The advantages of using polymer-bituminous concentrate for the production of polymer-bituminous binders

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Abstract. Construction of road surfaces with an extended service life, as well as the transition to methods of volumetric and functional design of asphalt concrete mixtures, leads to the need for the use of polymer-bituminous binders, as bitumen without polymer modifiers does not provide the required physical and mechanical characteristics and durability. Traditional PBB production technologies involve the use of complex technological processes and equipment. In addition, existing technological features lead to a significant decrease in the quality of the resulting polymer-bituminous binder. In this paper, we consider the possibility of obtaining PBB with high physical and mechanical parameters by using the PB concentrate (polymer-bituminous concentrate). The modifier under study is a polymer dispersed in an oil base and stabilized with active components. When added to bitumen, a colloid mill and complex processes of preparation and maturation of the binder are not required. Experiments have shown that the resulting binder has the characteristics of PBB, in particular, an extended temperature range of plasticity, elasticity and resistance to cyclic loads. At the same time, gentle heating modes provide increased resistance to aging during the preparation of asphalt concrete mixture and its operation. The ease of use of this modifier makes it possible to obtain PBB with a wide range of characteristics that correspond to the operating conditions.

1. Introduction

New requirements for the operational reliability of roads, as well as the transition to volumetric and functional methods of designing asphalt concrete mixtures leads to the need for expanded use of polymer-bituminous binders in road construction. Polymer asphalt concrete in the covering has a lower temperature dependence of strength and deformation characteristics compared to the use of unmodified asphalt concrete [1]. At high operating temperatures in the summer period, the use of PBB provides greater rigidity and lower creep of the material, as well as stability of the dynamic elastic modulus of the material. At low temperatures during the winter period of operation, the material remains in an elastic state longer, preventing the material from increasing its stiffness and preventing the appearance of temperature and fatigue cracks [2]. In addition, the use of PBB allows obtaining a covering that combines high resistance to the accumulation of plastic deformations with significant resistance to fatigue failure, due to high elasticity and the ability to relax internal stresses [3]. The use of polymer-bituminous binders produced using traditional technology in the production of asphalt concrete mixtures is associated with technological and economic difficulties [4]:

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- complex equipment, including: colloid mills, a large capacity park for preparing and maturing the binder, a complex system for pumping bitumen;
- technological process that includes the selection of the composition, dosage and preparation of components, homogenization and subsequent maturation of PBB;
- the need for high-quality PBB components: bitumen, polymer, plasticizer.

These difficulties largely limit the production of PBB by road construction companies. Purchasing finished PBB from specialized manufacturing companies also has a number of negative aspects:
- high cost;
- tendency to delamination of PBB during transportation and storage, which leads to the need for additional preparation of the binder;
- variable quality of the binder and complicated input control.

In addition, long-term production of the binder at high process temperatures leads to increased aging, which significantly reduces the service life of such a material [5].

It is worth considering the use of polymer-bituminous binders in asphalt concrete mixtures developed by the method of volumetric and functional design. In the technical conditions for such mixtures, special requirements for binders are imposed. In particular, depending on the temperature conditions of operation and the frequency and intensity of load application, the binder must have different temperature and strength characteristics, including under dynamic influences. At the moment, manufacturers of PBB are not able to cover the required wide range of binders.

To solve the above problems, BSTU named after V.G. Shukhov together with the Research and Production Association “Selena” developed a polymer modifier for bitumen - polymer-bituminous concentrate (PBC). This modifier is a styrene-butadiene-styrene polymer dispersed in a high concentration in an oil base and stabilized with active additives. Due to the stable structure of the polymer in the additive, its distribution in the bitumen can occur without the use of a colloid mill, using a paddle stirrer. Multi-stage polymer grinding is excluded from technological processes and the maturation time is significantly reduced, which has a positive effect on the quality of the resulting product. In contrast to the traditional PBB formulation, the binder with PBC does not require the use of a plasticizer, which greatly facilitates the procedure for selecting the composition of various PBB brands. In this paper, we study the physical and mechanical characteristics of bitumen modified with the addition of PBC, in comparison with a polymer-bituminous binder of factory production.

2. Materials and methods
BND 60/90 bitumen was used as a binder for further modification. The concentration of the PBC modifier is 8% of the bitumen mass. Homogenization of the additive in bitumen was performed using a paddle stirrer. Uniformity was determined using an optical microscope and visually. As an object of comparison, the factory-produced PBB-60 was selected, corresponding to the actual brand PG 57-16.

The following research methods were used: determination of the dynamic viscosity of bitumen using a rotary viscometer with a coaxial spindle (ASTM D4402/D4402M) [6], determination of the fatigue strength of the binder under the action of a repeatedly applied load (AASHTO T350) [7], determination of high-temperature and low-temperature properties of the binder using a shear rheometer (AASHTO T 315) [8]. Aging of the binder in a thin layer for 5 hours was carried out at a temperature of 165°C with constant air convection. The optical fluorescence microscope was used to assess the uniformity of PBB.

3. Results and discussions
The obtained data indicate the effectiveness of PBC as a polymer modifier for bitumen. The results of measurements of physical-mechanical and rheological characteristics are shown in table 1.
Table 1. Rheological properties of modifying binders.

| Properties                     | Measurement unit | Bitumen + 8% additive | Polymer bitumen binder PBB 60 |
|--------------------------------|------------------|------------------------|-------------------------------|
| Dynamic viscosity at 165 °C    | Pa*s             | 0.082                  | 0.124                         |
| Dynamic viscosity at 135 °C    | Pa*s             | 0.287                  | 0.411                         |
| Shear stability at temperature | kPa              | 1.12                   | 1.90                          |
| Critical low temperature       | °C               | -28.77                 | -19.01                        |
| Critical cracking temperature  | °C               | -31.16                 | -37.04                        |
| Fraas brittle point            | °C               | -25                    | -20                           |
| Fatigue resistance             | kPa              | 3832                   | 1503                          |
| Elasticity                     | %                | 58                     | 64                            |

These results indicate a positive effect of the modifier on the properties of bitumen. Indicators of fatigue resistance and elasticity indicate the formation of a polymer spatial coagulation grid in the bitumen, so that the binder has acquired the ability to relax the internal stresses arising in it. Special attention should be paid to the low-temperature characteristics of the PBB under study. In comparison with a factory-produced binder, bitumen modified with PBC additive works much more effectively in the low temperature region, as evidenced by a decrease in the Fraas brittleness temperature and a significant decrease in the critical low temperature creep index. This is due to the absence of a plasticizer in the binder under study, which is usually made from light oil fractions. The balance of oil components in such a binder is not disturbed, the structure of the binder is stabilized by natural surfactants and introduced modifiers, as a result of which the glass transition processes of the light fraction occur at lower temperatures, allowing the formed structure “bitumen-polymer” to work in a viscoelastic state [9]. At the same time, it should be noted that the high-temperature properties of the resulting binder are not inferior to factory-prepared PBB. According to the technical requirements of GOST 58400.1-2019 binder, obtained with the use of PBC is of PG 58-28 brand (actual temperature limits of operability of the binder 58.7-28.7), tested the factory analogy is of PG 52-16 brand (the actual temperature limits of operability of the binder 57.7-19). Thus, the binder under study has a temperature range of the plastic state of 87.4°C, while this parameter for the factory analog is 76.7°C.

The method of fluorescence microscopy was used to study the homogeneity of the polymer distribution in the binder under study. Microphotographs are shown in figure 1.

Figure 1. Microphotographs of factory-produced PBB (left) and the binder under study (right).

The obtained data indicate a more uniform distribution of the polymer in the structure of the binder under study, compared with PBB produced using a colloid mill.
The simplified technology of PBB production with the use of polymer-bituminous concentrate reduces the time when the binder is at high temperatures. This technological feature leads to less aging of the binder, and, consequently, will have a positive impact on its durability [10-12].

For the analysis of the aging process, after the aging procedure in a thin layer for 5 hours at a temperature of 165 °C, the dynamic viscosity was measured for each of the samples at different temperatures in order to determine the degree of change in the structure of the binder by the stability of its rheological characteristics. Curves of changes in the dynamic viscosity of polymer-bituminous binders are shown in figure 2.

These data demonstrate that modified PBB bitumen has more stable rheological characteristics compared to factory-produced PBB. These dependencies indirectly characterize smaller structural and qualitative changes in the binder under study under the influence of high temperatures and oxygen. To quantify the degree of aging, a solidification index can be introduced, which is the ratio of the dynamic viscosity before aging to the dynamic viscosity after aging. The results of calculating the solidification index are shown in table 2.

| Bitumen + 8% additive | Polymer bitumen binder PBB 60 |
|-----------------------|-----------------------------|
| 0.93                  | 0.77                         |

A higher value of the solidification index for the binder under study indicates a smaller change in the dynamic viscosity, and, consequently, a smaller influence of the aging processes of the binder on its structure and qualitative composition.

4. Summary
Research shows that the use of polymer-bituminous concentrate allows getting a high-quality binder without the use of complex equipment and multi-stage technology. The dissolution of the PBC additive in bitumen occurs evenly with mechanical mixing and requires less prolonged maturation. In the production of PBB using the modifier under study, the use of a plasticizer is not required. At the same time, the resulting polymer-bituminous binder is not inferior to industrial-made binder in terms of its main physical and mechanical characteristics, including key parameters: strength and elasticity. Due to the absence of a traditional plasticizer in the formulation, the PBB composition under study has
a much larger temperature range of the viscoelastic state compared to its analog. The simplified technology for obtaining PBB based on polymer-bituminous concentrate reduces the duration of exposure to high temperature on the binder, which made it possible to learn a more aging-resistant composition.

5. References

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