An Impact of Waste Foundry Sand on Asphalt Concrete Mixture

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Abstract. The article discusses the use of waste metallurgical plant, waste foundry sand (OFS) in comparison with other small aggregates in the composition of asphalt concrete mixture. Due to the constantly growing intensity and loads from the rolling stock, there are high demands on asphalt concrete pavements. Basically, the stability of asphalt to shear deformations depends on the strength characteristics. Thus, the higher the strength of the asphalt concrete when testing samples at high temperature, the higher the shear stability of the road surface. One way to reduce the cost of building a highway, possibly through the use of industrial waste in the structural layers of pavement. The article presents the results of asphalt concrete tests using natural sand, quartz sand and waste foundry sand.

1. Introduction
Due to the constant increase in the volume of construction of roads with asphalt concrete pavement, the question of the cost of the used road-building materials arises. An analysis of the asphalt mixes market showed that the production of hot, dense asphalt mixes in June 2017 increased by 17.9% compared with June 2016. In the period from 2014 to 2017, the average cost of asphalt concrete mixtures increased in price by 13.6%, from 2731.3 rub / ton to 3,102.8 rub / ton. The cost increase occurred primarily due to the increase in the cost of mineral materials used in the composition of asphalt concrete. There are several ways to reduce costs in the construction of roads, such as the use of local mineral materials, rational competent organization of construction work, the use of high-performance technologies, materials, as well as industrial waste. The greatest reduction in the cost of the asphalt mix can be achieved through the use of alternative mineral materials that are not inferior to those traditional in basic physical and mechanical parameters. Such materials include waste ferrous and nonferrous metallurgy, in particular spent molding sand (OFS), used in technological processes of casting metal products.
Waste ferrous and nonferrous metallurgy, namely, slags found wide application in the composition of asphalt concrete as a mineral powder, as well as in the form of crushed stone and sand in the construction of the pavement base layers [1-4]. For the construction of asphalt and cement concrete pavements, as research has shown, alternative raw materials are also used. In particular, studies on the use of various industrial wastes are conducted in the works of the Volgograd and Belgorod scientific schools [5-10]. In many foreign countries, research is being conducted on the modification of asphalt concrete using industrial waste. In Dalhat M.A., Al-Abdul Wahhab H.I. (Saudi Arabia) presents data on the use of plastic waste in the composition of asphalt concrete [11]. A number of works present data on the use of rubber powder, obtained by processing broken automobile tires, as a modifier for improving the properties of asphalt concrete mixture [12-14].

2. The effect of fine mineral aggregate on the structure of asphalt concrete.
Every year there is an increase in energy prices, which in turn leads to an increase in the cost of raw materials in particular, crushed stone, sand from crushing crushed screenings, sand and gravel mixture, natural sand, mineral powder, bitumen, all those components of which the road construction consists clothes. The depletion of natural stone mineral materials can serve as one of the factors for the rise in the cost of the raw material base. It is worth noting that many regions have industrial facilities that, as a result of their activities, create significant amounts of waste called man-made. So the coal industry creates 56% of the total waste, 11% - ferrous metallurgy, 15% - non-ferrous metallurgy, 14% - other minerals, 1% falls on forestry and agriculture, respectively. Many technogenic materials have potential for use in the construction and road-building industries, since some of them are similar or superior in their physical, mechanical, and physical and chemical parameters to materials traditionally used in construction.

One of the undervalued man-made materials is waste foundry sand (OFS) obtained in the process of casting metal products, where silica sand together with a hardener and formaldehyde is used as molds. After repeated use of the molds, acting on the quartz sand by mechanical, chemical and temperature effects modifies the surface of the material particles, creating a unique material in its characteristics.

When mixing OFS and bitumen for 20-30 minutes, the structure of the mixture is formed, which is characterized by a decrease in its mobility. This is due to the transition of part of maltenes and resins under the action of attractive forces between liquid bitumen and solid molecules (mineral particles) into the surface porous layer of the OFS mineral base. In the layer of free bitumen, the content of maltenes and resins falls, which leads to an increase in its viscosity. The penetration of bitumen and its components into the porous layer largely depends on the pore size. Macropores filter bulk bitumen. Micropores on the surface of mineral particles form the selective diffusion of the moving constituent parts of bitumen. The formed surface layer on the mineral part is enriched with asphaltenes, thus forming the phase separation region, which determines the physicom mechanical properties of asphalt concrete.

With this representation of the process, less viscous bitumen fractions can be moved both into and out of the porous material (into free bitumen), Figure 1. This process will be determined by external loads, ambient temperature and diffusion transfer of the substance described by Fick’s laws. The amount of the substance transported is proportional to the concentration gradient dC / dx, the cross section q and time t (x is the coordinate along the diffusion path). With the active emission of free bitumen of maltenes into the environment, it is possible to compensate a part of their volumes due to precisely diffusion processes, in view of the difference in the concentrations of maltenes inside the pores and in the free bitumen. The inner layer of the phase separation region performs the function of a “donor” of maltenes. This will restore the original rheological properties of bitumen.
3. Experience of using OFS in foreign countries

The lack of space for the placement of spent molding sand and other industrial waste materials gave impetus to the creation and expansion of the range of building composite materials due to the inclusion of industrial raw materials into their composition [15].

In India, there is a significant shortage of standard stone mineral materials, which creates difficulties in the construction of industrial and civil buildings and structures. However, there are large reserves of OFS, which can replace fine mineral aggregate in the composition of concrete mixtures, which significantly reduces the consumption of natural non-mineral raw materials. Laboratory tests of concrete cubes were carried out at strength set-up after 7, 28, 56, 90 days, with the replacement of spent sand (OFS), fine mineral aggregate by 20, 25, and 30%. The best result in terms of strength and waterproof performance was achieved with an OFS content of 30% [16,17].

In Brazil, when there was a threat of environmental imbalance and a shortage of building materials that meet the requirements of national standards, concrete compositions were proposed that meet the requirements for an indicator of the compressive strength of at least 25 MPa. In one of the developments of Brazilian scientists, the selection of crushed stone-mastic asphalt concrete and blocks for paving was carried out OFS as a fine mineral aggregate [18,19].

In Mexico and Italy, OFS has found wide application in the composition of cement concrete [20,21]. In the United States, between 10 and 16 million tons are produced annually, spent foundry sand, of which 15-28% of the total volume is reused and the rest is disposed of. It is possible to increase the volume of processing by-products of steel foundry by replacing fine aggregate in Portland cement, besides, OFS may be added to natural sand during the construction of constructive pavement layers [22].

4. Experiments

In the Russian Federation, the design of the grain composition of the asphalt concrete mix is carried out according to the requirements of GOST 9128-2013 "Mixes of asphalt concrete, polymer asphalt concrete, asphalt concrete, polymer asphalt concrete for highways and airfields", according to the grain composition curve. For further research, hot dense fine-grained asphalt type B grade I was
chosen. For comparative tests of the asphalt concrete mixture, natural sand, quartz sand and OFS were used as fine aggregate. The grain composition of the original mineral materials are presented in table 1.

Table 1. Grain composition of mineral materials used.

| The name of the material                        | Grain size, mm, smaller than this size |
|------------------------------------------------|---------------------------------------|
|                                                 | 20  | 15  | 10  | 5   | 2,5 | 1,25 | 0,63 | 0,315 | 0,16 | 0,071 |
| Crushed stone fr. 5 to 20 mm                    | 99,6 | 82,1 | 44,6 | 1,5  | 0,6 | 0,6  | 0,6  | 0,5   | 0,4  |
| Natural sand                                   | 100  | 100  | 99,7 | 98,1 | 91,8| 87,6 | 78,8 | 47,4  | 2,4  | 0,6   |
| Quartz sand                                    | 100  | 100  | 100  | 100  | 100 | 100  | 94,3 | 44    | 1,4  | 0     |
| OFS                                            | 100  | 100  | 100  | 100  | 100 | 100  | 98,7 | 74,5  | 1,8  | 1     |
| Sand from crushing screenings                  | 100  | 100  | 100  | 98   | 72  | 55,6 | 38,1 | 28    | 18,8 | 14,5  |
| Mineral powder                                 | 100  | 100  | 100  | 100  | 100 | 100  | 98,5 | 89,7  | 79,2 |

The presented data of grain compositions of mineral materials in table 1 allows you to choose the optimal content of each fraction necessary for the continuous particle size distribution of the asphalt-concrete mixture. What allows you to achieve maximum physico-mechanical parameters when testing asphalt samples by standard methods specified in GOST 12801-98 “Materials based on organic binders for road and airfield construction. Test methods.

The manufacture and testing of asphalt samples were carried out at the Perm National Research Polytechnic University, Department of Highways and Bridges, in the laboratory of the DORIS laboratory. The results of testing asphalt samples are presented in Table 2. Mixture 1 — grain composition from crushed stone fraction from 5 to 20 mm - 46%, natural sand - 12%, sand from crushing screenings - 39%, mineral powder - 3%, BND 60 grade bitumen / 90 in excess of 100% - 5.0%. Mix 2 - grain composition of crushed stone fraction from 5 to 20 mm - 46%, quartz sand - 12%, sand from crushing screenings - 39%, mineral powder - 3%, Bitumen of grade BND 60/90 in excess of 100% - 5.0 % Mix 3 - grain composition of crushed stone fraction from 5 to 20 mm - 46%, OFS - 12%, sand from crushing screenings - 39%, mineral powder - 3%, Bitumen of grade BND 60/90 in excess of 100% - 5.3%.

Table 2. The test results of asphalt type B grade I according to GOST 12801-98.

| Indicators                  | Requirement GOST 9128-2013 (2009) | Mix 1 | Mix 2 | Mix 3 |
|-----------------------------|-----------------------------------|------|------|------|
| Average density, g/cm³      | -                                 | 2,43 | 2,43 | 2,44 |
| Water saturation, %         | 1,5-4,0                           | 1,88 | 1,40 | 1,00 |
| Residual porosity, %        | 2,5-4,0                           | 3,57 | 3,57 | 2,79 |
| Limit compressive strength, |                                   |      |      |      |
| MPa:                        |                                   |      |      |      |
| 20 °C, not less             | 2,5                               | 4,15 | 4,73 | 3,61 |
| 50 °C, not less             | 1,2                               | 1,47 | 1,67 | 1,69 |
| 0 °C, not more              | 11,0                              | 9,93 | 9,48 | 8,37 |
An analysis of the results showed that an increase in the average density, a decrease in water saturation and residual porosity indicates a better layout of the grains of the mineral core of asphalt concrete, using OFS as a fine aggregate. Reducing the number of free pores in asphalt concrete suggests a better resistance to shear deformations that occur under the influence of rolling stock.

Strength characteristics are determined by the ultimate compressive strength of asphalt samples, with thermostating with a different set temperature. It can be assumed that with a smaller difference in the results obtained at 50 °C and 0 °C in terms of tensile strength, asphalt concrete with OFS is used more widely in different climatic conditions with hot and cold climates.

5. Conclusion
The use of OFS in asphalt concrete is possible instead of traditional mineral materials, such as natural sand, with not only economic benefits, but also environmental benefits due to recycling of the steel industry and refusing to use natural mineral resources.

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