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Investigation of the Effect of Adhesive Additive on the Plasticity of Road Bitumen and Physical-Mechanical Properties of the Road Concrete Mix

I. I. MUKHAMATDINOV, P. S. FAKHRETDINOV, A. F. KEMALOV, R. E. MUKHAMATDINOVA

Institute of Geology and Petroleum Technologies, Kazan Federal University, Kazan, Russia

E-mail: iimuhamatdinov@gmail.com

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Abstract

The current level of traffic development is characterized by a continuous increase in the intensity of cargo transport vehicles and a rise of dynamic load on road coatings. Improvement of the quality of road bitumen through the search for novel technical and technological solutions remains an urgent problem for achieving high physical-mechanical characteristics of asphaltic concrete pavements and for ensuring their long lifetime. The effect of a cation-active adhesive additive on the range of plasticity of oxidized and non-oxidized bitumen is considered. The physical and mechanical properties of asphalt-concrete mix prepared on the basis of bitumen modified with the additive in different concentrations are investigated. A technology is developed for obtaining a modified bitumen binder involving the adhesive additive. On the basis of BND 60/90 grade bitumen, an experimental lot (40 t) of bitumen modified with the designed additive was manufactured, the test region of the roadway with the total area of 7900 m^2 was paved in Naberezhnye Chelny (Tatarstan, Russia), construction design supervision of the state of the test road region was performed.

Keywords: adhesive additive, modified bitumen, asphalt mix, plasticity interval, physicochemical properties

INTRODUCTION

Road infrastructure is a vitally essential system affecting the country's economy. In this connection, there is a direct dependence between the traffic-related performance of the coating of motor roads and the dynamics of industrial development in the country, which provides a permanent increase in traffic intensity and load. Improvement of the physical-mechanical characteristics of asphaltic concrete pavement and provision of their long-term operation lifetime through improving the quality of road bitumen remains an urgent problem. One of the essential disadvantages of petroleum bitumen manufactured at present is its low adhesion to the surface of mineral materials, which leads to a decrease in the lifetime of the structures [1, 2]. For instance, in the construction and repair of asphaltic concrete pavements with the help of poured road mastic fillers, the quality and operation lifetime depend on the strength of mastic adhesion to the mineral filler and with the material of road coating.

As a rule, road bitumen contains surface-active substances (SAS) – asphaltogenic acids and their anhydrides. In the case, if a sufficient amount of these compounds is present, satisfactory adhesion of bitumen with the dry surface of mineral materials of acid and basic rocks is provided. For the purpose of improving bitumen adhesion to stone, adhesive additives possessing surfactant properties are introduced [4]. One of the most important features of SAS is the ability of their molecules to bind tightly to the surfaces of bodies, that is, to get adsorbed on these surfaces and to coat them with a thin layer [3]. The amount of SAS used for this purpose is not large but this coating causes a sharp change in the properties of the surface.

SAS molecules are concentrated on the bitumen – stone interface. Adhesive additives act as a bridge or glue between bitumen and the surface of the stone material resisting the replacing action of water.

The introduction of even a small amount of SAS into bitumen causes a decrease in the surface tension at the boundary between bitumen and mineral material, which simplifies the wetting of these materials with bitumen. The surfactant is adsorbed on the surface of mineral grains at the boundary between the phases, which causes a decrease in the excess interphase surface energy. Adhesive additives allow also improvement of the quality of asphalt concrete and have a positive effect on the technological process of preparation, paving and pressing asphaltic-concrete mixtures [5].

The mechanism of the SAS effect is based on the processes of chemical and physical adsorption with the orientation of diphilic molecules by their polar groups towards the surface of the disperse mineral phase, while non-polar groups are oriented into the dispersing medium (fused bitumen). Prevalence of chemical adsorption is most preferable because SAS molecules, chemically bound with the surface, almost do not desorb, and thus they provide saturation of interphase layer with lower consumption. On the chemically inert part of the surface, physical adsorption holds additional importance for the provision of densification of the adsorption interphase layer. In addition, physically adsorbed SAS molecules form a diffuse part of the interphase volume and provide an increase in its thickness and the energy of intermolecular interactions of the dispersing medium (bitumen) with the hydrocarbon fragments of adsorbed SAS.

The efficiency of adhesive additives is connected with the ampholytic properties of individual polar groups or SAS compositions and the chemical structure of non-polar fragments of these SAS to provide their strongest interactions with the surface of the dispersed phase and the bulk dispersion medium [6].

There are several procedures to determine bitumen adhesion to mineral materials. The most widespread method is the qualitative (visual) procedure according to GOST 11508–74. Its advantages include minimal labour contribution and good reproducibility of results, while shortcomings include substantial labour content, duration and discreteness of results. On the basis of the qualitative method, a quantitative procedure was proposed [7], which is based on the gravimetric determination of the mass of bitumen remaining on the surface of mineral material after boiling the bitumen-mineral mass in water.

The authors of [8] proposed quantitative methods to determine adhesion. These methods are based on the ability of mineral materials to adsorb the polar molecules of methyl blue dye, and on the radioactive method to measure the selective adsorption of the salts of divalent metals. Disadvantages of these methods include expensiveness and substantial duration of measurements (1.5–2 h).

The adhesion properties of bitumen depend on the polarity of its components and the kind of SAS. Because of this, one more parameter characterizing adhesion may be dielectric permittivity depicting the forces of interaction between the charges in the medium with respect to vacuum. This parameter may indirectly characterize the presence of polar groups in bitumen and therefore its adhesion characteristics. Dielectrometry is a set of methods for the quantitative determination of substances and for the investigation of their molecular structure on the basis of the measurement of dielectric permittivity and the dielectric loss tangent. Dielectric characteristics are studied in the constant and variable (with the frequency up to 1012 Hz) electric fields [9].

So, bitumen adhesion to the surface of a mineral material may be determined using either qualitative or quantitative methods. Their results do not contradict each other, nevertheless, quantitative methods are more objective.

Various SAS may be used in road construction: anionic, cationic, non-ionogenic. The most efficient adhesive additives are cationic SAS based on nitrogen-containing chemical compounds – imidazolines, amidoamines, amines. The major part of foreign and Russian companies manufacture adhesive additives on this basis. However, evaluating adhesive and other performance characteristics of these additives, specialists in the road branch formulate complaints concerning their unpleasant odour, which depends on the raw material used [10].

To enhance the adhesion of bitumen with mineral materials, the following adhesive additives are used: imidazolines (amido-, bis-, alkyl-); polyamide fibre; compounds containing amine groups (hexamethylenetetramine, triethanolamine, aniline resin). The use of bitumen with imidazoline additives in asphaltic concrete allows an increase in water resistance factor from 0.85 to 1.2, other physical-mechanical characteristics of asphaltic concrete are improved, too. With additives based on imidazolines, it is possible to carry out road works under extremely unfavourable conditions (for example, paving the territory of chemical plants impregnated with organic products) [11, 12].

However, an extensive introduction of cation-active adhesive additives into the practice of road construction is held back by the limited possibilities of the production of these additives and the lack of raw materials, which implies also high prices. Even the cost of home-made adhesive additives is at a level of 100–160 thousand roubles per one ton.

Adhesive additives residing in hot bitumen lose their activity with time, so it is better to introduce the additives at the final stage of the process [13]. This loss of activity is due to the interaction of alkaline amine with the acid components of bitumen. Overheating of modified bitumen should not be admitted because this may affect the efficiency of the additive.

Adhesive additives are to be stored in vessels made of carbon steel to prevent corrosion because many of them are extremely corrosion-active. Some SAS exhibit high toxicity with respect not only to the human organism but also to aquatic organisms (fish, daphnia and algae) [14].

The goal of the work was to investigate the effect of cation-active adhesive additive on the range of plasticity of oxidized and non-oxidized bitumen, as well as to develop a technology for obtaining bituminous binder modified with the adhesive additive and to study the physical-mechanical properties of asphaltic concrete mixtures based on it from the experimental region of road pavement.

EXPERIMENTAL

The objects of investigation we e oxidized bitumen (manufactured at the PC TAIF-NK, Russia) and non-oxidized bitumen (manufactured at the Elkhovskoe NPU NIGDU Elkhovneft, Russia). The physicochemical properties of these bitumen samples are presented in Table 1.

Adhesive additive Adgezolin was developed as an additive to bitumen for road construction [15–21]. Physicochemical characteristics of the additive are presented in Table 2.

Tests of the physical-mechanical properties of asphaltic concrete mixtures based on bituminous binder were carried out according to the State Standard GOST 12801–98 "Materials based on organic binders for road and aerodrome construction. Testing methods" in agreement with GOST 9128–97

TABLE 1

Physicochemical properties of bitumen

Parameter	GOST 22245–90	Bitumen samples	
		Oxidized (PC TAIF-NK)	Non-oxidized (Elkhovskoe NPU)
		BDN 60/90	BNN 80/120
Depth of needle penetration, 0.1 mm:	not less than		
at 25 °C	61–90	79	85
at 0 °C	20	23	16
Softening temperature according to по KiSh[a] °C	not lower than 47	48	45
Stretchability, cm:	not less than		
at 25 °C	55	79	>150
at 0 °C	3.5	3.6	7.5
Brittleness temperature according to Fraas, °C	not more than −17	−18	−16.8
Penetration index	from -1 to +1	−0.5	−1.3
Change of softening temperature after heating, °C	not more than 5	5	8.2

[a] Determination method: ring-and-ball procedure.

TABLE 2

Physicochemical characteristics of cation-active adhesive additive Adgezolin (TU 0257-007-02066730-2013)

Parameter	Norm according to TU	Test method
Appearance	Viscous honey-like mass	Visually
Colour	From light-yellow to dark-brown	Visually
Odour	Weak, typical	Organoleptic
Density at 20 °C, g/cm^3	0.9500–0.9550	GOST 3900–85
Kinematic viscosity at 100 °C, mm^2/s	138.0–139.5	GOST 33–2000
Content of major substance, %, not less	98.5	item 7.4 (TU 0257-007-02066730–2013)
Content of volatile substances boiling below 130 °C, %, not more	1.5	item 7.5 (the same)
Adhesion of bitumen with marble and sand	Score: 5	GOST 12801–98

"Road and aerodrome asphaltic concrete mixtures and asphalt-concrete. Product specifications".

RESULTS AND DISCUSSION

Determination of plastic range

Asphaltic concrete pavements are objects in which bitumen is subjected to the highest deformations. This phenomenon is manifested especially clearly in connection with the increased intensity and cargo load of the traffic. The introduction of various modifying additives into bitumen may provide relaxation arising in the road coatings in the form of cyclic deformations.

In the regulation documents for road bitumen, the temperature dependence of its rheological properties is depicted by softening temperature (t_{soft}) and Fraas brittleness temperature (t_{br}).

The plastic range (PR, °C) is calculated using the equation:

$$PR = t_{soft} - t_{br} \quad (1)$$

The lower is t_{br} and higher t_{soft} (that is, the wider is PR), the better is a binder for asphaltic concrete mixtures. Because of this, a very important parameter characterizing the quality of bitumen is its working PR calculated using equation (1).

To investigate the effect of Adgezolin additive on the PR of bitumen, measurements of its softening temperature and brittleness point were carried out.

It should be stressed that in Tatarstan the minimal air temperature in winder reaches −40 °C, while the maximal temperature in summer exceeds 30 °C, so the required PR for binders is more than 70 °C, while PR for BND grade bitumen rarely is more than 65 °C, while for BNN grade – 55 °C. One can see from the data presented in Fig. 1 that the PR of the modified binder is much wider than that of initial bitumen, and continues to grow with the introduction of the adhesive additive into bitumen. In our opinion, this is primarily due to the lower viscosity of the dispersing medium of the binder.

The PR of initial oxidized bitumen is equal to 73.7 °C, while for binder with Adgezolin additive 0.6, 0.8 and 1.0 mass % it is 75.3, 78.5 and 79.1 °C, respectively (see Fig. 1). So, it is demonstrated that modified bitumen depending on the amount of the introduced additive may have the necessary PR for any region of Russia.

The corresponding calculations were also carried out for non-oxidized bitumen. In particular, PR for initial non-oxidized bitumen is equal to 61.7 °C, while in the presence of Adgezolin at a level of 0.8, 1.0, 1.2 mass % PR value is 63.2, 65.2 and 66.6 °C, respectively (Fig. 2).

The difference between PR values for oxidized and non-oxidized bitumen with different concentrations of the additive is approximately 15 °C, which may be explained by a higher brittleness point and low penetration at 0 °C characteristic of non-oxidized bitumen.

Comparative evaluation of the physicochemical properties of the obtained samples of modified bitumen according to GOST 22245–90, GOST R 52056–2003, EN 12591, and their correspondence to the requirements of the Federal Road Agency (Rosavtodor) is shown in Table 3. One can see that the comparison of the standards for initial and modified bitumen reveals substantial

$$\mathrm{Var3} = -155.8709 + 15.8156x + 5.3179y + 1.5126x^2 - 0.227xy - 0.0298y^2$$

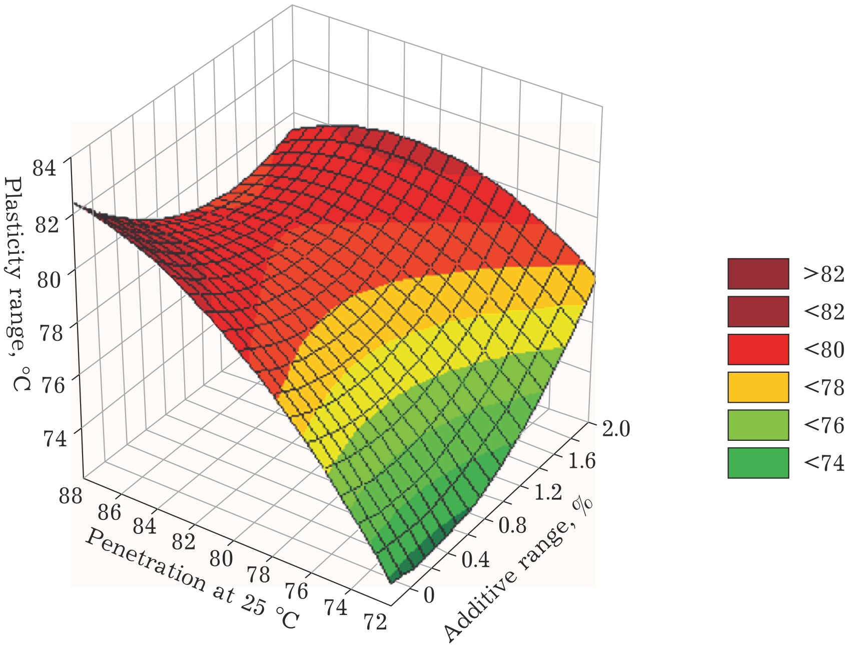

Fig. 1. Dependence of plasticity range and penetration of oxidized bitumen manufactured at the PC TAIF-NK on the content of additive in bitumen.

$$\mathrm{Var3} = 697.3292 + 8.0588x - 13.0017y - 10.0777x^2 + 0.2019xy + 0.065y^2$$

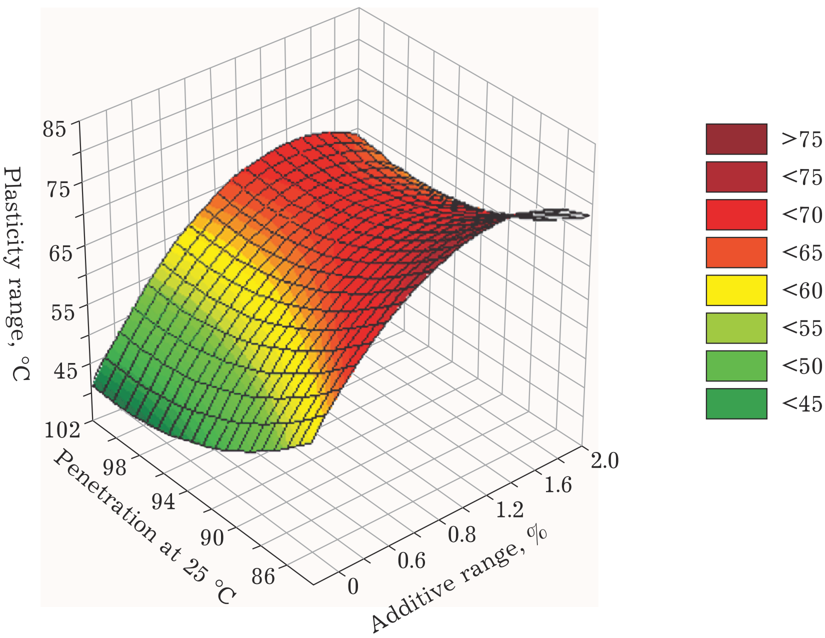

Fig. 2. Dependence of plasticity range and penetration of non-oxidized bitumen manufactured at the Elkhovskoe NPU NGDU Elkhovneft on the content of additive in bitumen.

advantages of the latter. For instance, for bitumen modified with Adgezolin additive and for polymeric bituminous binders (PBB) according to GOST R 52056–2003, similar in consistency to the bitumen of BND grades:

– the softening temperature is higher by 6 and 15 %, respectively;

– the brittleness temperature determined according to Fraas procedure, characterizing crack resistance of road pavement is lower by 90 and 33 %, re-

TABLE 3

Correspondence of technical characteristics of modified bitumen with the requirements to binding materials in Russia

Parameter	Sample								
	Bitumen + 1 % Adgezolin		BND 90/130	BND 60/90	PBV 90	PBV 60	Grade 70/100	BND 90/130	BND 60/90
	Manufacturer		Норма						
	ENPU[a]	TAIG-NK	GOST 22245–90		GOST R 52056–2003		EN 12591	Requirements of Rosavtodor	
Penetration, 0.1 mm, not less than									
at 25 °C	97	86	91–130	61–90	90	60	70–100	91–130	61–90
at 0 °C	18	25	28	20	40	32	–[в]	28	20
Ductility, cm, not less than									
at 25 °C	130	120	65	55	30	25	–	65	55
at 0 °C	15.3	4.5	4.0	3.5	15	11	0	4.0	3.5
Softening temperature , according to KiSh[b], °C, not lower than	46	50	43	47	51	54	43–51	45	49
Brittleness temperature, °C, not higher than	−19.5	−29.1	−17	−15	−25	−20	−10	−20	−18
Change of softening temperature after heating, °C, not more than	5.0	3.5	5	5	6	5	8	5	5
Penetration index	−0.7	0.2	from −1 to +1		–	–	–	from −1 to +1	
Adhesion with marble or sand, score	5	5	not normalized[г]		4	4	–	4	4

[a] Elkhovskiy NPU.
[b] Determination method: ring-and-ball procedure.
[c] No data.
[d] Not normalized.

spectively, and embraces the whole range of minimal temperatures of the coldest days recorded in Russia;

– penetration at 0 °C, which characterizes deformability of the binder, is higher by 25 and 60 %, respectively.

It should be stressed that the average values of the characteristics of modified samples and much higher than the average parameters presented in GOST 22245–90, GOST 52056–2003, EN 12591 and requirements of Rosavtodor, while there is a substantial margin in such parameters as softening and brittleness temperatures, the working plasticity range, ductility, change of softening temperature after heating.

Technical requirements to the binding materials in Russia (see Table 3) and a number of other countries according to Table 4 allowed a comparative analysis of the quality of bitumen obtained by us and modified with Adgezolin additive.

One can see in the presented data that modified binders based on Adgezolin additive are at the level of world standards possessing a clear advantage with respect to the crack resistance and deformability at low temperatures (brittleness temperature, penetration and ductility at 0 °C), which is quite acceptable for the Republic of Tatarstan.

The results of the analysis allow us to stress that the obtained samples of modified binders for asphaltic concrete mixtures are oil dispersion systems composed of bitumen and adhesive additive. Depending on the ratio of these components, the binder is able to possess the required parameters of heat resistance, crack resistance, plasticity and viscosity for any climatic conditions of the Republic of Tatarstan and the Russian Federation in general.

Investigation of physical-mechanical properties of asphaltic concrete mixtures

Mineral fillers for asphaltic concrete mixtures were rock debris from the Sangalyk diorite quarry crushability (crushability grade 1400 according to GOST 8267–93), riddling of crushed stone from the Sangalyk quarry and river sand with fineness modulus 1.25 (GOST 8736–93) from the Kama deposit. The mineral powder was activated mineral powder MP-1, powdered filler obtained through fine grinding of carbonate rocks (calcium carbonate) to the fraction of 300–315 μm. The major goal of using this powder is to fill intergrain cavities between crushed stone and sand,

TABLE 4

Correspondence of technical characteristics of modified bitumen samples and the requirements to binding materials in different countries

Parameter	Sample							
	Bitumen + 1% Adgezolin		Grade 50/130	Karibit 85	Grade 90-140S	RV 80A	B-90	EM-4
	Manufacturer							
	ENPU[a], Russia	TAIF-NK, Russia, Russia	Belgium	Denmark	Australia	Germany	Italy	Spain
Penetration, 0.1 mm, not less than at 25 °C	97	86	50–130	70–100	89–140	120	80–100	80–130
Ductility, cm, not less than at 25 °C	127	110	35 (5 °C)	–[c]	55 (13 °C)	100 (7 °C)	100	40 (5 °C)
Softening temperature according to KiSh[b], °C, not lower than	45.7	50	–	47–55	42	40–48	85–95	60
Brittleness temperature, °C, not higher than	−19.5	−29.1	−18	−15	−18	−20	−20	−15
Changes of softening temperature after heating, °C, not more than	5.1	3.5	–	–	–	6.5	–	6–10

[a] Elkhovskiy NPU.
[b] Determination method: ring-and-ball procedure.
[c] No data.
Note. Actual temperatures at which tests were carried out in each country are shown in parentheses.

that is, to provide the required density of asphaltic concrete. Activated mineral powder in comparison with the non-activated sample is characterized by lower porosity and almost two times smaller swelling in contact with liquid and viscous media of different chemical compositions. Granulometric characteristics of activated mineral powder remain the same, similarly to the technologies of its application, transportation and storage.

Binding materials used in the studies were initial bitumen and bitumen manufactured at the PC TAIF-NK modified with Adgezolin additive in the amount of 0.8 to 1.2 mass %. The composition of hot dense asphaltic concrete (type B, grade II), which is most widely used in the climatic zone of the Republic of Tatarstan, was taken as a prototype. The designed mineral composition of the sample of hot fine-grained asphaltic concrete taken for further studies is presented in Table 5. The content of binders in the asphaltic concrete was 4.6 mass % (above 100 % with respect to the mineral part).

To determine the characteristics of asphaltic concrete, we used the samples shaped as cylinders with the dimensions (diameter and height) $d = h = 71.4$ mm. Samples were formed in a metal mold with two inserts, heated to a temperature of 90–100 °C. Then the samples were tightened in a press under the pressure of 40 MPa for 3 min. The physical-mechanical properties of asphaltic concrete are presented in Table 6.

According to the data obtained, asphaltic concrete samples based on modified binder possess better deformation-related characteristics at low temperatures, that is, the compression strength at 0 °C (R_0) decreases. This has a favourable effect on the stability against crack formation in winter during pavement performance. It is stressed that the addition of the additive (up to 0.8 mass %) leads to an increase in compression strength of asphaltic concrete mixtures at positive temperatures in comparison with common bitumen.

The introduction of the additive into bitumen has a positive effect on the parameters related to viscosity and cohesion strength. Indeed, compression strength increases by 75 % at 20 °C (R_{20}), by 50 % – at 50 °C (R_{50}) with a simultaneous decrease (by 10 %) of R_0, which is evidence of rather high thermal stability of bitumen sample.

This confirms that under the same conditions the degree of destruction of the modified bitumen under deformation is lower than for initial bitumen. An improvement of the physical-mechanical characteristics of asphaltic concrete mixtures obtained on the basis of modified bitumen is connected first of all with an increase in adhesion strength of the mineral and organic parts of the composite material.

Water resistance of asphaltic concrete samples is determined by the amount of water absorbed by asphaltic concrete at 20 °C, as well as by a decrease in the strength of the water-saturated sample in comparison with the initial sample. Rapid water saturation of asphaltic concrete is performed by creating vacuum above the surface of water into which the samples are immersed. During the evacuation of the asphaltic concrete samples, air is pumped out at first from interconnected pores, and they are filled with water [22]. Air released from closed pores destroys the bitumen film and thus causes an increase in the porosity of asphaltic concrete, which leads to a decrease in its strength (Fig. 3). This kind of film destruction is almost excluded for modified bitumen because the viscosity of the binder and the strength of asphaltic concrete based on modified bitumen are substantially higher than in the case of initial bitumen. For instance, for asphaltic concrete with initial bitumen, with close average density and residual porosity, the water saturation factor is 1.5 times higher than in the samples with adhesive additive. Therefore, the porous structure of asphaltic concrete with the additive contains a larger amount of closed pores, which promotes higher frost resistance of asphaltic concrete [23].

TABLE 5

Quantitative composition of fine-grained dense asphaltic concrete mixture (II grade type B)

Composition	Content, mass %
Crushed rock Sangalyk, fraction 5–20	46
Crushing sieved residue, Sangalyk, fraction 0–5	26
River sand Kamskiy	20
Activated mineral powder MP-1	8
BND Bitumen 60/90	4.6

One of the most important tasks in making asphaltic concrete pavement is in the development of binders successfully resisting the formation of shear deformations at high temperatures, and crack formation with a definite coefficient of temperature sensitivity [24].

It is necessary to stress that asphaltic concrete should possess a definite shear strength, which is usually 2–3 times lower than the compression strength. The strength is determined using shear devices at a temperature of 50 °C. Insufficient shear resistance leads to the formation of waves on the coating during automobile braking [25]. It was revealed in the tests that the shear resistance of asphaltic concrete based on modified binder (0.8 mass %), estimated from the internal friction coefficient and grip index is higher by 20 % than for the sample based on initial bitumen (Fig. 4).

It should be stressed that shear resistance and thermal stability of asphaltic concrete are interconnected parameters (the shear resistance of the sample is proportional to its thermal stability). It is known that the thermal stability of asphaltic concrete is characterized by the change in its strength with temperature variations. The ther-

TABLE 6

Results of tests of fine-grained dense asphaltic concrete mixtures

Content of Adgezolin additive in bitumen, mass %	Parameters								
	Average density, g/cm^3	Water saturation, %	Compression strength, MPa			Water resistance coefficient	Crack resistance, MPa	Shear resistance, MPa	Internal friction coefficient
			R_{20}	R_{50}	R_0				
0	2.55	2.5	3.2	1.1	8.5	0.86	3.1	0.35	0.99
0.8	2.55	1.7	5.6	1.67	8.0	0.92	3.5	0.42	0.94
1.0	2.55	1.8	4.8	1.60	7.60	0.91	3.4	0.39	0.93
1.2	2.55	1.7	4.7	1.53	7.34	0.90	3.3	0.38	0.92
Requirements of GOST 9128–2009		1.5–4.0	>2.2	>1.0	<12.0	>0.85	3.0–6.5	>0.35	>0.81

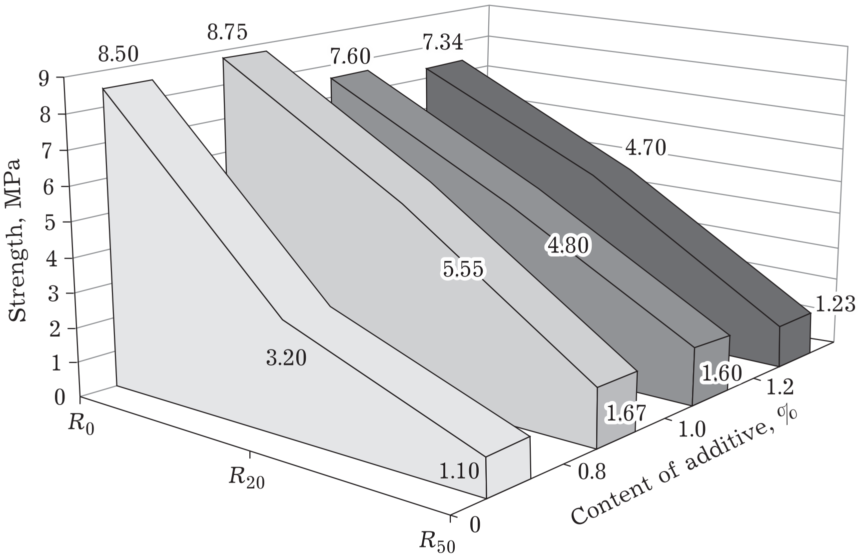

Fig. 3. Dependence of the strength of asphaltic concrete mixtures (R_0, R_{20} and R_{50}) on the content of adhesive additive.

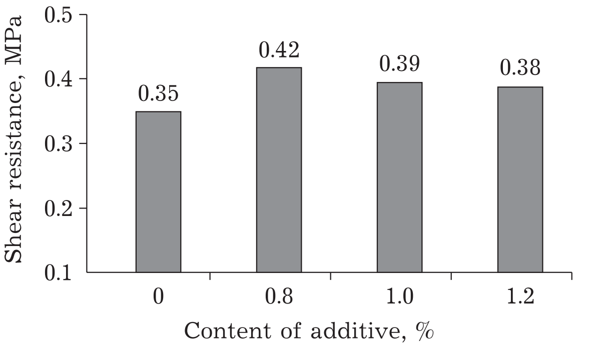

Fig. 4. Dependence of shear resistance of asphaltic concrete mixtures on the content of adhesive additive.

mal stability parameter (K_t) of asphaltic concrete was estimated from the relations between the strength values R at 20 and 50 °C (R_{20}/R_{50}), as well as at 0 and 50 °C (R_0/R_{50}).

High thermal stability of asphaltic concrete samples based on modified binders means that under increased temperature conditions in summer the formation of plastic deformations in the road pavement will be substantially lower. This is seen in an increase in the ratio R_{20}/R_{50} and a decrease in the ratio R_0/R_{50} for modified samples in comparison with initial bitumen (Table 7).

TABLE 7

Thermal stability coefficients of asphaltic concrete mixtures

Content of Adgezolin additive in bitumen, mass %	Theram stability coefficient (K_t)	
	R_{20}/R_{50}	R_0/R_{50}
0	2.91	7.73
0.8	3.32	4.79
1.0	3.00	4.75
1.2	3.07	4.80

Development of the technology for obtaining modified binder using adhesive additive

An experimental lot (40 g) of the binder modified with Adgezolin additive was manufactured from BND grade bitumen produced by PC TAIF-NK in agreement with the presented technological flowchart (Fig. 5).

The necessary amount of bitumen for the production of modified binder is taken with pump *2* from vessel *1* and is supplied to the mixer of modification unit (mixing reactor) *4*. The mixer unit is a device equipped with a mixing facility with a blade mixer. Bitumen is loaded into the mixer with idle mixing blades. The temperature of bitumen loaded into the mixer should be not lower than 120–130 °C. Measurement of the upper level in the mixer and signalling are employed, and pump *2* is switched off when the upper level of bitumen is achieved. The mixer drive is switched on only after the reactor is filled with bitumen. To exclude the effect of transition processes (stabilization of hydro- and thermodynamic regimes in the equipment), bitumen circulation without supplying the modifying agent should be carried out for 15–20 min.

Transition processes are complete when stabilization of bitumen temperature in the mixing reactor *4* occurs as recorded by a temperature sensor. Then the calculated amount of the additive is fed into mixing reactor *4* from vessel *3* equipped with a screw-type dosing device. Circulation of modified bitumen additionally increases the intensity of mixing, which leads to a decrease in the time of modification. During mixing, the temperature of the mixture should be not less than 130 °C, because a decrease in temperature below this value leads to an increase in modification time. After mixing time is over, the ready binder is let into the storage tank, bitumen-carrying vehicle or the vessel of the asphalt-mixing unit.

Investigation of the physical-mechanical properties of asphaltic concrete mixtures from the experimental region of road pavement

The experimental region of road pavement was made using asphaltic concrete mixture prepared on the basis of BND 60/90 grade bitumen manufactured at the PC TAIF-NK with the addition of Adgezolin additive (1 mass %) was paved during August 25–26, 2012, at the bridge deck crossing the Melekeska river in Naverezhnye Chelny (the Republic of Tatarstan, Russia).

One year later after paving the experimental region, core samples were taken. During the time since paving, an improvement of strength characteristics of asphaltic concrete mixtures based on modified binder should be stressed: compression strength at 20 °C (R_{20}) increased from 4.7 to 5.0 MPa, at 0 °C (R_0) it decreased from 12.0 to 11.1 MPa, water saturation parameter corresponded to the GOST requirements (with the standard value of not more than 4.5 % from the pavement, 1.0–4.0 % from mixtures) and was equal to 1.3 and 3.0 %, respectively; water resistance factor increased from 0.94 to 0.99.

Cores were sampled once more after two years and nine months since paving. For the period since the previous test, an improvement of physical-mechanical parameters of asphaltic concrete mixtures prepared on the basis of modified bitumen was revealed: compression strength at 20 °C (R_{20}) increased from 5.1 to 6.1 MPa, at 50 °C (R_{50}) it increased from 1.7 to 2.1 MPa, water saturation factor decreased from 1.3 to 1.2 %. Shear resistance in comparison with the value detected at the moment of paving (0.44 MPa) increased to 0.59 MPa. Crack resistance, similarly to other properties of asphaltic concrete, correspond to the requirements of GOST. Results are presented in Table 8.

CONCLUSION

Thus, investigations and experimental tests showed that bitumen modified with cation-active adhesive additive Adgezolin is at a level of world standards and possess evident advantages over European and other samples in crack resistance and deformativity at low temperatures (brittleness point, penetration and stretchability at 0 °C), which is quite acceptable for use at the territory of the Republic of Tatarstan. It is established that the preparation of asphaltic concrete mixtures on

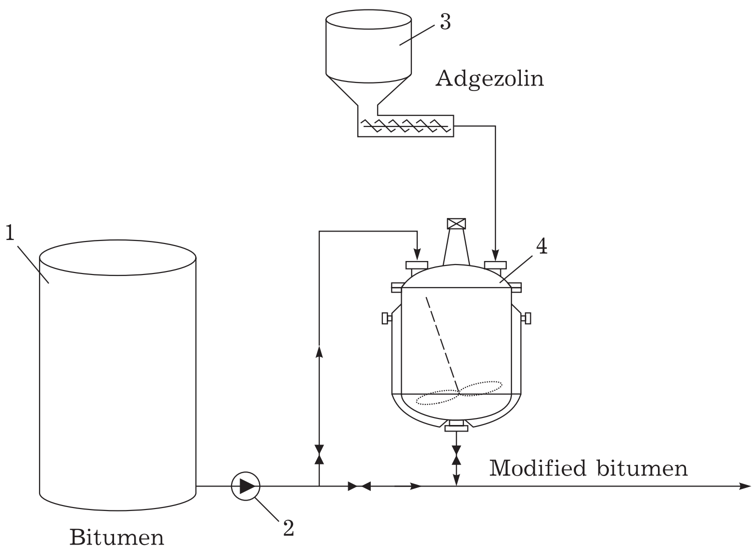

Fig. 5. Schematic technological flowchart for obtaining modified binder using adhesive additive.

TABLE 8

Results of tests of fine-grained dense asphaltic concrete mixtures during the operation of road pavement

Operation time	Parameters of asphaltic concrete mixture						
	Compression strength, MPa			Average density, g/cm^3	Water saturation, %	Coefficient of	
	R_{20}	R_{50}	R_0			water resistance	densification
Results of sample testing							
At the moment of paving	4.7	1.8	12.0	2.53	1.8	0.94	0.99
1 year later	5.1	1.7	11.1	2.52	1.3	0.99	1.02
2 years and 9 months later	6.1	2.1	11.4	2.58	1.2	0.91	1.1
According to GOST 9128–2009	Not less than 2.2	Not less than 1.0	Not more than 12.0	–	Not more than 4.5 (from coating) 1.0–4 (from mixtures)	Not less than 0.85	Not less than 0.98

the basis of modified bitumen improves its physical-mechanical characteristics: compression strength at 20 and 50 °C increases by 75 and 50 %, respectively, with a simultaneous decrease in compression strength at 0 °C by 10 %, which characterizes rather high thermal stability of the obtained material. The ratios of compression strength at 20 and 50 °C increased, while the ratios of compression strength at 0 and at 50 °C decrease, which provides a decrease in plastic deformation in the road pavement during summer.

Tests that were carried out with core samples of road pavement after two years and nine months to evaluate physical-mechanical properties of asphaltic concrete mixtures based on BND 60/90 bitumen manufactured by PC TAIF-NK modified with Adgezolin additive (1 mass %) showed that the manufactured mixtures correspond to the requirements of GOST 9128–2009 ‘Asphaltic concrete mixtures for roads, aerodromes, and asphaltic concrete. technical specifications’.

So, B type asphaltic concrete prepared with modified binders relates to grades II, III according to the physical-mechanical properties (supplement A, Table A.1 GOST 9128–2009) and is intended for II, III climatic zones (supplement B, Table B.1 GOST 9128–2009). Thus obtained results of laboratory studies gave the ground to carry out experimental-industrial tests with paving the experimental region of road coating, followed by construction supervision of the state of this region.

Results of the experimental-industrial tests of asphaltic concrete mixtures based on bitumen modified with Adgezolin additive allow us to expect an increase in overhaul period and in operating life of the pavement.

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