Modification of bituminous binders for guss asphalt

Marina Vysotskaya*[1][0000-0003-4572-7839], *Anastasia* Kurlykina[1][0000-0003-3265-5856], *Artem* Shiryaev[1][0000-0001-9850-9320], *Anna* Tkacheva[1][0000-0002-6083-3878], and *Dmitry* Litovchenko[1] [0000-0001-7128-9380]

[1]Belgorod State Technological University named after V.G. Shukhov, 308012 Belgorod, Russia

Abstract. Over the past few years, the research of the use of cast asphalt concrete mixtures in the upper layers of the coating of bridge structures has been actively carried out. The experience gained allows us to conclude that one of the most common effective ways to improve the durability and thermal stability of cast asphalt concrete pavements is the use of modified bituminous binders. The modified bitumen part of cast asphalt concrete acts as a medium capable of initiating the «self-healing» of the composite, independently eliminating structural defects. This study aims to research the rheological characteristics of modified bituminous binders. Bitumen grade BND 50/70 was used as a raw material in the study; the following types of additives were used as its modifiers: rubber modifier (RM), EVATHERM and SBS. The optimal concentrations of the proposed additives for modification allowing to achieve the effect of structuring the mastic component of cast asphalt concrete with insignificant increases in the temperatures of mixing and compaction of mixtures based on them have been revealed.
Keywords. Modified Bitumen, self-restoration, guss asphalt.

1 Introduction

Today the urgent problem of the transport network is the emergency and pre-emergency state of bridges and overpasses and this thing affects both developed and developing countries. Bridge structures, as the most complex and important elements of road infrastructure, require increased attention during the life cycle since the negative consequences of destruction entail significant economic losses, deaths of road users, and also cause significant inconvenience to the population. The elementary causes of the destruction of bridge structures are mistakes made at the stage of their design, construction or operation. Equally, the cause of the destruction of bridges can be the circumstances that do not depend on the human factor, caused by nature and which influence the structural elements of structures [1]. It is necessary to take into account the existing operating experience and to take into account the main factors affecting their durability and reliability to achieve the maximum positive effect from the repair and reconstruction of engineering structures.

One of the main ways to increase the reliability of a bridge structure is to build a durable pavement. Nowadays, no materials that would prove themselves well enough in work, both at positive and at significant negative ambient temperatures have been invented. But the use

*Corresponding author: vysotskaya.ma@mail.ru

of cast asphalt concrete in the construction of a roadbed on bridge structures is able to ensure the durability of the entire structure and meet the requirements more efficiently than other types of coatings [2-7]. Cast asphalt concrete has a number of advantages such as: water resistance, high plasticity and fatigue life, while the value of the indicators increases several times when used in the composition of modified binders.

The main difference between cast asphalt concrete and traditional mixtures is the increased content of bitumen and mineral material. This means that the characteristics of poured asphalt concrete directly depend on the asphalt binder. Nowadays, there are many studies [8-20] aimed at researching the properties of the asphalt binder, which demonstrate that the mixture of bitumen and mineral material requires a balanced ratio taking into account the general characteristics of poured asphalt concrete including the ability to self-heal. Self-healing of a composite implies a property of a material capable of initiating the process of elimination of structural defects, the rate of which exceeds the rate of their spontaneous growth and the resistance to operating conditions of the formed structure is not less than the initial one [9]. Healing can extend the life of the pavement in the structure and the achievement of such an effect is possible due to the use of a binder with high elastic and cohesive properties. Thus, an asphalt binder that combines the individual mineral aggregate particles is critical for the self-healing of asphalt materials.

Self-healing of cracks in the asphalt concrete mixture occurs mainly due to the flow of bitumen contained in the space between the aggregates [10]. Until now, it was considered that the flow of bitumen is influenced by such physical quantities as the force of gravity and the presence of surface tension forces of bitumen and aggregate. However, some studies demonstrate that bitumen is able to recover to baseline values after healing for a sufficient time or at a sufficiently high temperature due to viscous healing. The time-dependent recovery results show a distinctive difference between the constant-gap control mode and the constant-force control mode [11]. The ability of the binder to heal itself steadily increases with increasing temperature. The results of computed tomography obtained by the authors [12] indicate that the temperature at which self-healing occurs is more important than time. Thermal expansion of bitumen plays an important role in the self-healing of the asphalt mix. In addition, it was found that the activation energy of asphalt self-healing is similar to the activation energy of bitumen rising due to thermal expansion, which confirms the contribution of thermal expansion to the self-healing of asphalt due to the effect of temperature increase.

Obviously, the quality and ability of asphalt concrete mixtures to self-heal directly depends on the characteristics of the applied bitumen binder. It is possible to influence the temperature characteristics of the binder through the use of various modifying additives; therefore, the development of effective modified bituminous binders is an urgent trend in road construction.

In this work, the subject of research was bitumen modified with additives of various bases for the purpose of studying the self-healing ability of the obtained binders, with subsequent use for the preparation of cast asphalt concrete. It is known that the composition of cast asphalt concrete contains an increased content of the microstructural component (binder-mineral powder); it is obvious that in order to obtain an effective composite it is necessary to adjust the properties of the mastic part. This study aims to research the rheological characteristics of modified bituminous binders in order to better understand the mechanisms of interaction between modifying additives and bitumen, as well as to study the ability of the binder to self-heal for a presumptive assessment of the durability of the structure of poured asphalt concrete.

2 Materials and methods

In the study bitumen BND 50/70 was used as the base bitumen, the properties of which are presented in Table 1, the following additives were used as modifiers: rubber modifier (RM),

EVATHERM and SBS, Fig. 1. The percentage of additives introduced varied from 1 to 5 % with a concentration step of 1%.

Table 1. Physical and mechanical properties of traditional bitumen.

The name of indicators	Requirements of GOST 33133-2014 BND 50/70	Actual results
Needle penetration depth 0.1 mm at 25^0C, at 0^0C	 51-70 not less than 18	 58 39
Elongation, cm at 25^0C, at 0^0C	 60 3.5	 78 4.3
Softening temperature ^{0}C	51	52

a) b) c)

Fig. 1. Used modifying additives: a) PM; b) EVATHERM, c) SBS.

Modified bituminous binders were prepared on a Silverson L5T laboratory paddle mixer. The preparation technology was carried out in two stages: at the first stage the components of the system were mixed at a temperature of 170 °C for 1 hour and 30 minutes, after which the prepared modified binder was ripened in an oven for 1 hour in order to finally form the structure. The evaluation of the characteristics of binders was carried out according to the basic indicators: penetration, softening temperature and extensibility.

Also, for bituminous binders, indicators of cohesive strength of adhesion of organic binders and dynamic viscosity were found. The cohesion test was carried out in accordance with the method outlined in the standard EN 12274-4 «Slurry surfacing. Test methods. Determination of cohesion of the mix». The essence of the method is to measure the torque on the Controls 80-B0193 device under a pressure of 200 kPa. Sample preparation was carried out by pouring a binder heated to 170 °C onto special brass rings with a diameter of 60 mm pre-installed in the center of the roofing material square. The poured samples were kept in air at room temperature for 24 hours after which the torque was measured. The prepared sample was placed in the center of the device under the neoprene base after which the air pressure of the device was set equal to 200 kPa, then the piston was lowered to the sample at a speed of 8 cm/sec. After 6 seconds of compaction of the sample, the torque meter was zeroed, placed on the upper edge of the cylinder rod and twisted by a smooth, constant, horizontal movement at an angle from 90° to 120° for 7 seconds. The resulting torque was recorded.

The dynamic viscosity was determined in accordance with the method described in GOST 33137-2014 «Public automobile roads. Viscous oil road bitumen. Method for determination of dynamic viscosity with a rotary viscometer». Finding the dynamic viscosity of the binder consists in measuring the relative resistance to flow caused by the shear action of the rotating

elements of the configuration on the substance. To determine the viscosity, a Brookfield DV2TRV rotational viscometer was used, the principle of which is to measure the twisting of a calibrated spring when the spindle rotates in bitumen at a constant speed. The operating temperature of the experiment was 165°C. The roller was attached to the viscometer and lowered into an empty container for 60 minutes to achieve temperature equilibrium. The binder, heated to the required temperature in the amount of 8-9 grams, was poured into a container for bitumen, which was then installed back into the thermostat. The spindle of the viscometer was immersed in the test material so that the roller was completely immersed in the test material, then the sample was thermostated for 30 min. Then the device was put into action. The objective of the test was to obtain the dynamic viscosity of the substance at the speed of rotation of the roller so as to achieve a shear coefficient of 50±10%. The test result obtained was shown on the display.

3 Results and discussion

The widespread opinion that the reliability and durability of asphalt concrete pavements is determined by the quality of the used binder is still valid. However, if at least indirect prediction is possible regarding to the effect of the physicochemical characteristics of bitumen on the water and frost resistance of asphalt concrete [21], then its mechanical behavior is usually not considered as an aspect of the effect on the mechanical properties of asphalt concrete.

In this regard, at the first stage, a study of the physical and mechanical characteristics of the modified bitumen was carried out.

The test results are presented in table 2.

Table 2. Physical and mechanical properties of studied binders.

Indicator name		Needle penetration depth, 0.1 mm		Softening temperature ^{0}C	Elongation, cm	
		at 25 °C	at 0 °C		at 25 °C	at 0 °C
Bitumen + PM	2 %	40	27	56	50	1.3
	3%	39	25	56	47.3	0.9
	4%	37	23	59	38.5	0.4
	5%	36	17	61	28.8	0.0
Bitumen + EVATHERM	1%	40	21	60	56	3.9
	2 %	37	20	63	35	3.9
	3%	37	19	63	27.9	2.2
	4%	28	24	65	16.9	2.2
	5%	24	22	70	15	0.9
Bitumen + SBS	1%	18	19	75	70.2	3.8
	2 %	27	25	64	60.7	3.8
	3%	20	19	70	42.8	3.8
	4%	20	17	74	34	12.5
	5%	19	19	75	11.0	0.0
GOST R 52056 requirements RMA 40		not less 40	not less 25	56	not less 15	not less 8

The test results show that the penetration of bitumen after the introduction of the studied modifying additives decreases with the transition to a more viscous grade. In general, an increase in the softening temperature is noticeable for all samples, however, for a binder modified with complex rubber the change in this indicator is insignificant. Since the

preparation of cast asphalt concrete mixtures is characterized by a high working temperature of mixing the components it can be judged that the obtained high softening points for modified bitumen have only a positive effect. Due to the high softening point the plasticity interval increases, which also contributes to an increase in adhesion properties, asphalt concrete on such a binder will be less prone to rutting. From the above, it should be assumed that the use of modifiers significantly affects the properties of organic binders in the direction of improving performance at high temperatures. Since the preparation of cast asphalt concrete is characterized by a high mixing temperature of preparation.

Nowadays, the value of penetration is considered as an insufficiently objective indicator by which it is permissible to judge the quality of bitumen. Viscosity was taken as an objective characteristic, which makes it possible to more accurately determine the structural features of bitumen due to the low information content of this indicator. The viscosity of the binder is an indispensable indicator when assessing the influence of any factors on bitumen such as aging the introduction of modifying additives, etc.

Therefore, further in this work, we analyzed the change in dynamic viscosity at a temperature of 165 °C for more temperature-resistant binders, i.e., for samples with the highest additive content (4 and 5%). The study of the rheological properties of bitumen with additives will make it possible to assess more accurately their effect on the structure of bitumen, asphalt binder and asphalt concrete mixture with the required technological properties. The dynamic viscosity test results are shown in Table 3.

Table 3. Effect of modifiers on bitumen viscosity at 165 °C.

Indicator name	BND 50/70	Bitumen + PM		Bitumen + EVATHERM		Bitumen + SBS	
		4%	5%	4%	5%	4%	5%
Viscosity, Pa·s	0.14	0.33	0.30	0.63	0.87	0.95	1.28
Torque, %	5.16	49.3	51.1	50.1	51.9	49.5	51.0
Speed, RPM	190	75	85	40	30	13	20
Temperature, °C	165						

The test results show that an increase in the amount of modifier increases the dynamic viscosity of the binder while there is a significant decrease in the shear rate.

However, the determination of viscosity at service temperatures is difficult. Moreover, when calculating and designing non-rigid road pavements, scientists rely on predicting the behavior of the pavement in real conditions, taking into account the strength indicators of asphalt concrete at different temperatures and deformation rates. Therefore, it is necessary to have a characteristic equivalent to strength to assess the quality of bitumen.

This characteristic can be the cohesion of the bituminous binder, which allows predicting the strength of asphalt concrete and the behavior of materials at different temperatures. The results of testing the adhesion strength of the studied binders are shown in Fig. 2.

Based on the results obtained, it can be concluded that an increase in the amount of additive in bitumen makes it possible to increase the cohesive strength of adhesion, which will have a beneficial effect on the strength of poured asphalt concrete. The greatest reinforcing effect was achieved with binders modified with SBS polymers. Presumably, it is necessary to increase the content of this modifier in bitumen by more than 5% to obtain a similar result when using a rubber modifier.

Presumably, bitumen with the addition of SBS will behave more effectively in a poured asphalt-concrete mixture, since they are more temperature-resistant than other samples. Also, samples of bitumen and EVATHERM modifier with an additive content of 4 and 5% have good performance.

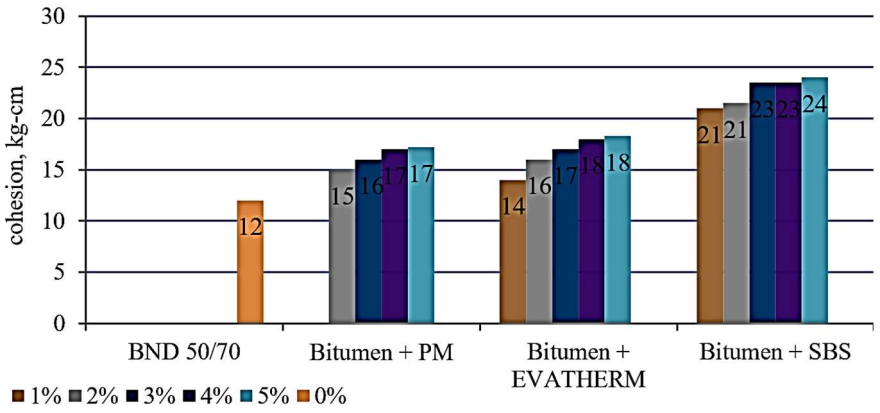

Fig. 2. Results of determining the cohesion of bitumen modifications.

As previously stated, a key factor in the durability of the structure of poured asphalt is the ability of the binder to heal itself. To assess the ability of the prepared binders to such phenomena, samples of selective binders (BND 50/70, Bitumen + PM (4%), Bitumen + EVATHERM (4%), Bitumen + SBS (3%)), tested for cohesive strength were subjected to a cycle of subsequent tests. For this, the binder in ring-shaped forms was placed in a drying oven at a temperature of 50 °C for 12 hours for the possibility of «healing» the defects formed during testing, after which they were re-tested to assess the cohesive strength, Fig. 3.

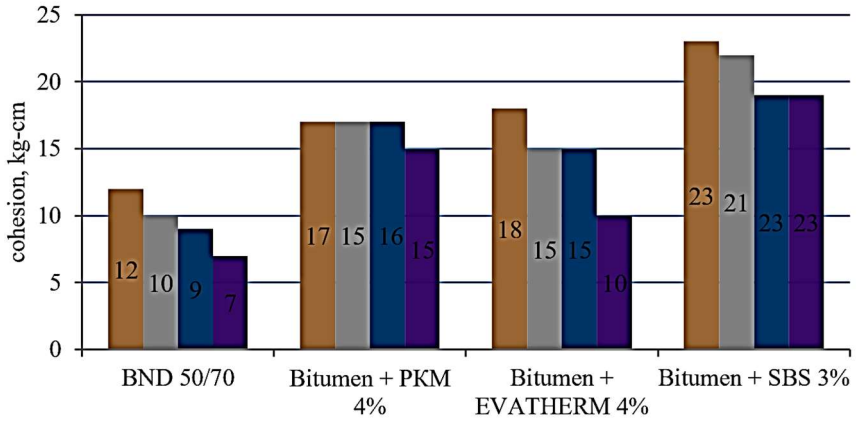

Fig. 3. Results of determining the cohesion of bitumen modifications.

In the course of the study, it was found that self-healing processes in the structure of the modified binder are observed when modified with rubber powder for 3 test cycles after which a slight decrease in cohesion is observed.

There is a gradual decrease in cohesion with a plateau at 3-4 test cycles in the case of considering the SBS modifier.

It can be assumed that such binders will work effectively in the structure of poured asphalt concrete, with the manifestation of a self-healing effect.

In the regulatory document issued in 2020 for cast asphalt concrete mixtures (GOST 54401-2020 «General use of automobile roads. Hot cast asphalt concrete road mixes and cast road asphalt concrete. Technical conditions») set forth the basic requirements for the raw materials used. It is said that the use of modified bituminous binders is allowed, provided that the quality indicators of cast asphalt concrete from these mixtures are not lower than those established in the standard. Therefore, in further studies it is necessary to see how the resulting

binders will behave in the composition of poured asphalt concrete and how they will affect its properties. Then it will be possible to judge the possibility of their use in practice.

4 Conclusions

The influence of the studied modifying additives on the physical and mechanical properties of binders made on their basis has been established.

The greatest reinforcing effect was achieved in bitumen modified with SBS polymers in an amount of 3-5%. This is obviously due to the fact that after mixing with bitumen, the polymers are distributed in a dispersed medium and create their own reinforcing structural network in the composition of the binder. Such a polymer framework provides the strength of the bitumen composition, which contributes to the fact that at elevated temperatures its fluidity is minimized, and, consequently, the working limit of organic binders and asphalt concrete based on them expands. Thus, the use of the SBS type polymer, in our opinion, is technologically justified, and the change in the properties of organic binders in the process of modification is predictable.

The EVATHERM additive showed satisfactory results in terms of the softening point, especially the samples with the additive content of 4 and 5%. These samples have good viscosity characteristics at a reduced shear rate and with an increase in the concentration of the additive an increase in the adhesion strength of the binder (cohesion) is noticeable, which indicates an improvement in the structure of the binder.

Bituminous binders with a rubber modifier slightly changed the properties of the original bitumen. In order to trace the growth of the effect of the additive on the feedstock and influence the cohesive strength, it is necessary to increase the content of this additive. And the introduction of a plasticizer will help increase the extensibility and elasticity of the samples.

The two-stage technological process of bitumen modification with additives contributes to an increase in the homogeneity of the system and the formation of a dispersed framework that reinforces the binder which, in general, leads to the production of a binder with improved physicochemical characteristics.

Studies aimed at studying bituminous binders and the results obtained allow a better understanding of the mechanisms of interaction between modifying additives and bitumen, as well as direct the production of a binder with excellent properties in industry.

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