The individual components’ influence on aging of bitumen mineral materials

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Abstract. When heating bitumen-mineral mixtures at high temperatures under the air access conditions, their accelerated aging is observed, i.e. the values and quality indicators’ decrease of the compacted samples from them. Due to the different structure of bitumen films on the mineral components’ surfaces of different compositions and sizes, aging processes may occur in different ways. In this regard, a need for a differentiated study of the aging process on the surfaces of large fine aggregates and the crushed part of the bitumen-mineral (asphalt concrete) mixture arose. The experiments in laboratory conditions are carried out according to the Volga State Technological University developed at the Department of Construction Technologies and Automobiles (according to RF patent No. 2654954). The aging processes analysis of the samples from bitumen-mineral mixtures is carried out using the dimensionless aging coefficient in terms of the ultimate compressive strength at +50 °C. The nature and dynamics of the samples’ aging over time are assessed using special indicators - the aging coefficient and the aging intensity. As a result of the experimental study, the optimal ratios of bitumen with mineral components, taking into account their susceptibility to aging over time, were established. The changes’ dynamics in the bitumen aging intensity in time in the bitumen-mineral mixture as a whole and separately on the mineral components’ surfaces separately has been studied. The results of this study can be taken into account when revising the standard service life values of the roads with structural layers of bitumen-mineral materials.

Introduction
The purpose of this study is to establish the aging process dynamics of bitumen in bitumen-mineral mixtures (asphalt-concrete mixtures) in time in laboratory conditions, and separately on the components’ surfaces.

It is known that the physical and mechanical properties’ values of bitumen-mineral materials significantly decrease in the aging process, as a result of which their performance indicators can reach the maximum permissible values. The need to take into account the aging processes on the bitumen-mineral materials’ durability has been pointed out by many domestic and foreign authors [1-6]. At the same time, the various factors’ influence on the oil bitumen aging process at the stages of its production, storage and use was revealed [6-13]. At the same time, the proposals to take into account the aging processes at all the above-mentioned stages have been put forward.

Despite the existing experience in studying the aging processes of bitumen and bitumen-mineral mixtures, there is little information about bitumen aging on the surfaces of their individual mineral components to date.
Materials and research methods
The hot-laid fine bituminous concrete of the B type according to GOST 9128-2013 and the mixtures of its individual components with construction bitumen CB 90/130 were taken for the experiments:

1) asphalt concrete type B composition, % by weight: granite crushed stone M 1200 fr. 5-20 mm – 47,0; crushed sand (screenings of crushing of hard rocks) - 43,0; limestone mineral powder - 10.0; bitumen CB 90/130 – 5,5 (in excess of 100,0 %);
2) mixture of limestone mineral powder with bitumen CB 90/130 in the ratio (by weight) 0,85:0,15;
3) crushed sand mixture fr. 0,14-5,00 mm with bitumen in the ratio 10:1;
4) mixture of crushed granite M 1200 fr. 5-20 mm with bitumen in the ratio by weight 25:1.

The ratio of the components corresponds to the optimum and were assigned based on a preliminary study of their average density and compressive strength at +20 °C and +50 °C degrees, including after artificial aging at +150 °C.

Since there is currently no standard technique, the study of the bitumen-mineral mixtures’ aging was carried out according to the new technique proposed by the authors (according to the RF patent № 2654954) [14]. The essence of the technique is as follows:

1. Sampling of mineral materials under study, drying and heating them to the operating temperatures (150-170 °C);
2. Preparation of a petroleum bitumen sample by dehydration and heating to the operating temperature: for heavy asphalt CB 90/130 – 140-150 °C;
3. Mixing the components in specified proportions;
4. Placing the prepared mixture samples on trays in even layers and holding in an electric furnace (furnace RTFOT) at high temperature +150 °C and in the conditions of free air access during the estimated time (0, 1, 3, 5, 7, etc. hours).

After the intended period of time expiration, the mixtures are removed from the furnace, the standard cylindrical samples are formed from them, according to the standard method of GOST 12801-98, they are tested and the values of their physical and mechanical properties are set.

Results and discussion
The results of the experimental data are shown in Table. 1.

| No. | Warm-up time at +150 °C | Asphalt concrete type B | Bitumen mixture with mineral powder | Bitumen mixture with crushed sand | Mixture of crushed granite with bitumen |
|-----|-------------------------|-------------------------|-----------------------------------|-----------------------------------|-------------------------------------|
|     |                         | $R_{\text{comp}}^{+50 \, ^{\circ}C}$ | $K_{\text{ag}}$ | $R_{\text{comp}}^{+50 \, ^{\circ}C}$ | $K_{\text{ag}}$ | $R_{\text{comp}}^{+50 \, ^{\circ}C}$ | $K_{\text{ag}}$ |
| 1   | 0                       | 2.10                    | 1.00                             | 0.80                              | 1.00                         | 1.37                               | 1.00                         |
| 2   | 1                       | 1.40                    | 0.67                             | 0.80                              | 1.00                         | 1.40                               | 1.02                         |
| 3   | 3                       | 1.50                    | 0.71                             | 0.90                              | 1.13                         | 1.97                               | 1.43                         |
| 4   | 5                       | 1.40                    | 0.67                             | 1.30                              | 1.63                         | 2.76                               | 2.00                         |
| 5   | 7                       | 1.40                    | 0.67                             | 1.10                              | 1.38                         | 1.47                               | 1.37                         |
| 6   | 9                       | -                       | -                                | 1.05                              | 1.31                         | -                                  | -                            |

Table 2 shows the results of calculating aging intensity of the studied mixtures according to the aging coefficient values.

| No. | Warming-up time t\text{w} at +150 °C | Aging intensity values of bitumen-mineral mixtures $i_{\text{ag}}$ |
|-----|-------------------------------------|-------------------------------------------------------------|
|     |                                     | $R_{\text{comp}}^{+50 \, ^{\circ}C}$ $K_{\text{ag}}$ |

Table 2
For visual presentation, the obtained experimental results are shown in Fig. 1 and 2 as graphs.

**Figure 1.** Graphs of the aging coefficient values’ dependencies in terms of ultimate strength in compression at +50 °C from the time of warming up at a temperature +150 °C: 1 – asphalt concrete mix of type B (bitumen content 5.6% of the mineral part mass, over 100%); 2 - mixtures of limestone mineral powder with bitumen in the ratio by weight B:MP=1:5,67; 3 – a mixture of crushed sand (granite screenings) with bitumen in the ratio 1:10; 4 – mixture of crushed granite fr. 5-10 mm with bitumen in the ratio 1:25

**Figure 2.** Graphs of the aging intensity values’ dependences according to the aging coefficient on the heating time at temperature +150 °C: 1 – asphalt concrete mix of type B (bitumen content 5.6% of the mineral part mass, over 100%); 2 - mixtures of limestone mineral powder with bitumen in the ratio...
by weight B:MP=1:5,67; 3 – crushed sand mixture fr. 0-5 mm with bitumen in the ratio B:CS=1:10; 4 – mixture of crushed granite fr. 5-20 mm with bitumen in the ratio B:CG=1:25.

As it can be seen from the graphs in Fig. 1, change in the aging coefficient values in terms of $R_{\text{comp}}^{+50 \degree C}$ for asphalt concrete and a mixture of crushed granite with bitumen occur according to the law of the following classes loss, as the heating time increases, respectively:

$$y = e^{(-A \cdot t_w)^B},$$
$$y = C \cdot e^{-D \cdot t_w},$$

where $A$, $B$, $C$, $D$ – are the constant coefficients, the values of which depend on the type of bitumen-mineral mixture.

For the mixtures of fine-grained mineral materials (limestone mineral powder and crushed sand) with bitumen, the aging coefficient values in terms of $R_{\text{comp}}^{+50 \degree C}$ can be extrapolated by the dependency:

$$y = a \cdot e^{\frac{(t_w-b)^2}{2c^2}},$$

where $a$, $b$, $c$ – are the constant coefficients.

Selection accuracy (approximation rank) by the dependencies (1 ... 3) is within 0,9796...0,9909.

It can be seen from the graphs in Figure 2 that coarse-grained bitumen-mineral mixtures age most intensively during 1 ... 3 hours of heating and with further heating there is a sharp attenuation of this process. The intensity of the aging process in fine-grained mixtures is relatively weak up to 3 hours of warming up, then it increases within 3 ... 5 hours.

The analysis of the experimental results given in Table 1 and Table 2 and in Figure 1 and Figure 2, show:

1) Bitumen mixtures with crushed components of bitumen-mineral materials (mineral powder and crushed sand) for 1 ... 3 hours of heating lead to some increase in the samples’ strength, and with further heating, the process of its decrease starts;

2) Bitumen mixtures with crushed stone age to the greatest extent during the first hour of heating at a high temperature, and then this process stabilizes and the aging coefficient of the samples tends to zero;

3) The greatest contribution to the mechanical strength of type B asphalt concrete is provided by asphalt binder (a bitumen mixture with mineral powder) and a bitumen mixture with crushed sand. Moreover, this conclusion turns out to be true for all the mixtures’ aging stages at high temperatures;

4) By the highest values of aging intensity, the studied mixtures are arranged in the following row: bitumen mixture with crushed stone; asphalt concrete mix type B; bitumen mixture with crushed sand; bitumen mixture with mineral powder.

The change in the mechanical strength of bitumen mineral materials during aging can be explained from the previous studies [15]:

1) When bitumen is combined with powdery materials in comparison with coarse-grained, firstly, on the particles’ surfaces, especially of carbonate origin, relatively thin bituminous films are formed and the binder is more structured in them. As a result, the bitumen-mineral system becomes more resistant to external influences, including the action of high temperatures;

2) Due to an increase in the asphalt-resinous component in bituminous films during heating in the initial period, a certain increase occurs in the adhesion strength of the bitumen film on the surfaces of mineral particles, which leads to a slight increase in the mechanical strength of the entire system. In the future, this process goes into a zone of weakening due to bituminous films’ embrittlement and a decrease in their adhesive ability;

3) In coarse-grained systems, due to the less structured bitumen and the greater thickness of the bitumen films, the adhesion strength of the bitumen films on the minerals’ surfaces is relatively weak. Despite a slight increase in the cohesive strength of bituminous films in the initial period of heating, the embrittlement processes’ intensity prevails in them and cannot prevent the general weakening of the
entire system as a whole from the beginning of the process.

The results of the work performed in this study are fully consistent and explained by the previously known provisions on the bitumen binders’ interaction with the stone materials’ surfaces and the change in the bitumen properties when heated.

Summary
1. The aging process of bitumen-mineral materials and its intensity are influenced by both the composition and the mineral components’ size. At the same time, bitumen compositions on the large particles’ surfaces and with inactive and acidic surfaces at high temperatures age faster than on the fine-grained components;
2. The greatest contribution to the mechanical strength in compression of type B asphalt concrete at all stages of aging is made by a bitumen mixture with fine-grained aggregates and crushed mineral components. In general, it should be expected that the aging coefficient values’ change of bitumen-mineral mixtures during heating will closely depend on the comparative content, size and mineralogical composition of the mineral components relative to each other.

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