Use of wood processing industry waste for bitumen modification

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Abstract. The paper provides information about the method of obtaining a modifying additive to bitumen, including wood filler. The pore space of the filler contains a basalt reinforcing filler with an average particle size of 150-300 nm. Scots pine bark with an average particle size of 0.5-1 mm was used as a wood filler. The modifying additive was obtained by mixing fine basalt (30 \% by weight) and wood bark. After careful mixing for 5 minutes, water was added, the mass of which is twice more than the calculated mass of the reinforced bark. Then the mixture was homogenized. The use of an additive for the preparation of a bituminous binder improves the thermal and physical characteristics of the organic binder (softening temperature and brittleness temperature). In comparison with other traditional stabilizing additives, the use of the proposed composition for the preparation of a bituminous binder also improves the thermal and physical characteristics of the organic binder, such as the brittleness temperature. A decrease in the brittleness temperature of the mixture indicates an increase in the frost resistance of the modified organic binder. For other characteristics, the modifying additive has a comparable effect on the properties of the binder with traditionally used materials.

1. Introduction

The current level of development of road transport is associated with a constant increase in the volume of cargo transportation, with the intensity of movement of cargo vehicles, which in turn leads to an increase in dynamic loads on covering of roadway. These and other objective factors indicate that it is necessary to improve the quality of road bitumen.

Improving the quality of bitumen can be achieved by searching for new technological solutions that improve the physical and mechanical characteristics of asphalt covering [1]. The main way to solve this problem is currently the use of modifying additives in the bituminous binder. Moreover, the additive has a significant influence on the physical and mechanical properties of asphalt concrete [2, 3].

In practice and in the scientific literature, the necessary material has been collected on the effects of various substances on the properties of petroleum bitumen. For example, plasticizers, providing mobility of the dispersed bitumen system, have found their application in the production of roofing materials and polymer-bitumen, road bitumen with improved viscosity-temperature properties. Heavy gas-oil, selective oil purification extract, shale softener, used and fresh oils [4-7], etc., which are plasticizers, have also found their application. One of the types of modifying additives is surface-
active chemical compounds (surfactants). In [8-12], we consider the classification of surfactants and the mechanism of their action on the spatial dispersed structure of bitumen, the implementation of which leads to an increase in the contact area between the active centers of diphilic molecules of the additive and the organic substrate. This fact allows maintaining the necessary aggregate stability of the binder particles (the average particle size of the dispersed phase has decreased), which ultimately increases the adhesion interaction between the organic and mineral components of the reaction system.

Additives to bitumen that increase the adhesion of bitumen to the surface, such as alkyldiamines, amidoamines, diamidoamines, are widely used abroad and in Russia [13-15].

Polymer-bituminous binder (PBB), formed by the introduction of polymer additives for modifying bitumen, behaves as a material with a certain internal reinforcement when the internal structure is deformed. The use of PBB belongs to one of the dynamically introduced technologies of road covering construction and repair in the Russian Federation. The introduction of polymers into bitumen sets a primary goal – it is to reduce the temperature susceptibility of the binder, i.e. it is necessary that the hardness decreases in winter and increases in summer, in addition, the binder must have good elasticity. If this goal is achieved, the manufactured asphalt concrete containing PBB will have high shear resistance, low-temperature crack resistance, and fatigue life.

Polymer-based modifiers are distributed in a dispersion medium, and their own structural grid is formed in bitumen. The polymer frame compensates for the lack of fluidity when the temperature rises, as well as deforming properties when it decreases. Thus, the range of performance of various bituminous materials increases [16, 17].

As a possible modifier for bitumen, the use of lignin-containing plant components, such as waste from the woodworking industry, namely bark, is promising (in our opinion). In the structure of the lignin macromolecule, there are a significant number of functional groups that differ in their activity. In addition, the presence of some amino acids that are part of the protein structure and have an aromatic grouping in their composition is noted in native lignin [18].

However, it is known that the wood bark is a porous material that has a significant moisture capacity and anisotropy of properties. At the same time, there are currently works that allow obtaining an organic and mineral complex based on wood bark, which significantly reduces the above-mentioned negative effects. This organic and mineral composite can be very promising for use as an additive in bituminous mixtures.

In [19-22], the technology of filling the pore space of wood bark with highly dispersed basalt particles is considered, thus obtaining the material of a plant matrix reinforced with mineral particles. In the structure of the bark, there is an increase in the content of closed pores and reduce the open, due to the indicators of hygroscopicity and water absorption are greatly reduced, thermal characteristics are stabilized, even in case of high environmental humidity.

It should be noted that wood bark is a large-tonnage waste of enterprises associated with the mechanical processing of plant raw materials, which is currently stored in dumps or, at best, burned. Therefore, its use is also an important task in terms of environmental management [23]. One of the most common wood species that is well suited for the building materials industry is pine wood, so the use of the bark of this tree species is of primary interest. Being the most common and suitable for the production of building materials in the Russian Federation, pine bark is of the greatest interest in terms of reinforcement of the wood matrix.

Among the various reinforcing components, the most optimal, in our opinion, is basalt, as one of the most common natural stones. This rock is characterized by good strength and a fairly high density. It is also necessary to note the chemical resistance of the material to corrosion and aggressive environments and resistance to high temperatures. Withstanding temperatures of over 1500 °C, basalt has found use as a fire-resistant material for fire protection. In addition, it is necessary to note the low cost of basalt [24].

Based on the above, the aim of the research presented in this paper is to create a modifying additive that contains waste from the woodworking industry, namely bark reinforced with fine basalt, and
assess its impact on the thermal and physical (brittleness temperature, softening temperature, and flash point) characteristics of bitumen.

However, a necessary step in the preparation of wood raw material is the removal of water-soluble extractives. This action is necessary to increase the volume of free pore space of the bark, which will later be filled with an aqueous suspension of fine basalt particles. For these purposes, good results are shown by the use of the developed extractor, which allows for accelerated extraction of water-soluble substances from plant raw materials [25].

2. Materials and methods
One of the research objects was the bark of Scots pine, which was selected from the dump of a timber processing enterprise. Pine logs were cut on rotary machines and piled in one dump. The bark was evenly sampled along the perimeter of the dump from a depth of 30 cm to avoid boundary effects on the bark-air interface. Previously, water-soluble extractives were removed from it. The bark for the study was dried to a constant mass in a drying cabinet at 60 °C for three days.

The reinforcing element has been sifting of crushing basalt sampled from the field Myandukha in the Arkhangelsk region. The basalt was pre-ground in a ball mill to a size of 4 ± 1 mm and then dried to a constant mass at a temperature of 110 °C.

BND-U 100/130 “Biturox” bitumen was used for experiments. It is manufactured using the patented Biturox technology, which is based on the process of concentrating oil oxidation by vacuum distillation. As a result, a material with a complex high-tech structure is formed: 75-80 % carbon, 10-15 % hydrogen, 5 % oxygen, metals, and nitrogen.

As the plant additive is a composite consisting of highly dispersed materials (bark and basalt), mechanical grinding of raw components was performed. Grinding was carried out using the Retsch PM 100 planetary ball mill. The bark was dispersed using stainless steel equipment. Basalt was crushed in the dry phase using carbide-tungsten equipment (grinding jars and balls).

Crushed fine wood bark and basalt were mixed in the required ratio (% by weight): bark – 70 and fine basalt – 30 for 5 minutes. Then water was added to the wood-mineral composition, the mass of which is twice more than the calculated mass of the reinforced bark, and the resulting mixture was homogenized. The components were homogenized using a vertical rotary agitator with digital control of the WiseStir model. After that, the resulting mixture was dried to a constant mass. Quality control of bark modification with fine basalt was performed by determining the specific surface area, the porosity of the composition (by gas sorption on the Autosorb analytical system), true and bulk density (by standard methods). Then the resulting additive (hereinafter D1) was introduced into dehydrated bitumen, which was preheated to 105 °C. Mixing was carried out using a two-bladed laboratory agitator.

Comparison of thermal and physical characteristics was carried out with respect to bitumen without additives (D0), and two main stabilizing additives were selected for comparison – “Stylobite” (hereinafter D2) and “Granulite-66” (hereinafter D3). The choice of these additives for bitumen is due to their wide use in road works.

The number of additives used in bitumen was assumed to be the same, based on the recommendations for the use of traditional components.

The following thermal and physical characteristics were selected: softening temperature (ring and ball method), brittleness temperature, and flash point. The choice of these characteristics is due to their influence on the quality properties of the final asphalt concrete – resistance to abrasion, cracking, and rutting. Samples for testing to determine the thermal and physical characteristics had a form that meets the necessary standards.

To determine the softening temperature of petroleum bitumen, a laboratory automatic Kish-20M4 device was used. The softening temperature of bitumen was taken as the arithmetic mean of two parallel measurements.
An automatic ATX-20 apparatus was used to determine the brittleness temperature of petroleum bitumen. The average arithmetic value of the three measurement results was taken as the result of the Fraas test of the bitumen brittleness temperature.

The flash point was determined in a closed crucible using the ATV-21 apparatus. The average arithmetic value of at least two consecutive measurements was taken as the test result.

All the obtained numerical values of the characteristics listed above were rounded up to integers.

3. Results and discussion
During the grinding of raw materials, the following dimensional characteristics of the initial components for developing the additive were obtained: bark – 0.5–1 mm; basalt – 150-390 nm. By mixing a highly dispersed fraction of the bark with an aqueous suspension of basalt, spontaneous filling of the free pore space of the bark occurs due to the process of its swelling. After separation of the solid phase from the aqueous suspension, the latter was brought to a constant mass in a drying cabinet at a temperature of 40 °C. The grayish tint of modified bark particles (figure 1) and changes in its physical and chemical characteristics (table 1) indicate a significant amount of fine basalt fixed on the surface of the plant material.

The results of determining the thermal and physical characteristics of bitumen with the considered additives and the control sample are presented in table 2.

![Figure 1. The wood bark of the pine: a – initial; b – modified.](image)

**Table 1.** Indicators of the quality of the modified bark.

| Sample          | Bulk density, kg/m³ | True density, kg/m³ | Specific surface area, m²/kg | Porosity, cm³/g |
|-----------------|---------------------|---------------------|-------------------------------|-----------------|
| Initial bark    | 185                 | 1150                | 41887                         | 0.257           |
| Modified bark   | 313                 | 1380                | 70311                         | 0.093           |

The analysis of the obtained data presented in table 2 shows that the use of the additive (D1) has a positive effect on the determined thermal and physical characteristics of bitumen.

Comparing the obtained experimental data on the thermal and physical characteristics of bitumen with the quality requirements for road bitumen BND-U 100/130, it can be noted that when using an additive that includes wood filler, the softening temperature increased (compared to bitumen without additives) not significantly (2 °C). To a greater extent, the use of the D1 additive led to a significant reduction in the brittleness temperature. Thus, according to the data available in the literature, the softening temperature of organic binder BND-U 100/130 varies in the range of 40-48 °C, the brittleness temperature is -17 °C. Our experiments to determine these characteristics for the control sample fully correspond to the standard values. Thus, the softening temperature for the test sample D0 was 46 °C, and the brittleness temperature is -17 °C.
Table 2. Thermal and physical properties of bitumen.

| Test name                  | Bitumen 100/130 |
|----------------------------|-----------------|
|                            | D0  | D1  | D2  | D3  |
| Softening temperature, °C  | 46  | 49  | 52  | 48  |
| Brittleness temperature, °C | -17 | -24 | -20 | -21 |
| Flash point, °C             | 240 | 229 | 233 | 228 |

In comparison with other stabilizing additives, the use of the D1 additive for the preparation of the bituminous binder also improves the thermal and physical characteristics of the organic binder, such as the brittleness temperature. A decrease in the brittleness temperature of the mixture indicates an increase in the frost resistance of the modified organic binder. For other characteristics, the modifying additive has a comparable effect on the properties of the binder with traditionally used materials.

4. Summary

Thus, after analyzing the results obtained during the research, it can be assumed that a modifying additive, including a wood aggregate reinforced with fine basalt, can be used to produce asphalt concrete. However, it should be noted that the preliminary preparation of wood filler should be based on the removal of water-soluble extractives (increase the free pore space) from the plant material and bringing the size characteristics of particles of plant raw materials up to 1 mm (the practical absence of anisotropy properties of the bark). The use of additives based on a large-tonnage waste from the technology of mechanical processing of wood will help to solve issues of rational use of natural resources and reduce the environmental impact in the regions where the enterprises of the timber industry are concentrated.

5. References

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