The use of metallurgy waste in the roads sustainability improving

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Abstract. The purpose of our scientific work is to develop recycling techniques metallurgical slag (MS) of the Kemerovo regions’ industrial enterprises in the Russian Federation in order to increase the roads sustainability. The research methodology was based on our developed technological schemes of MS recycling, which justified the need for a consistent transformation of their properties through a series of mechanical and physic-chemical effects. Express method of selecting mixtures composition for the bases of pavements from various MS fractions was used for the rapid selection of the densest asphalt mixtures composition. The obtained results indicate that the use of steelmaking slag in the composition of asphalt mixtures determines the possibility of improving their operational properties. This circumstance determines the possibility of using such mixtures for pavements repair, increasing the life of existing roads, as well as the construction of new ones. This means that metallurgical slag can become an important reserve for natural building materials in the process of preparing and laying asphalt mixes on city streets and highways of various classes and categories. Their cost and reserves will make it possible to build pavements resistant to dynamic loads and alternating temperatures with relatively low material costs.

1. Introduction
The development of rational ways to use metallurgical waste in the construction industry is of the great importance from the standpoint of the environment improving, since hundreds millions of industrial waste tons were accumulated in production areas [1].

However, the well-known technologies for processing industrial waste are largely unprofitable [2,3], most of them return to dumps, forming large-tonnage heaps. In this regard, the problems urgency of developing rational ways to use metallurgical waste in the construction industry is beyond doubt.

At the same time, the effectiveness of ways and methods of metallurgical slag using is largely dependent on the results of studying their physicochemical properties. A feature of such methods is that technogenic raw materials have already undergone high-temperature processing, which determined the formation of crystalline and amorphous structures, the absence of organic impurities, and the possibility of the secondary use of such raw materials in the construction industry.

In addition, the basic principles of the development strategy for the building materials industry during the period up to 2020 and a further perspective until 2030 (approved by the Order of the Russian Federation Government, dated 10.05.2016 No 868-r) [4] focus on the development of the
construction industry using waste industrial production. At the same time, technogenic products of metallurgical enterprises are traditionally an important raw material resource for the construction industry, which convincingly emphasizes the relevance of developing recycling technologies for the production of building mixtures for various functional purposes [5], which are successfully used to increase the roads stability [6].

2. Methods
The goal of our research work is to develop technological methods for the disposal of waste products at industrial enterprises of the Kemerovo region in the Russian Federation in order to increase the roads stability.

The object of the study was the metallurgical slag (open-hearth, fraction 0–40 mm; converter, fraction 0–40 mm), which were stored in dumps under the conditions of varying effects of temperature and humidity. The study of the slag physical and mechanical properties was carried out, based on the testing laboratory of the Building Materials, Standardization and Certification Department in Novosibirsk State University of Architecture and Civil Engineering (Sibstrin). All metallurgical slag has a code according to the Federal Classification Catalog of Wastes (FCCW) [7]: 3 51 210 21 20 4, hazard of IV class, state of aggregation - solid; these are low hazardous substances with a low degree of environmental impact.

The research methodology is based on our metallurgical slag recycling technological schemes [5], which justify the need for the consistent transformation of their properties through a series of mechanical and physic-chemical influences.

The measuring instruments and equipment, used for testing, were verified, calibrated and certified in accordance with SST 8.513; SST 8.326; SST 24555. The study of the basic physical and mechanical properties of metallurgical slag was carried out, using standard methods to ensure the required accuracy of the results.

3. Results
Our practice shows the metallurgical slag are actively used in road construction, including both using them for the preparation of asphalt mixes [6,8-10], for roads repairing [11,12] and also improving the quality of the pavement elements [13,14], taking into account such properties as deformability [15].

The express method of selecting the mixtures composition for the pavement bases from various fractions of metallurgical slag was used for the rapid selection of the densest asphalt mixtures’ composition (see Table 1).

| Type of metallurgical slag | True density kg/m³ | Bulk density kg/m³ |
|----------------------------|---------------------|--------------------|
| open-hearth, fraction 20-40 mm | 2230                | 1040               |
| open-hearth, fraction 5-20 mm  | 2230                | 1200               |
| open-hearth, fraction 0-5 mm   | 2410                | 1740               |

Both the average grain size and the size of the voids between the grains of the previous fraction were taken into account, choosing a specific fraction and successful grain packing: the grain size of a specific fraction should be about 1/3 of the average size of the previous fractions in accordance with the sieves standard set. Analysis of the metallurgical slag physic-mechanical properties showed their use possibility for the preparation of medium- and low-crushed asphalt concrete mixtures for the upper and lower layers of the roads coatings (types B and C II and III of the brand in accordance with SST 9128).

We previously showed [16] that the designed mixture composition should have a maximum density at the lowest deformability under load, and take into account the rheological properties of granular...
substrates determined by various interactions with the surrounding soil during the operation of the road (see Figure 1).

![Figure 1. Samples of slag-asphalt-concrete.](image)

The obtained results’ analysis shows that slag-asphalt-concrete mixture and slag-asphalt-concrete meet the requirements of the current standards according to the main indicators, and according to some indicators, characterizing the operational work of the material - strength at 50 °C, shear resistance and crack resistance - exceed by 1.3 - 1.9 times (see Table 2).

Table 2. Indicators of physic-mechanical properties of slag-asphalt-concrete.

| Units                        | Dense of slag-asphalt-concrete mixture | Crushed stone dense fine-grained asphalt mixture (type B grade II according to SST 9128) |
|------------------------------|----------------------------------------|--------------------------------------------------------------------------------------------|
| Average density kg/m³        | 2370                                   | -                                                                                           |
| Water saturation %           | 1.7                                    | 1.5                                                                                         |
| Tensile strength at compression, at a temperature of 50 °C Pa          | 2.6*10⁶                               | >2.0*10⁶                                                                                     |
| Tensile strength at compression, at a temperature of 20 °C Pa          | 4.4*10⁶                               | >2.2*10⁶                                                                                     |
| Tensile strength at compression, at a temperature of 0 °C Pa           | 7.0*10⁶                               | <12.0*10⁶                                                                                     |
| Water resistance -           | 0.87                                   | 0.85                                                                                         |
| Shear resistance:            | -                                      | 0.88                                                                                         |
| - coefficient of internal friction -                                  | 0.87                                   | 0.81                                                                                         |
| - shear adhesion at a temperature of 50 °C Pa                       | 0.66*10⁶                              | >0.35*10⁶                                                                                     |
| Fracture resistance to tensile strength at split at a temperature of 0 °C Pa and a strain rate of 50 mm / min | 2.8                                   | 2.5-6.0                                                                                      |

The analysis of the physic - mechanical properties of the asphalt binder showed the possibility of its laying in places subject to shear deformations [13,17]. The road surface was saturated with water under the conditions of hard-plastic and elastic work of asphalt concrete, characterized by lower air temperatures. At the same time, intensive destruction of asphalt concrete can occur due to the
expanding action of water lenses and the operation of the coating-base system. However, microcracks formed due to a more intensive increase in the strength in the material structure, which reduced the penetration of water into them, and the stresses at their boundaries would be much lower than the tensile strength of the asphalt concrete itself [18,19]. This circumstance made it possible to exclude the formation of low-temperature macrocracks, thereby preserving the required continuity and evenness of the material [15,17,18].

It is known [19] that the formation of asphalt concrete coatings from slag materials continues for a long time. At the end of these processes, a stable coating corresponds to the density of samples, obtained under laboratory conditions with a load of 30*10^6 Pa. During the coatings operation, porosity is redistributed and the pore volume of a large diameter decreases. This redistribution of porosity has a positive effect on increasing frost resistance [20,21], strength [22] durability [23-26] of asphalt concrete.

4. Conclusion
The obtained results indicate that the use of metallurgical slag in the composition of asphalt concrete mixtures determines both the possibility of improving their operational properties [20], which is associated with the use of such mixtures for repairing pavement [27] and also the construction of new roads and an increase in terms road operation in general [28-30].

This means that metallurgical slag can become an important reserve for natural building materials in the process of preparing and laying asphalt mixes on city streets and highways of various classes and categories. Their cost and reserves will make it possible to build pavements resistant to dynamic loads and alternating temperatures with relatively low material costs.

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