Technology of making asphalt concrete using sand slag

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Abstract. In the Central Black Earth Region, there are settlements that do not have hard-surfaced access roads, and existing access roads require major repairs. In order to reduce the cost of construction, it is proposed to use asphalt concrete mixtures from slag materials for the construction of road pavements. Slag materials have hydraulic binding properties; the processes of structure formation in them take a long time. The study of the properties of asphalt concrete was carried out depending on the time from the moment of manufacture, after prolonged water saturation and the number of freeze-thaw cycles. The obtained results indicate an increased durability of asphalt concrete road pavements made of slag materials.

1. Introduction
In many areas, rural settlements do not have paved access roads, and existing roads require major repairs. To improve the infrastructure of settlements, large budgetary funds are needed, which are not available in municipalities. To reduce the cost of construction, it is necessary to maximize the use of local building materials.

In areas with a developed metallurgical industry, local materials are slag from ferrous metallurgy. The use of asphalt concrete from slag materials in road construction will not only increase the durability of asphalt concrete pavements, but also solve socio-environmental problems by using by-products of metallurgical plants. In road construction, asphalt mixtures based on steel-smelting slags are widely used for paving devices [1-7].

Asphalt mixtures based on blast furnace slags have not yet been widely used. A feature of asphalt concrete coatings from blast-furnace slag materials is that their formation occurs during operation due to the chemical and hydraulic activity of the slag and the transformation of the structure from coagulation to coagulation-condensation [8].

2. Materials and Methods
To study the physical and mechanical properties, granulated blast furnace slags of the Novolipetsk Metallurgical Plant were used. Tests of asphalt concrete were carried out according to GOST 9128-2013. Given the hydraulic properties of slag materials, asphalt concrete properties were studied not only at the age of 2 days—as required by the standard—but also periodically from the time of manufacture of the samples after prolonged water saturation, and after repeated exposure to alternating temperatures. To study the processes of structure formation, scanning electron microscopy was used.
3. Results
The results of the study of the structural and mechanical properties of asphalt over time are presented in Table 1. Analysis of the presented results allows talking about ongoing processes of structure formation over time. The increase in compressive strength at a temperature of 20 °C can be explained from the standpoint of the diffuse theory of adhesion. The diffuse theory of adhesion easily explains this dependence by the slow diffusion of bitumen molecules and its components into the pores of slag material [9].

Table 1. Change in the physical and mechanical properties of asphalt concrete from granulated slag over time

| Asphalt Composition                  | Age [days] | Average density, [g/cm³] | Water saturation [vol.%] | Extension [vol.%] | Tensile strength at compression [MPa] at temperature [°C] | Water resistance coeff. |
|-------------------------------------|------------|--------------------------|--------------------------|-------------------|--------------------------------------------------------|------------------------|
| Granulated blast furnace slag (100%), BND 60/90 bitumen (8%) | 2          | 1.98                     | 13.52                    | 0.02              | 2.5 1.1 - 2.5 1.00                                      |                        |
|                                     | 7          | 2.00                     | 12.36                    | 0.08              | 2.9 1.2 - 2.9 1.00                                      |                        |
|                                     | 28         | 2.01                     | 12.60                    | 0.09              | 3.2 1.1 - 3.2 1.00                                      |                        |
|                                     | 60         | 2.00                     | 11.99                    | 0.08              | 3.5 1.1 - 3.5 1.00                                      |                        |
|                                     | 180        | 1.99                     | 11.34                    | 0.00              | 3.7 1.1 - 3.7 1.00                                      |                        |

The effect of freezing and thawing on the physicomechanical properties of asphalt concrete is presented in Table 2.

Table 2. Effect of freezing-thawing on the physical and mechanical properties of asphalt concrete

| Asphalt Composition                  | No. of freezing cycles | Tensile strength at compression [MPa] at temperature [°C] | Average density, [g/cm³] | Water saturation [vol.%] | Extension [vol.%] | Coefficients |
|-------------------------------------|------------------------|--------------------------------------------------------|--------------------------|--------------------------|-------------------|--------------|
| Granulated blast furnace slag (100%), BND 90/130 bitumen (9%) | 50                     | 2.8 1.1 7.0 2.7 1.99 13.11 0.00 | 0.96 1.40               |                          |                  |              |
|                                     | ref.                   | 2.0 1.2 7.0 2.0 1.98 13.10 0.00 | 1.00  -                  |                          |                  |              |
|                                     | 75                     | 2.4 1.1 6.5 2.3 1.99 12.11 0.00 | 0.96 1.09               |                          |                  |              |
|                                     | ref.                   | 2.2 1.1 7.0 2.2 1.98 13.20 0.00 | 1.00 -                   |                          |                  |              |
|                                     | 100                    | 2.2 1.1 6.3 2.2 1.99 11.98 0.00 | 1.00 0.79               |                          |                  |              |
|                                     | ref.                   | 2.8 1.1 7.2 2.7 1.98 13.30 0.00 | 0.97 -                   |                          |                  |              |

Materials based on hydraulic binders have the ability to restore the original structure due to the "self-healing" of defects that occur during alternate freezing-thawing [8, 10]. In addition, the bitumen film on
slag grains has a complex supramolecular (secondary) structure similar to polymer films, which indicates an increased durability of asphalt concrete.

Figure 1. Supramolecular belt fibrillar structure of a bitumen film on the surface of slag materials

The stability of the structure of asphalt concrete from slag materials during prolonged water saturation (table 3) is explained by a peculiar mechanism of structure formation processes during the interaction of slag material with water. The interaction of slag materials with water begins from the moment they are produced.

Table 3. Effect of prolonged water saturation on the physical and mechanical properties of asphalt concrete

| Asphalt Composition | Duration of water saturation, days | Tensile strength at compression [MPa] at temperature [°C] | Ave-rage density, [g/cm³] | Water saturation [vol.%] | Extension [vol.%] | Water resistance coeff. |
|---------------------|----------------------------------|----------------------------------------------------------|--------------------------|--------------------------|-------------------|-------------------------|
|                     | 20  50  0                        |                                           |                          |                          |                   |                          |
| Granulated blast furnace slag (100%), BND 90/130 bitumen (9%) |
| 10                  | 1.9  1.1  6.5                    | 2.15                                       | 8.20                     | 0.45                     | 1.00              |
| ref.                | 1.6  1.1  7.0                    | 2.19                                       | 5.40                     | 0.36                     | 0.98              |
| 30                  | 1.5  1.1  6.7                    | 2.16                                       | 8.30                     | 0.00                     | 1.02              |
| ref.                | 1.8  1.1  7.4                    | 2.12                                       | 9.20                     | 0.00                     | 1.11              |
| ref.                | 2.0  1.1  7.2                    | 2.17                                       | 8.10                     | 0.00                     | 1.01              |
| ref.                | 2.0  1.1  7.7                    | 2.18                                       | 9.50                     | 0.00                     | 1.20              |
| ref.                | 2.2  1.1  7.4                    | 2.20                                       | 7.88                     | 0.00                     | 0.90              |
| ref.                | 2.7  1.1  10.6                   | 2.18                                       | 9.00                     | 0.00                     | 1.08              |
| ref.                | 3.5  1.1  10.9                   | 2.21                                       | 9.50                     | 0.00                     | 1.00              |
During the heating of the slag material and its combination with bitumen, the processes of hydrolysis and hydration are enhanced. By the time of water saturation, the structure of asphalt concrete from slag materials is coagulating.

During the water saturation of asphalt concrete from granulated slags, slow hardening and stabilization of the structure occur, primarily due to an increase in the strength of adhesive bonds between bitumen and slag material, which is due to the modification of the surface of the slag material during hydration (Figure 2).

When using hydraulic mineral materials, water falling under a bitumen film is spent on slag hydration, and the system of pore channels draws excess moisture inside the slag grain. As a result, the structure of asphalt concrete from slag materials is transformed from coagulation to coagulation-condensation [9, 11].

![Image](image.png)

**Figure 2.** Surface modification of slag material after 90 days of water saturation (bitumen is extracted)

### 4. Conclusion
- The processes of structure formation immediately from production to prolonged water saturation and a number of freeze-thaw cycles were investigated.
- The use of asphalt concrete from slag materials in road construction will not only reduce the cost of construction and increase the durability of asphalt concrete pavements, but also solve socio-environmental problems by using by-products of metallurgical plants.

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