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Modifying the Properties of Bitumen Binders with Polyethylene Waxes

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Abstract—In this paper, the problem of modifying the physicochemical and rheological characteristics of bitumen binders with polyethylene wax additives is considered. Based on the study of physicochemical and rheological properties, it is shown that the addition of these modifiers results in binders with improved characteristics, such as the softening temperature, rutting resistance, and fatigue cracking. Taking into account the quantitative estimate for the degree of change in the properties of modified bitumen binders, optimal doses of modifiers are determined.

Keywords: bitumen binder, rheological characteristics, critical performance temperature, fatigue resistance

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The expansion of highway networks and the growth of traffic flows, freight traffic rates, and vehicle axle loads fundamentally tighten the requirements to the resistance of road pavements to the formation of defects, which depends to an significant extent on the quality of applied binders [1], but the performability and durability of asphalt–concrete pavements are related immediately with the physicochemical and rheological characteristics of a binder [2].

Petroleum bitumens are widely applied in the production of different sealing, adhesive, paint-and-varnish, and insulating materials. Due to a number valuable properties, they are most widely used as a binder in highway construction [3]. However, the quality of currently produced road bitumens has already fallen below all the contemporary requirements. The modification of a petroleum bitumen with different polymer additives is one of the promising ways to improve the performability and durability of a road pavement [4, 5].

One of the trends in the production of polymer-modified bitumen binding materials is the use of thermoplastic polymer modifiers, such as high- and low-density polyethylenes and polypropylene [6, 7]. In addition to high-molecular-weight polyolefins, low-molecular-weight polyolefin waxes are in great demand for bitumen modification. The advantages of these modifiers are described in papers [2, 8] using the example of Sasobit and Honeywell Titan products and consist in that, in the region of performance temperatures, these additives strengthen the binder and expand the plasticity interval by increasing the softening temperature. Due to the orientation of strategic industry branches to import substitution, the testing of domestic polyolefin waxes for the production of polymer-modified bitumen binders is of scientific and practical interest.

The objective of this paper was to study the effect of domestic polyethylene waxes on the physicochemical and rheological characteristics of bitumen binders.

MATERIALS AND METHODS

The used model bitumen base was BND 100/130 bitumen (GOST (State Standard) 33133—2014). The physicochemical characteristics of this bitumen are given in Table 1.

The tested modifiers were additives based on Plastobit Titan and Plastobit 2.0 polymer waxes (OAO

Table 1. Physicochemical characteristics of BND 100/130 bitumen

No.	Characteristic	Value	Test method
1	Softening temperature by the ball and ring method, °C	45.4	GOST (State Standard) 33142
2	Needle penetration depth at 25°C, 0.1 mm	112	GOST (State Standard) 33136
3	Fraas brittle point, °C	–25	GOST (State Standard) 33143

Table 2. Principal characteristics of used additives

No.	Characteristic	Plastobit 2.0	Plastobit Titan
1	Form	Micrograin	Micrograin
2	Size	Up to 1 mm	Up to 1 mm
3	Color	White	White
4	Dropping temperature, °C, GOST (State Standard) 6793–74	103–110	126–132
5	Dynamic viscosity at 140°C, mPa s, ASTM D3236	100–300	600–800
6	Penetration, 1/10 mm, ASTM D1321	No more than 3	No more than 3
7	Specific density at 20°C, GOST (State Standard) 15139–69	0.89–0.92	0.95–0.96

Table 3. Physicochemical characteristics of modified bitumen binders

No.	Characteristic	Value				Method of testing
		0.5%	1%	1.5%	2%	
	Plastobit 2.0					
1	Softening temperature by the ball and ring method, °C	48.0	49.2	50.2	52.4	GOST (State Standard) 33142
2	Needle penetration depth at 25°C, 0.1 mm	85	83	82	78	GOST (State Standard) 33136
	Plastobit Titan					
1	Softening temperature by the ball and ring method, °C	50.0	56.4	58.8	61.8	GOST (State Standard) 33142
2	Needle penetration depth at 25°C, 0.1 mm	90	86	81	76	GOST (State Standard) 33136

Forplast Trading, Russia, Perm). The principal characteristics of the used additives are listed in Table 2. These modifiers represent polyethylene based polymer materials with a molecular mass of 14000 amu (Plastobit 2.0) and 6500 amu (Plastobit Titan).

The studied modifiers were added in doses of 0.5, 1.0, 1.5, and 2.0 wt % per bitumen mass. The reference specimen was bitumen binder free from modifying additives.

The basic binder was homogenized and mixed with the modifiers on a Silverson L5R disperser. The resulting product was tested for homogeneity by the method described in paragraph 6.1 of GOST (State Standard) R 52056–2003.

The process of preparing the binders to be tested incorporated two stages, such as the preliminary heating of a binder in a drying cabinet to 160°C and the mixing of the initial binder with a modifier at 3200 rpm for 1 h at a temperature of 170–175°C, keeping the resulting binder in a dryer at 170°C for 1 h, whereupon the resulting binder was subjected to testing.

The tests were performed by both the standard techniques, in which the softening point is determined by the ring and ball method (GOST (State Standard) 33142) and by the method of measuring the needle penetration depth at 25°C, and by the techniques described in GOST (State Standard) R 58400.1. Initial bitumen binders and binders aged by the RTFOT (GOST (State Standard) 33140) and PAV (GOST (State Standard) R 58400.5) were subjected to tests. The rheological characteristics of binder specimens were estimated by the changes in the complex shear modulus and phase angle. The rutting resistance of asphalt–concrete pavements was estimated by the critical temperature before and after aging by the RTFOT method. The fatigue resistance was used to estimate the resistance of bitumen binders ager by the RTFOT and PAV methods to fatigue cracking. These tests were carried out on a Physica MCR 102 rheometer by GOST (State Standard) R 58400.10.

RESULTS AND DISCUSSION

At the first stage, studies of the effect of modifying additives on the principal physicochemical characteristics of bitumen binders (softening temperature and depth of needle penetration into a bitumen) were carried out. The results of studies are given in Table 3. From the presented data, it can be seen that the introduction of modifying additives leads to an increase in the softening temperature of bitumen binders, but the needle penetration depth decreases. Notably, the most fundamental changes are observed in the mentioned characteristics when Plastobit Titan modifier is used due to a higher molecular mass of this modifier, which has higher dropping temperature and dynamic viscosity values as compared to Plastobit 2.0.

According to the SuperPav method, the principal rheological characteristics of bitumen binders are the shear modulus and phase angle. The complex shear modulus is a measure for the overall resistance of a material to deformation under repeated sheal force

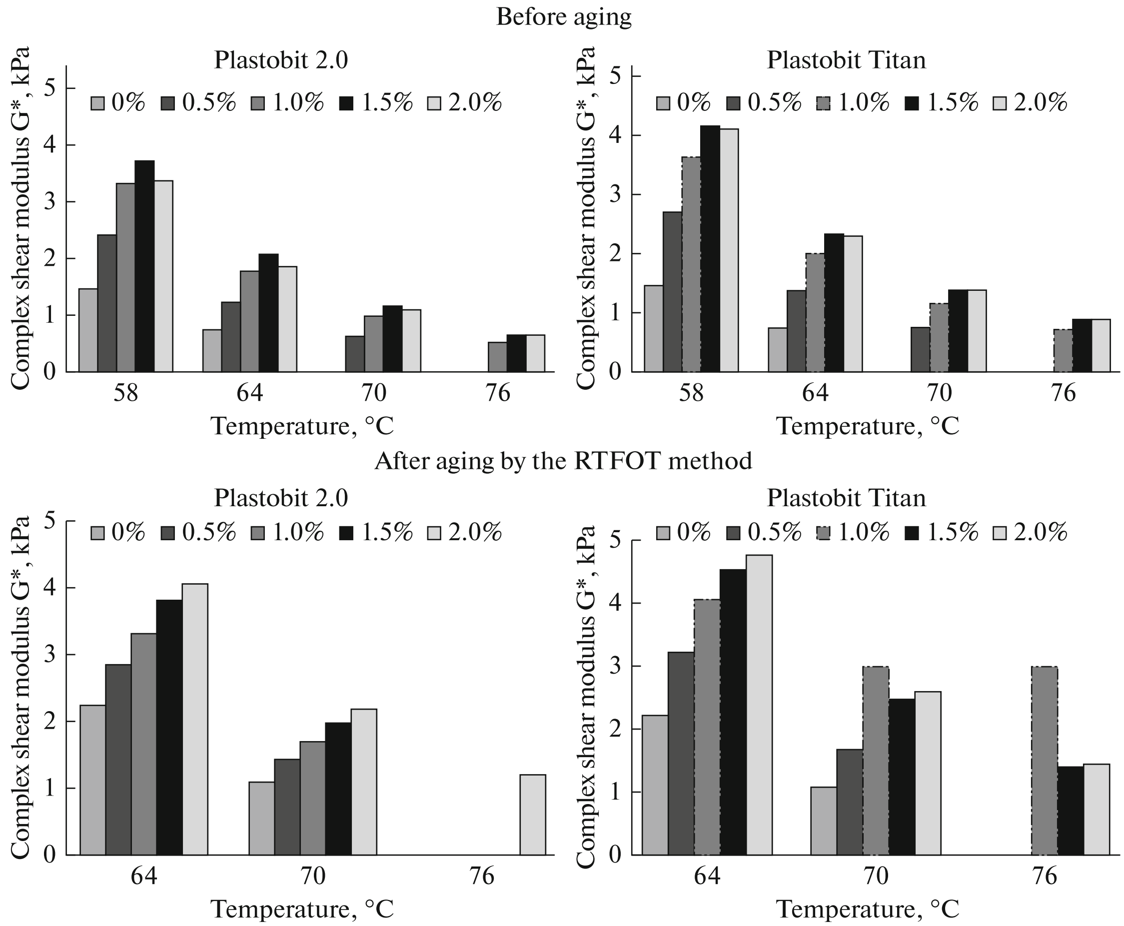

Fig. 1. Effect of the nature and content of modifiers on the complex shear modulus of binders depending on the temperature of tests.

[9–11], whereas the phase angle is the parameter determining the lag between a sinusoidal deformation and a sinusoidal stress [12]. Both parameters characterize the resistance of an asphalt–concrete pavement to rutting [13].

These parameters were determined in the temperature interval of 58–76°C with a step of 6°C for the original specimens and at a temperature of 64–76°C with a step of 6°C for the specimens subjected to short-term aging in air by the RTFOT method. The results of tests are shown in Figs. 1 and 2.

The results of measuring the critical performance temperatures of bitumen binders before and after aging by the RTFOT method are given in Table 4, from which it follows that the introduction of modifying additive is promotive for an essential increase in the complex shear modulus, and this evidences that the stiffness of the bitumen binder also increases. For the specimens with 1.5% of modifier, this parameter is almost three times higher than for the initial bitumen.

A decrease in the phase angle of a binder indicates that the bitumen binder containing a modifier has more pronounced elastic properties than initial bitumen does. This circumstance evidences that the asphalt pavement formed with the use of this modified binder is more capable for healing after applied loading as compared to the pavement containing the initial bitumen.

Hence, the introduction of polyethylene waxes into a polymer-modified bitumen binder makes a pavement more resistant to rutting.

In addition to improved rheological characteristics, the obtained binders have higher resistance to high-temperature performance conditions. The criterion characterizing this property is the critical performance temperature, i.e., the temperature at which the ratio of the complex shear modulus to the phase angle sinus is 1 kPa for the unaged binders and 2.2 kPa for the binders aged by the RTFOT method. The critical temperature indicates the actual grade of a binder according to the Performance Grade (PG) classification.

From the data of Table 4, it can be seen that the introduction of modifying additives increases the actual grade of a binder. Thus, the addition of 1.5 wt % of Plastobit Titan increases the critical performance temperature of the aged binder by 7°C. The binders

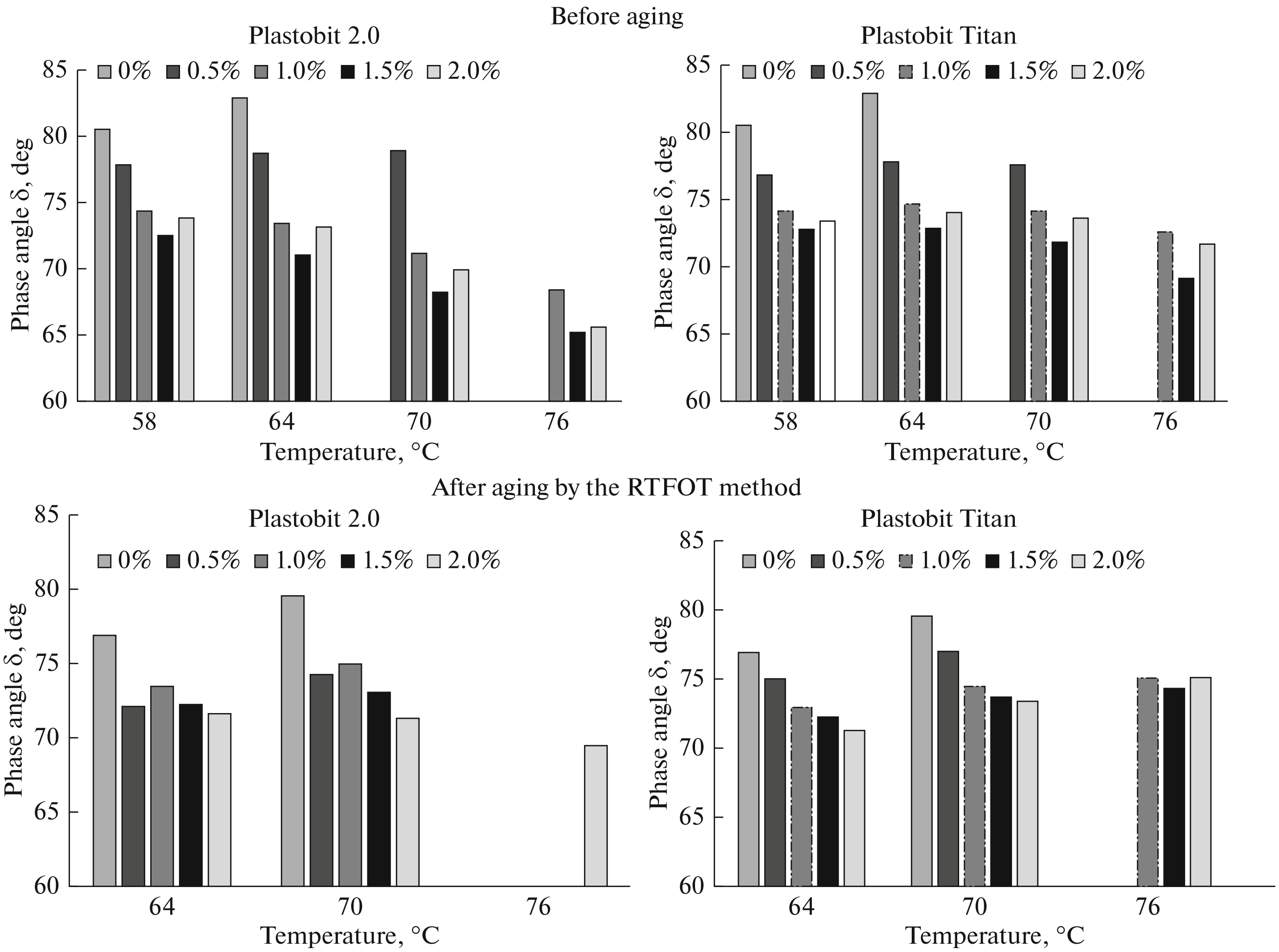

Fig. 2. Phase angle of binders versus temperature of tests.

prepared in this way are less sensitive to high-temperature performance conditions and can be used in asphalt—concrete pavements at higher annual-average temperatures and, in turn, this will decrease rutting on highways.

In addition to rutting resistance, the durability of asphalt—concrete pavements is strongly influenced by the resistance of a bitumen binder to the accumulation of fatigue cracks, which is characterized by fatigue resistance. This parameter is determined on binder

Table 4. Dependence of the critical performance temperature of a binder on the type and content of a modifier

Modifying additive	Modifying additive dose, wt %	Critical performance temperature of a binder, °C	
		before aging	after aging
Plastobit 2.0	0.0	61.6	64.4
	0.5	66.0	66.7
	1.0	70.4	68.1
	1.5	72.6	69.5
	2.0	72.0	70.5
Plastobit Titan	0.5	67.6	67.9
	1.0	72.4	70.4
	1.5	75.7	71.8
	2.0	75.1	72.2

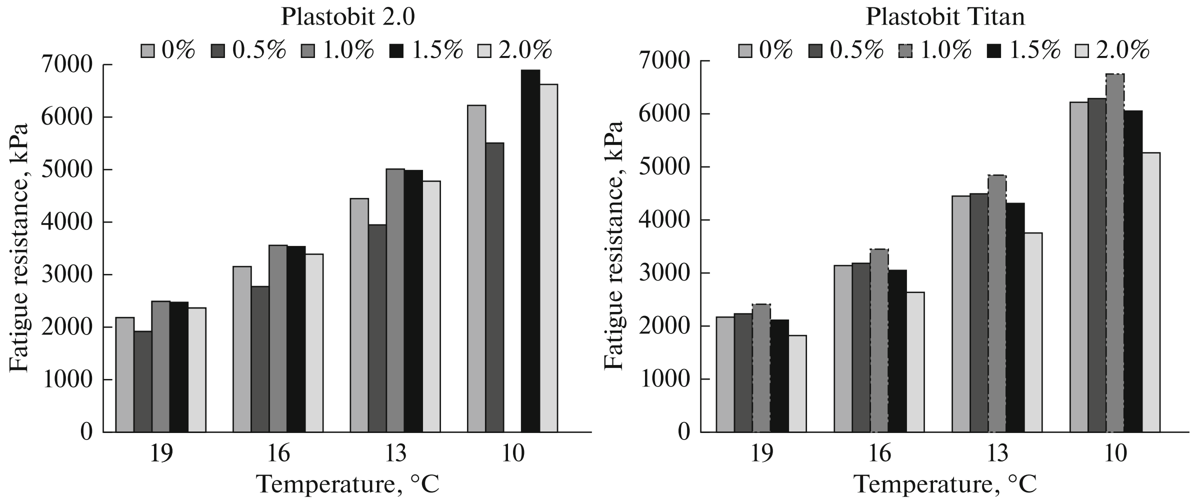

Fig. 3. Effect of the type and dose of a modifier on the fatigue resistance of bitumen binders.

specimens aged by the RTFOT method and, thereafter, by the PAV method. The results of determining the fatigue resistance of the studied binders in the temperature interval from 19 to 10°C with a step of 3°C are shown in Fig. 3.

From the presented data, it can be seen that the introduction of modifying additives improves the resistance to fatigue cracking. In this case, the highest value is attained at a dose of 1.0 wt %. An increase in the Plastobit Titan additive dose leads to a decrease in fatigue resistance. At an additive dose of 2 wt %, this parameter at 10°C is 19% lower than for the reference specimen.

When Plastobit 2.0 is used in doses more than 1 wt %, the fatigue resistance also decreases, but remains higher than for the reference specimen.

CONCLUSIONS

Plastobit 2.0 and Plastobit Titan polyethylene waxes of domestic production have been tested as modifiers of bitumen binders for the first time. Based on the results of performed studies, it has been revealed that the application of these modifiers makes it possible to obtain asphalt–concrete pavements with increased resistance to rutting and the accumulation of fatigue cracks. It has been established that the most optimal content of polyethylene waxes in modified bitumen binders is doses from 0.5 to 1.0 wt %. In this case, the most pronounced modifying effect on both the physicochemical characteristics of binders and their rheological characteristics is observed when additive Plastobit Titan is used due to its higher molecular mass as compared to Plastobit 2.0.

Based on the data obtained as a result of studies, it is reasonable to recommend the application of polyethylene waxes as modifiers for the bitumen binders designed for use in regions with warm and hot climate.

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CONFLICT OF INTEREST

The authors of this paper declare that they have no conflicts of interests.

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