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Aging of Sandy Asphalt Mixes with Anti-aging Additives

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Limestone; Asphalt; Asphalt mixtures; Durability; Elevated temperature; Binders; Modified bitumen

Abstract:

The object of research is sandy asphalt concrete mixtures. Asphalt concrete in the process of preparation and operation irrevocably reduces its mechanical properties, which is called aging. This process depends on the composition, structure, and size of mineral materials, the physical and mechanical properties of the bitumen used, temperature, and other factors. To reduce the intensity of aging of asphalt concrete, a method has been proposed to improve its properties by introducing additives of anti-aging agents. **Method.** When preparing sandy asphalt concrete mixtures, various additives are introduced into their composition. Subsequently, samples are formed, and a comparative assessment of various physical and mechanical properties is carried out. Carbon black, sulfur, and the stabilizing additive Viatop-66 were used as additives. The estimation of the rate and intensity of aging was established according to the method provided for by the patent of the Russian Federation No. 2654954 (Volga State Technological University, Department of Building Technologies and Highways). Aging was carried out by preliminary keeping the prepared mixtures in an oven at a temperature of 150 °C for 1, 3, 5, and 7 hours. The static modulus of elasticity was estimated by stepwise loading of asphalt concrete samples by fixing the values of total and residual deformations. **Results.** It was found that the introduction of some of the proposed additives made it possible to reduce the intensity of aging of asphalt concrete. The aging coefficient of the base composition (without additives) for 7 hours at a temperature of 150 °C was 1.40, the composition with carbon black was 2.33, with sulfur it was 1.39, and with a stabilizing additive, it was 2.74. Correlations between the values of the aging coefficient of asphalt concrete and mixtures with various additives were obtained in the CurveExpert software environment. The obtained dependencies allow us to analyze the influence of the applied additives on the processes of aging of asphalt concrete over time and rank them according to the degree of influence on the dynamics of this process.

1 Introduction

According to the results of numerous studies [1]–[6], it has been established that one of the main factors in reducing the performance of road pavements is the inevitable decrease in their operational properties over time. Especially, this problem is exacerbated in structures using petroleum bitumen – asphalt concrete, black crushed stone, and other bitumen-mineral materials. Due to the presence of bitumen in the film state, aging processes are more intense [7]–[14]. As a result of bitumen aging under the influence of internal and external environments, their adhesive ability decreases. In this regard, it is necessary to expect a decrease in strength and other indicators of bitumen-mineral materials. And this, in turn, leads to a decrease in the performance of the structural layers of pavement. The decrease in strength indicators is the result of the irreversible aging of bitumen in the composition of bitumen-mineral materials under the influence of high and low temperatures, aggressive environments, salt solutions, and other factors. To reduce the aging process, various researchers have proposed different methods. This is a change in the technological modes of preparation, transportation, laying, the selection of compositions more resistant to aging processes, the use of modifying additives, etc. [14]–[21]. One of the promising directions for reducing the aging process of asphalt concrete is the modification of bituminous binders with anti-aging additives. They can be various powdered substances and surface-active additives. At the same time, it is important to establish the patterns of change in time of the influence on the properties of bitumen films through the study of changes in the physical and mechanical properties of the bitumen-mineral material as a whole.

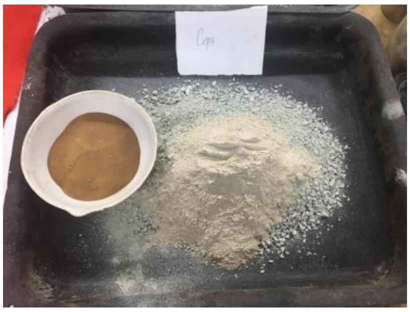
The purpose of this work is to study the aging process of asphalt concrete mixtures, consisting of inert materials, oil viscous bitumen grade BND 70/100, and various anti-aging additives. To achieve this goal, the **following tasks** were solved: 1) Establishment of the values of the modulus of elasticity, compressive strength at temperatures of +20 °C and +50 °C for standard cylindrical samples (height and diameter 50x50 mm). Samples are molded from previously aged mixtures at +150 °C for 0...7 hours; 2) Calculation of values of K_{aging} aging coefficient, I_{aging} aging rate and analysis of the change in values depending on the preheating time of the mixture at high temperature; 3) Statistical processing of data obtained during experiments by the method of one-factor planning in the CurveExpert software environment; 4) Obtaining mathematical models of the aging rate of bitumen-mineral mixtures depending on the holding time at a temperature of 150 °C.

2 Materials and Methods

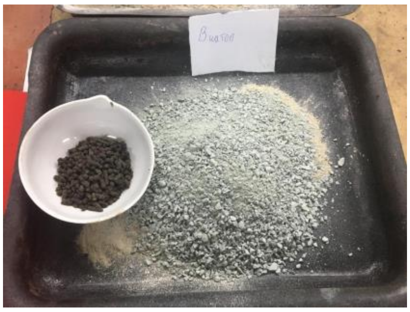
Evaluation of the aging processes of structural layers of bitumen-mineral mixtures can be carried out by continuous or periodic monitoring of their operational state over a long period and in the process of laboratory testing by artificial aging in a relatively short period. Due to the lack of a standard method, various authors have proposed various methods for studying this process. Each of them has its advantages and disadvantages. Taking into account the analysis of these methods at the Department of Building Technologies and Highways of the Volga State Technological University, a method protected by a patent of the Russian Federation was also proposed. One of its advantages and differences from the known ones is that it allows studying the aging processes of bitumen both in the composition of complex and in monomineral bitumen-mineral mixtures, which makes it possible to evaluate the role of each of the components in the aging of the entire bitumen-mineral mixture [22].

As a base (without additives), a sandy asphalt-concrete mixture of the following composition was adopted: screenings of crushing of igneous rocks with a brand of crushability of the original rock M 1200 fr. 0…5 mm – 90 %; limestone mineral powder 0…0.16 mm – 10 %; oil road bitumen BND 90/130 – 6 % (over 100 %). The main properties of the components used are presented in Table. 1-3. Powdered carbon black and sulfur, stabilizing additive Viatop-66 (in the form of granules) were used as additives (Fig. 1). The modified compositions are presented in Table. 4.

a)



b)



c)

Fig.1 – Appearance of components and additives: a) carbon black; b) sulfur; c) Viatop-66

Table 1. Some characteristics of bitumen 90/130

Indicator	Standard requirement	Actual value of the indicator
1. Needle penetration depth at temperature +25 °C, 0.1 mm	71-100	78
2. Softening point, °C, not lower	47	48
3. Tensile at °C, cm, not lower	3.7	3.7
4. Fragility temperature, °C, not lower	-18	-19
5. Flash point, °C, not lower	230	308
6. Change in sample mass after aging,%, not more than	0.6	0.3

Table 2. Granulometric composition of crushed stoneM1200 grade fr. 0...5 mm

Size of sieves, mm	Sieve fraction values								
	10	5	2.5	1.25	0.63	0.315	0.16	0.071	<0.071
Private balances, %	0,00	29,59	14,40	18,14	14,75	11,23	9,26	2,63	0,00
Total balances, %	0,00	29,59	43,99	62,13	76,88	88,11	97,37	100,00	0,00
Full passing, %	100,00	70,41	56,01	37,87	23,12	11,89	2,63	0,00	100,00

Table 3. Granulometric composition of mineral filler MP-1 grade, fr. 0...0.63 mm

Size of sieves, mm	Sieve fraction values					
	1.25	0.63	0.315	0.16	0.07	<0.07
Private balances, %	0	0.05	0.78	21.12	6.16	71.89
Total balances, %	0	0.05	0.83	21.95	28.11	100
Full passing, %	100	99.95	99.17	78.05	71.89	0

Table 4. Compositions of the studied mixtures

Component	Component content, % by weight for additives			
	Without additive	With carbon black	With sulfur	With Viatop-66
Screenings of stone crushing	92.0	88.0	87.0	91.5
Mineral filler	8.0	8.0	8.0	8.0
Carbon black	-	4.0	-	-
Sulfur	-	-	5.0	-
Viatop-66	-	-	-	0.5
Bitumen BND 90/130 (over 100 %)	8.0	8.0	8.0	8.0

The experiments were performed according to the method proposed by the authors, which allows taking into account all the above disadvantages of previously known methods and, in comparison with the known ones, it has several advantages:

1) studies are carried out in laboratory conditions using practically the entire set of standard equipment;

2) aging processes can be studied under conditions of bitumen distribution in thin layers on the surfaces of mineral materials under conditions of air access (i.e. under technological conditions) or in samples having different densities with limited air access (i.e. under operating conditions);

3) study of aging can be carried out under the influence of various high temperatures or other aggressive media;

4) it is possible to study the aging of bitumen separately in the composition of various mineral components and asphalt concretes of various compositions;

5) analysis of the results of artificial aging is carried out using a dimensionless indicator – the aging coefficient, the values of which do not depend on the scale factor.

Each of the advantages of the developed methodology listed above has a certain theoretical justification and practical approbation. The technique is protected by the RF patent for invention No. 2654954 [11], which has been tested in candidate dissertations and master's theses.

For experiments, samples of asphalt concrete mixtures were prepared according to the compositions presented in Table 4. After heating up to 130…140 °C, they were thoroughly mixed, placed in layers of 3…5 cm on trays, and kept under ventilation conditions (with free air suction) in an oven at a temperature of +150 °C for 0, 1, 3, 5, 7 hours. Then, from these samples at a temperature of 120-130 °C, according to the method of Interstate Standard GOST 9128-13 [23], standard cylindrical samples with a diameter and a height of 50.5 mm were formed. After 1 day of exposure in room conditions, by testing according to the standard methods of Interstate Standard GOST 12801-98 [24] on the test press (IP-10, SKIB, Russia, Fig. 2), the values of a number of their physical and mechanical properties were established, and according to the method of Departmental building standard VSN 46-72 [25] – the modulus of elasticity E. Next, the values of the aging coefficients are calculated according to $R_C^{+50°C}$ ($K_{aging}^{R_C^{+50°C}}$), aging rates $I_{aging}^{K_{aging}^{R_C^{+50°C}}}$ according to formulas 1-5 [21, 22]:

$$K_{aging}^{R_C^{+50°C}} = \frac{R_C^{+50°C,t_h=t_i}}{R_C^{+50°C,t_h=0}} \tag{1}$$

where $Ind_i^{T,t_h=t_i}$ and $Ind_i^{T,t_h=0}$ is values of the indicators of the studied physical and mechanical properties of the bitumen-mineral mixture before and after heating at a high temperature for a time from 0 to t_i, respectively; t_h is a heating time of mixtures;

$$I_{aging}^{K_{aging}^{R_C^{+50°C}}} = \frac{\Delta K_{aging}^{R_C^{+50°C}}}{\Delta t_h} \tag{2}$$

where $\Delta K_{aging}^{R_C^{+50°C}}$ is the change in the aging coefficient values during Δt_h .

$$E^{+50°C} = \frac{p \cdot D}{l_{el}} \cdot \left(1 - \mu^2\right) \tag{3}$$

$$p = \frac{P_{cr}}{S} \tag{4}$$

where P_{cr} is the load on the sample, fixed until the destruction of the sample; S is the sample area, 40 cm^2; μ is Poisson's ratio; l_{el} is the elastic deformation of the sample:

$$l_{el} = l_{comp} - l_{res} \tag{5}$$

where l_{comp} is the total deformation at the time of application of the load; l_{res} is the residual deformation after unloading.

Fig.2 – Testing of samples for compressive strength and determination of the elastic modulus: upper indication – displacement, MPa; lower indication – force load, kN

3 Results and Discussion

As a result of experiments on strength indicators, the values of the aging coefficients and aging intensity were calculated (Tables 5-6) and graphs were plotted for the dependence of their values on the holding time at a temperature of 150 ° C (Fig. 3-4.).

Table 5. Results of experiments to establish the values of compressive strength at +20 °C, modulus of elasticity, coefficient, and intensity of aging for the base composition

Duration time of aging at a temperature of +150 °C t_{dur}, h	Compressive strength $R_C^{+20°C}$, MPa	Elastic modulus E, MPa	Aging coefficient K_{aging} by indicator:		Aging rate I_{aging} by indicator:	
			E	$R_C^{+50°C}$	E	$R_C^{+50°C}$
0	3.65	887	1.00	1.00	0.13	0.26
1	4.14	1118	1.13	1.26	0.12	0.19
3	5.04	1450	1.38	1.64	0.16	0.43
5	6.20	2205	1.70	2.49	-0.03	-0.05
7	5.98	2112	1.64	2.38		

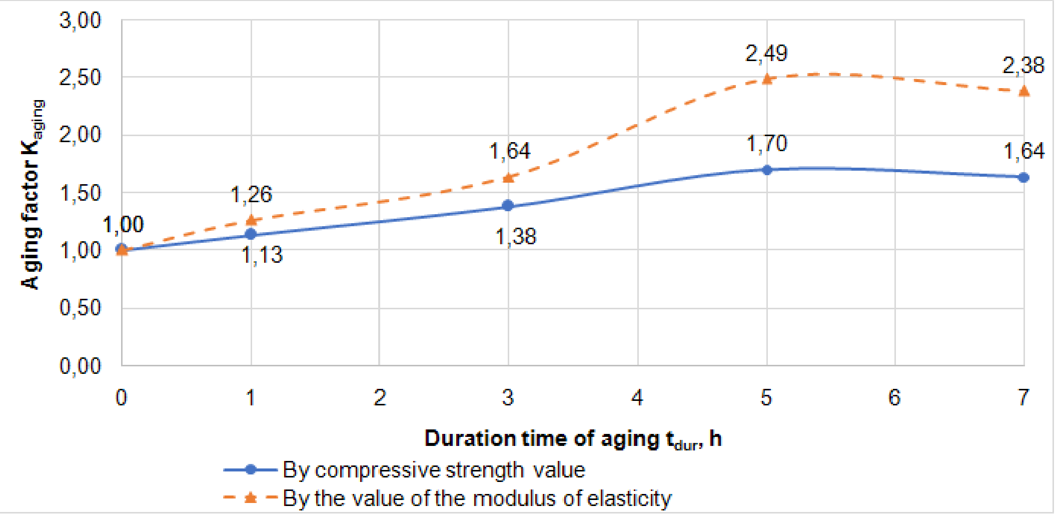


Fig.3 – Graphs of dependency values of the aging coefficients for the base composition at a temperature of +20 °C

Analyzing the Table. 5 and the graph in Fig. 1 you can see the following:

1) The base composition in the first 5 hours of exposure at a temperature of 150 °C, both in terms of compressive strength at 20 °C, and in terms of the elastic modulus, ages in the direction of increasing their mechanical strength and elasticity with an intensity of 0 ... 0.13 and 0, 19 ... 0.26 h^{-1}, and then after 5 hours of keeping in the downward direction;

2) The aging process has begun (t_{dur}=5 hours) but has not yet stopped, since the values of the aging coefficients even when kept for 7 hours have values greater than 1;

3) The values of the compressive strength of samples from mixtures kept at a temperature of 150 °C for the first 5 hours increased by 1.7 times, the elastic modulus – by 2.5 times. This is explained by the fact that due to the increase in the asphaltene-resinous component in bitumen films during heating in the initial period, there is some increase in the adhesive strength of the bitumen film on the surfaces of mineral particles, which leads to some increase in the mechanical strength of the entire system. In the future, this process goes into a zone of weakening due to the embrittlement of bituminous films and a decrease in their adhesive ability.

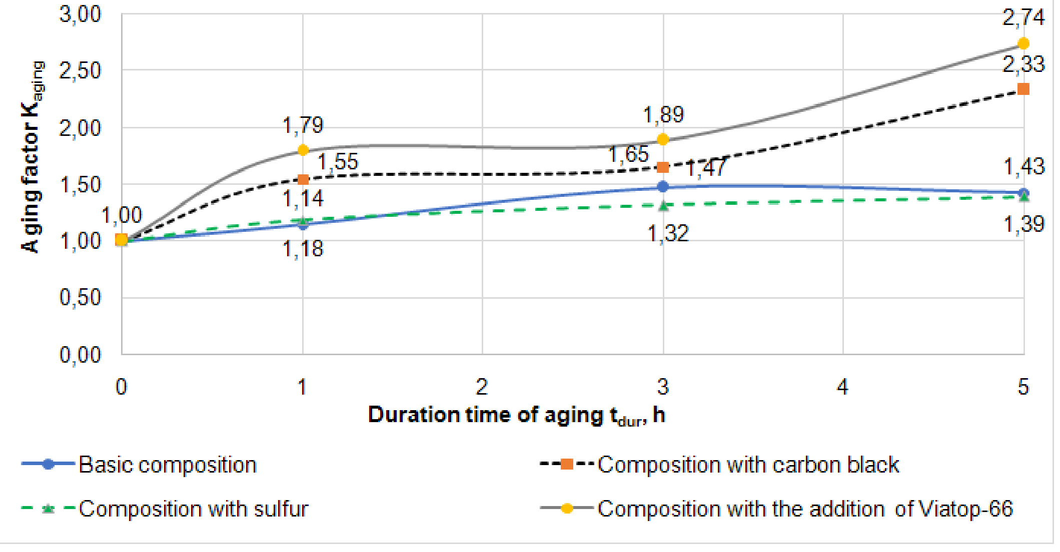


Fig.4 – Graphs of dependences of the values of the aging coefficients for various compositions in terms of compressive strength at a temperature of +50 °C

Table 6. Results of experiments to establish the values of density, compressive strength at +50 °C, coefficient, and intensity of aging for various compositions

Mixture composition №	Duration time of aging at a temperature of +150 °C t_{dur}, h	Average density δ, g/cm³	Compressive strength $R_C^{+50°C}$, MPa	Aging coefficient K_{aging}	Aging rate I_{aging}
Basic composition					
1	0	2.56	1.43	1.00	0.14
	1	2.56	1.63	1.14	0.16
	3	2.56	2.10	1.47	-0.02
	5	2.57	2.04	1.43	
Composition with carbon black					
2	0	2.38	1.17	1.00	0.55
	1	2.39	1.80	1.55	0.05
	3	2.40	1.93	1.65	0.34
	5	2.41	2.72	2.33	
Composition with sulfur					
3	0	2.50	0.76	1.00	0.18
	1	2.50	0.90	1.18	0.07
	3	2.50	1.00	1.32	0.04
	5	2.50	1.06	1.39	
Composition with the addition of Viatop-66					
4	0	2.55	0.53	1.00	0.79
	1	2.55	0.95	1.79	0.05
	3	2.55	1.00	1.89	0.42
	5	2,54	1,45	2,74	

As a result of the analysis of the Table. 6 and the graph in Fig. 2, the following conclusions can be drawn:

1) The introduction of carbon black additives and the stabilizing additive Viatop-66 into the studied mixtures makes it possible to significantly increase the resistance of the mixtures to thermal aging – the values of the aging coefficients at a holding time of 5 hours were 2.33 and 2.74, respectively. The same indicator for the base composition matters – 1.43;

2) The introduction of sulfur as an additive leads to a smaller effect of reducing aging;

3) As can be seen, the graphs of the change in the aging coefficient for compositions with carbon and the addition of Viatop-66 are in an ascending line. This is because the bitumen in such compositions is in a bound state with additives. However, it should be noted that the introduction of such additives requires an increased bitumen content compared to the base composition. In all formulations, the bitumen content is (8%). Table 6 shows that the introduction of any type of additives studied leads to a decrease in strength at the initial stage of the experiment, that is, without preliminary aging;

4) According to the absolute value of the aging coefficient of mixtures, in descending order, they are arranged in the following sequence: mixtures with a stabilizing additive Viatop-66; mixtures with carbon black; mixtures with sulfur.

Based on the data obtained, to clarify the role of each additive in the aging of asphalt concrete, in the CurveExpert software environment, correlation dependences of the values of the aging coefficient in terms of compressive strength at +50 °C were obtained:

1) a mixture of basic composition:

$$K_{aging}^{R_C^{+50°C}} = a_1 \cdot \exp^{\frac{-(b_1 - t_{dur})^2}{2 \cdot b_1^2}} \quad (6)$$

2) mixture with carbon black:

$$K_{aging}^{R_C^{+50°C}} = \frac{1}{a_2 + b_2 \cdot (t_{dur})^{c_2}} \quad (7)$$

3) mixture with sulfur:

$$K_{aging}^{R_C^{+50°C}} = a_3 + b_3 \cdot \cos(c_3 \cdot t_{dur} + d_3) \quad (8)$$

4) mixture with the addition of Viatop-66:

$$K_{aging}^{R_C^{+50°C}} = \frac{1}{a_4 + b_4 \cdot (t_{dur})^{c_4}} \quad (9)$$

Reliability of dependencies (6-7) in the temperature range t_{dur} = 0…5 hours: selection accuracy (approximation rank) is within 0.971…0.995, the sum of errors is S=0.302…0.316.

As can be seen from the data obtained, the change in the values of the aging coefficient in terms of compressive strength at +50°C during heating overtime for the base composition and the composition with sulfur occurs in the direction of decreasing according to exponential and sinusoidal dependences. For blends with carbon black and Viatop-66 additive, the changes occur upward according to the Harris dependence model.

4 Conclusion

As a result of an experimental study of the aging processes of sandy asphalt concrete with various additives:

1. The introduction of carbon black additives and the stabilizing additive Viatop-66 into the studied mixtures makes it possible to increase the resistance of the mixtures to temperature aging. It is noted that the introduction of such additives requires an increased content of bitumen in the mixture compared to the composition without additives;

2. The dynamics of changes in the modulus of elasticity correlate with the dynamics of changes in compressive strength;

3. According to the absolute value of the aging coefficient of mixtures, in descending order, they have arranged in the following sequence: mixtures with a stabilizing additive Viatop-66; mixtures with carbon black; mixtures with sulfur;

4. Mathematical models have been obtained that describe the aging processes of samples from sand mixtures depending on the duration of heating at high temperatures and the content of additives in them.

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