	Specific gravity of asphalt concrete mass	Volumetric weight of asphalt concrete mass	Residual porosity of asphalt concrete mass	Water permeability in %	Temporary compressive strength				Water permeability			
						At a temperature of – 20°C	At a temperature of – 50°C	At a temperature of – 70°C	Processing thickness in cm	At 0.5 atm. within 1 hour	At 1.0 atm. within 1 hour	At 1.5 atm. within 1 hour	At 2.0 atm. within 1 hour
1	10	2.39	2.28	4.50	–	28.04	–	–	2.95	The water didn't pass	The water didn't pass	The water didn't pass	Water appeared near the clamp
1	9.5	2.41	2.26	6.20	–	29.70	18.60	–	2.50	Water near the clamp	Water near the clamp	The water has passed	The water didn't pass
1	9.0	2.42	2.27	6.20	0.65	34.34	14.40	15.00	2.48	The water didn't pass	The water didn't pass	The water didn't pass	*
1	8.5	2.44	2.21	9.50	–	33.78	18.10	–	2.25	*	*	The water has passed	–
1	8.0	2.46	2.21	10.80	–	32.31	20.20	–	2.71	The water has passed	–	–	–
1-a	9.5	2.35	2.31	1.70	–	31.35	–	–	3.24	The water didn't pass	The water didn't pass	The water didn't pass	The water didn't pass
1-a	8.5	2.38	2.24	5.90	–	43.60	33.00	–	2.91	*	*	The water has passed	–
1-a	8.0	2.40	2.25	6.3	–	51.10	–	–	2.61	*	*	The water didn't pass	The water passed through the crack
1-a	7.5	2.41	2.18	9.5	–	54.90	36.80	–	317	*	*	*	The water has passed

Recipe no.	Amount of bitumen in %	Specific gravity of asphalt concrete mass	Volumetric weight of asphalt concrete mass	Residual porosity of asphalt concrete mass	Water permeability in %	Temporary compressive strength				Water permeability			
						At a temperature of – 20°C	At a temperature of – 50°C	At a temperature of – 70°C	Processing thickness in cm	At 0.5 atm. within 1 hour	At 1.0 atm. within 1 hour	At 1.5 atm. within 1 hour	At 2.0 atm. within 1 hour
1-a	7.0	2.43	1.98	18.5	–	28.60	13.80	–	2.88	The water has passed	–	–	–
1-b	9.5	2.35	2.16	8.1	–	31.00	18.80	–	3.24	The water didn't pass	The water didn't pass	The water didn't pass	The water didn't pass
1-b	9.0	2.37	2.23	5.9	–	36.40	29.10	–	3.10	The water has passed	–	–	–
1-b	8.5	2.38	2.17	8.8	–	31.86	24.00	–	3.01	*	The water has passed	The water has passed	The water has passed
1-b	8.0	2.40	2.09	3.1	–	34.80	15.00	–	2.43	*	–	–	–
1-b	7.5	2.41	2.07	14.1	–	34.10	17.90	–	2.96	*	–	–	–
2	7.5	2.46	2.28	7.3	–	26.53	10.00	–	2.73	The water didn't pass	The water didn't pass	The water didn't pass	–
2	7.0	2.48	2.25	9.3	–	26.90	20.30	–	2.85	*	*	*	
2	6.5	2.49	2.20	11.6	–	37.99	23.45	–	2.66	*	*	A drop appeared at the ring	A drop appeared at the ring
2	6.0	2.51	2.19	12.7	–	31.36	23.00	–	2.71	The water passed by the ring	–	–	–
2-a	8.0	2.40	2.30	4.17	–	32.70	–	–	3.19	The water didn't pass	The water didn't pass	The water didn't pass	The water didn't pass
2-a	7.5	2.42	2.34	3.3	–	35.40	33.50	–	3.12	*	*	*	*
2-a	7.0	2.43	2.29	5.4	–	35.90	23.40	–	2.82	*	*	*	Water appeared in the crack
2-a	6.5	2.45	2.28	6.9	–	32.90	23.10	–	3.06	*	*	*	The water has passed
2-a	6.0	2.47	2.10	15.10	–	37.28	10.60	–	2.64	The water has passed	–	–	–
2-b	8.5	2.38	2.23	6.3	–	30.60	20.50	–	3.16	The water didn't pass	The water didn't pass	The water didn't pass	The water has passed
2-b	8.0	2.40	2.23	6.6	–	32.61	13.60	–	3.31	*	*	*	The water didn't pass
2-b	7.5	2.41	2.20	8.7	–	39.60	13.50	–	2.70	The water has passed	–	–	–
2-b	7.0	2.43	2.22	8.7	–	26.70	16.60	–	3.51	The water didn't pass	The water didn't pass	The water didn't pass	The water has passed
3	10.0	2.39	2.27	5.13	–	25.29	–	–	2.47	*	*	*	*
3	9.5	2.41	2.17	9.98	–	25.70	–	–	2.19	*	A drop appeared in the crack	–	–
3	9.0	2.42	2.16	10.70	–	25.23	9.90	–	2.17	A drop appeared at the ring	A drop appeared in the crack	–	–
3	8.5	2.44	2.17	11.70	–	29.60	19.23	–	2.79	*	The water has passed	–	–
3	8.0	2.46	2.18	11.06	–	33.50	15.90	–	2.63	The water has passed	–	–	–
3	7.5	2.47	2.20	10.90	–	39.50	20.61	–	3.15	The water didn't pass	The water has passed	–	–
3	7.0	2.49	2.07	16.90	–	30.50	15.50	–	2.46	The water has passed	–	–	–
3-a	9.0	2.37	2.27	4.20	–	39.40	38.70	–	3.08	The water didn't pass	The water didn't pass	The water didn't pass	The water didn't pass
3-a	8.5	2.38	2.27	4.60	–	38.50	33.60	–	2.99	*	*	*	*
3-a	8.0	2.40	2.24	6.70	–	51.20	23.20	–	2.41	The water has passed	–	–	–
3-a	7.5	2.41	2.23	7.30	0.65	57.30	37.70	15.50	3.29	The water didn't pass	The water didn't pass	The water didn't pass	The water didn't pass
3-a	7.0	2.43	2.14	11.60	–	50.50	32.0	–	2.61	*	*	*	*
3-b	6.5	2.45	1.94	18.60	–	38.33	12.6	–	2.66	The water has passed	–	–	–
3-b	10.0	2.34	2.17	7.30	1.15	33.60	20.60	16.20	2.80	The water didn't pass	The water didn't pass	The water didn't pass	The water didn't pass

Recipe no.	Amount of bitumen in %	Specific gravity of asphalt concrete mass	Volumetric weight of asphalt concrete mass	Residual porosity of asphalt concrete mass	Water permeability in %	Temporary compressive strength				Water permeability			
						At a temperature of – 20°C	At a temperature of – 50°C	At a temperature of – 70°C	Processing thickness in cm	At 0.5 atm. within 1 hour	At 1.0 atm. within 1 hour	At 1.5 atm. within 1 hour	At 2.0 atm. within 1 hour
3-b	9.5	2.35	2.17	7.70	–	34.00	22.20	–	2.96	The water has passed	–	–	–
3-b	9.0	2.36	2.14	9.30	–	36.00	23.30	–	2.97	*	–	–	–
3-b	8.5	2.38	2.14	10.00	–	39.50	23.00	–	2.96	*	–	–	–
4	8.0	2.46	2.30	6.5	–	25.20	–	–	2.80	The water didn't pass	The water didn't pass	–	–
4	7.5	2.47	2.28	7.7	–	24.85	–	–	2.75	*	The water has passed	–	–
4	7.0	2.49	2.22	10.8	–	27.85	11.71	–	2.26	The water passed by the ring	–	–	–
4	6.5	2.51	2.16	13.90	–	27.97	16.00	–	2.66	The water has passed	–	–	–
4	6.0	2.53	2.18	13.80	–	34.11	10.21	–	2.66	*	–	–	–
4	5.5	2.54	2.04	19.70	–	21.60	9.6	–	3.21	*	–	–	–
4-a	8.0	2.49	2.31	3.65	–	26.30	–	–	3.66	The water didn't pass	The water didn't pass	The water didn't pass	The water didn't pass
4-a	7.0	2.43	2.28	6.20	–	34.75	19.0	–	2.51	The water has passed	–	–	–
4-a	6.5	2.45	2.25	8.00	–	36.64	32.10	–	2.12	*	–	–	–
4-a	6.0	2.47	2.20	10.90	–	39.82	21.00	–	3.50	*	–	–	–
4-b	8.0	2.40	2.28	5.00	–	23.20	22.00	–	3.36	The water didn't pass	The water didn't pass	The water didn't pass	The water didn't pass
4-b	7.5	2.42	2.19	9.50	–	31.00	20.40	–	3.42	*	*	*	*
4-b	7.0	2.43	2.16	11.10	–	31.90	14.00	–	3.52	The water has passed	–	–	–
4-b	6.5	2.45	2.12	12.70	–	27.80	11.80	–	3.37	*	–	–	–

No. 4-a, which turned out to be of higher quality than recipe No. 2-a, selected by the laboratory method.

3. Most asphalt concrete mixtures selected according to the Tsiat curves have a lower optimal amount of bitumen than similar asphalt concrete mixtures selected using the laboratory method (Table 9), with the exception of recipes (Nos. 1-a, 3-a and 2-b, 4-b).

Noteworthy is the high residual porosity of asphalt concrete mixtures selected according to the Tsiat curves in comparison with similar mixtures selected using the laboratory method, which is apparently explained by the following reasons: a) less bitumen; b) heterogeneity of the asphalt mixture, which gives sharp fluctuations in the volumetric weights of the samples, which in turn affects the residual porosity; c) apparently, because the residual porosity according to the above formula turns out to be exaggerated.

The porous micro- and nanostructure of the highest quality asphalt concrete samples was also analyzed by scanning electron microscope (SEM). Analysis of porous structures using SEM correlates with results obtained in vitro (Fig. 7).

The influence of various aggregates on the quality of asphalt concrete

From a review of Table 8, it is clear that fine-grained asphalt concrete prepared with limestone aggregate according to recipes No. 1-a and 3-a is of higher quality than fine-grained asphalt concrete prepared with loess and cement

Table 9

Optimal amount of bitumen according to different recipes

Recipe no.	1	2	3	4	1-a	2-a	3-a	4-a	1-b	2-b	3-b	4-b
Amount of bitumen in %	9.0	6.5	7.5	6.0	7.5	7.0	7.5	6.0	9.0	7.5	8.5	7.5

Note: 1. For recipe No. 1-b, the optimal amount of bitumen was chosen, equal to 9.0%, based on the temporary compressive strength of the samples; in terms of water permeability, 9.5% should be chosen.
2. For recipe No. 2-b, the optimal amount of bitumen was selected, equal to 7.5%, at which asphalt concrete has the greatest temporary compressive strength. The water permeability of asphalt concrete with this amount of bitumen is explained by the small thickness of the slab.
3. For recipe No. 3-b, the optimal amount of bitumen was chosen, equal to 8.5%, since with this amount of bitumen the asphalt concrete has the greatest temporary compression resistance. If we proceed from water permeability, then the optimal amount of bitumen should be 10.0%.

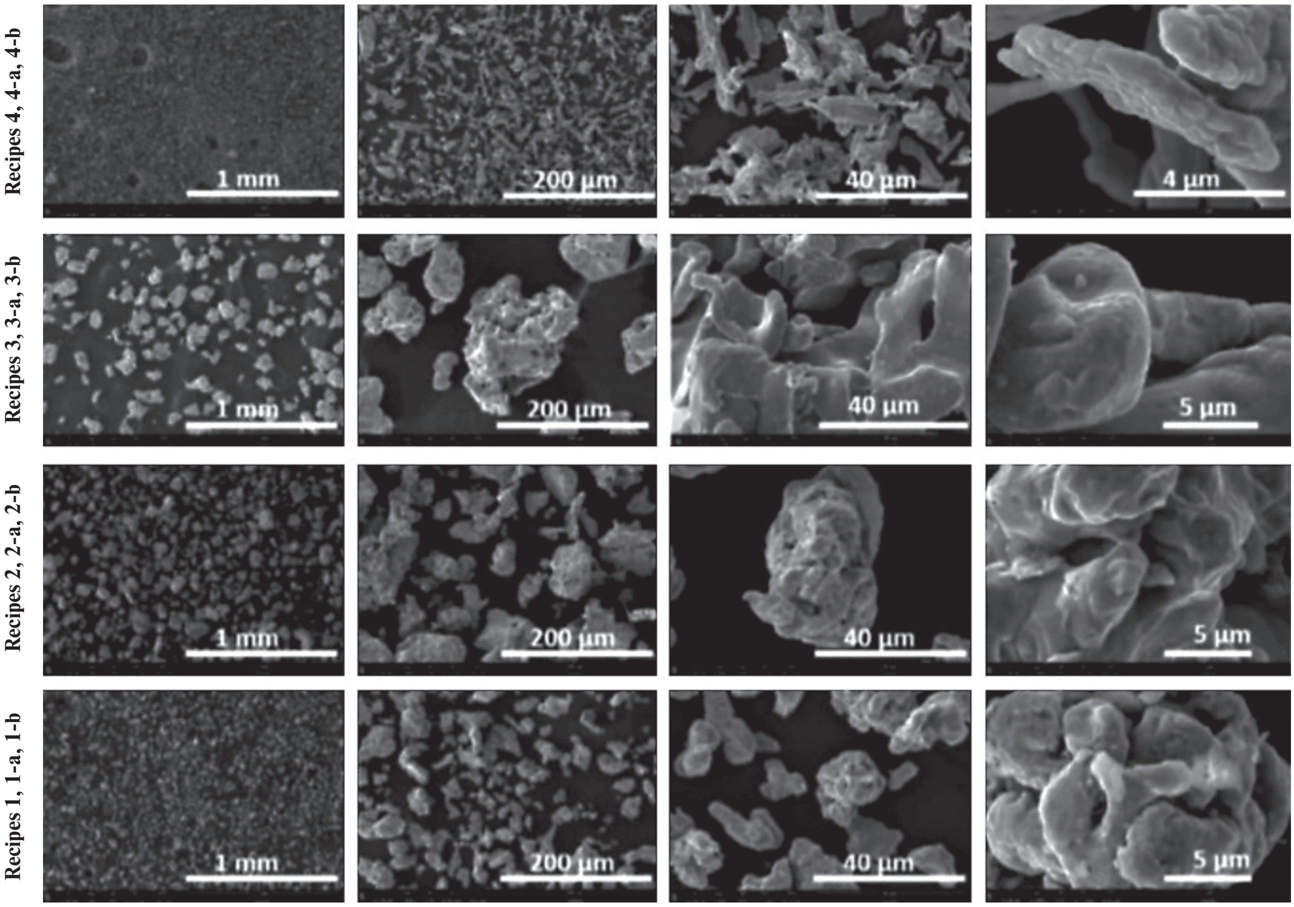


Fig. 7. **SEM — images of the structure of asphalt concrete samples**

as filler, i.e., according to recipes No. No. 1-b, 3-b, 1 and 3. Comparing fine-grained asphalt concrete prepared with loess (recipes No. 1 and 3-b) with similar asphalt concrete prepared with cement (recipes No. 1 and 3), we note that according to the temporary In terms of compression resistance, the first is of higher quality than the second, but in terms of water resistance it is worse than the second.

Looking at Table 8, we see that medium-grained asphalt concrete, selected using a laboratory method and prepared with loess according to recipe No. 2-b, has the greatest temporary compressive strength, then comes asphalt concrete prepared with cement according to recipe No. 2, and in last place is asphalt concrete prepared with limestone filler according to recipe No. 2-a. But in terms of water resistance, in first place is asphalt concrete prepared with limestone aggregate (according to recipe No. 2-a), then comes asphalt concrete prepared with cement according to recipe No. 2, and in last place is asphalt concrete prepared with loess according to recipe No. 2-b.

Moving on to the analysis of medium-grained asphalt concrete prepared according to recipes No. 4, 4-a and 4-b, selected according to the Tsiat curves with various aggregates, we note that in terms of temporary compressive strength, the best is asphalt concrete prepared with limestone according to recipe No. 4-a, then comes asphalt concrete prepared with cement according to recipe No. 4, and in last place is asphalt concrete prepared with loess according to recipe No. 4-b.

In terms of water resistance, the best was asphalt concrete prepared with loess according to recipe No. 4-b, which is explained by a 1% greater amount of bitumen compared to asphalt concrete prepared with limestone aggregate according to recipe No. 4-a and with cement according to recipe No. 4, and therefore not can be considered an advantage of loess.

Considering the particular importance of waterproofness of asphalt concrete intended for lining canals, it is necessary to draw the following conclusions from the above:

1. The best aggregate for asphalt concrete is ground limestone as it produces higher quality asphalt concrete than other aggregates. Limestone aggregate gives a particularly dramatic increase in quality in fine-grained asphalt concrete.

2. Cement and loess, as fillers, are in second place and produce asphalt concrete, almost similar in quality, but with a tendency to improve the quality of asphalt concrete when using cement as a filler.

The influence of Shymkent bitumen and its mixture with Aktau bitumen on the quality of asphalt concrete

To prepare asphalt concrete with Shymkent bitumen and its mixture with Aktau bitumen, recipes No. 1, 3-a and 3-b were chosen, i.e., one recipe for each aggregate.

Recipes such as fine-grained asphalt concrete were chosen for the reason that, having a larger amount of bitumen compared to medium-grained asphalt concrete, they would show a more dramatic effect of Shymkent bitumen and its mixture on the quality of asphalt concrete.

The test results for asphalt concrete prepared according to these recipes are shown in Table 10.

From Table 10 it can be seen that better quality asphalt concrete is obtained with Aktau bitumen and worse quality with Shymkent bitumen, which is apparently explained by the chemical and physical properties of Shymkent bitumen.

Adding a small amount of Shymkent bitumen (23%) to Aktau bitumen (75%) sharply reduces the quality of asphalt concrete, although the latter is slightly better in quality than asphalt concrete prepared with pure Shymkent bitumen.

It should be noted that here, too, the previously made conclusion about limestone as the best aggregate for fine-grained asphalt concrete compared to cement and loess is confirmed.

The influence of temperature on the quality of asphalt concrete

As can be seen from Tables 8 and 10, with increasing temperature, the temporary compressive strength of asphalt concrete decreases greatly. With an increase in temperature from 20 to 50°C, the temporary compressive strength decreases sharply, and with an increase to 70°C, less sharply (recipe No. 1 with 9.0% bitumen, recipe No. 3-b with 10% bitumen from Table 8).

Taking the temporary compressive strength of asphalt concrete at 20°C as 100% and expressing the temporary compressive resistance at 50°C as a percentage of the first, we obtain the following data for recipes with optimal amounts of bitumen (Table 11):

From Table 11 it can be seen that asphalt concrete prepared with cement reduces the temporary compressive strength at 50°C by 70–38%, prepared with limestone – by 47–33%, and prepared with loess – by 66–20%.

Thus, the smallest fluctuation in temporary compressive strength is produced by asphalt concrete prepared with limestone, which once again confirms the conclusion that limestone is the best aggregate among the aggregates studied in this work.

Regarding the influence of the amount of bitumen on the temporary compressive strength of asphalt concrete at a temperature of 50°C, no conclusions can be drawn,

Table 10
Asphalt concrete test results

Recipe no.	Name of bitumen	Amount of bitumen in %	Specific gravity of asphalt concrete mixture	Volumetric weight of asphalt concrete	Residual porosity of asphalt concrete mixture	Water absorption in %	Compression resistance time, kg/cm²		Water permeability				
							At 20°C	At 50°C	Sample thickness	At 0.5 atm. pressure for 1.0 hour	At 1.0 atm. pressure f or 1.0 hour	At 1.5 atm. pressure for 1.0 hour	At 2.0 atm. pressure for 1.0 hour
1	Aktau	9.0	2.42	2.27	6.20	0.65	34.34	14.40	2.48	The water didn't pass	The water didn't pass	The water didn't pass	The water has passed
2	Shymkent	9.0	2.42	2.22	8.30	–	17.40	6.10	3.60	*	The water has passed	–	–
3	Bitumen mixture	9.0	2.42	2.13	12.00	–	18.80	13.00	3.12	*	The water didn't pass	The water didn't pass	The water didn't pass
3-a	Aktau	7.5	2.41	2.23	7.50	0.65	57.30	36.70	3.29	*	*	*	*
3-b	Shymkent	7.5	2.41	2.19	9.10	–	29.60	11.40	3.08	*	*	*	*
3-a	Bitumen mixture	7.5	2.41	2.18	9.50	–	34.00	20.60	3.16	The water has passed	–	–	–
3-b	Aktau	10.0	2.34	2.17	7.30	1.15	33.50	20.60	2.80	The water didn't pass	The water didn't pass	The water didn't pass	The water didn't pass
3-b	Shymkent	10.0	2.34	2.21	5.60	–	19.90	13.00	3.22	*	*	*	–
3-b	Bitumen mixture	10.0	2.34	2.20	6.00	–	25.00	20.10	3.43	*	*	–	–

Table 11
Recipes with optimal amounts of bitumen

Recipe no.	Filler name	% bitumin	Temporary compressive strength			
			At a temperature of 20°C		At a temperature of 50°C	
			kg/cm²	%	kg/cm²	%
1	Cement	9.0	34.34	100	14.40	42
2-a	Lime	7.5	54.90	100	36.80	67
1-b	Loess	9.0	36.40	100	29.10	80
2	Cement	6.5	37.99	100	23.45	62
2-a	Lime	7.0	35.90	100	23.40	65
2-b	Loess	7.5	39.60	100	13.50	34
3	Cement	7.5	38.50	100	20.61	54
3-a	Lime	7.5	57.30	100	36.70	64
3-b	Loess	8.5	39.50	100	23.00	58
4	Cement	6.0	34.11	100	10.21	30
4-a	Lime	6.0	39.82	100	21.00	53
4-b	Loess	7.5	31.00	100	20.40	66

since contradictory data were obtained in Table 8 and this issue requires further research.

CONCLUSION

In conclusion, the following conclusions can be drawn:

1. Shymkent bitumen in its properties does not meet the technical requirements for bitumen used for asphalt concrete (low ductility and high penetration). But based on this, it cannot be concluded that it is impossible to obtain higher-quality bitumen from Shymkent oils, therefore Shymkent bitumens are subject to further study, subject to a change in the technological process of their production.

2. Shymkent bitumen is of little use for preparing asphalt concrete, since it reduces the quality of asphalt concrete by almost 50% compared to Aktau bitumen.

3. The quality of Shymkent bitumen can be improved by adding a relatively large amount of Aktau bitumen to it, but this is not economically profitable, since this slightly increases the quality of asphalt concrete.

4. The best aggregate for asphalt concrete is ground limestone as it produces higher quality asphalt concrete than other aggregates. Ground limestone gives a particularly dramatic increase in the quality of asphalt concrete in fine-grained asphalt concrete.

5. Cement and loess, as fillers, are in second place and produce asphalt concrete, almost similar in quality, but with a tendency to improve the quality of asphalt concrete when using cement as a filler.

6. An increase in temperature from 20 to 50°C sharply reduces the temporary compressive strength of asphalt concrete and less sharply with an increase from 50 to 70°C. The smallest fluctuation in temporary compressive strength with increasing temperature is produced by asphalt concrete prepared with ground limestone as a filler.

7. Regarding selection methods, it is necessary to draw the following conclusion: it is better to select fine-grained asphalt concrete using the Tsiat curves and select medium-grained asphalt concrete using the laboratory method, since this produces higher-quality asphalt concrete.

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