Influence of quality indicators of the surface of mineral particles on the properties of asphalt concrete

K G Pugin

Perm National Research Polytechnic University, Komsomolsky Prospect 29, Perm 614990, Russia.
Perm State Agro-Technological University named after Academician D.N. Pryanishnikov, str. Petropavlovskaya 23, Perm 614990, Russia

123zzz@rambler.ru

Abstract. Increasing traffic loads are driving the demand for durable asphalt concrete. The creation of new compositions of asphalt concrete mixtures is possible by studying the structure-forming processes at the interface between the phases “surface of mineral particles - organic binder”. The presented study makes it possible to assess the degree of influence of the specific surface area on the physical and mechanical properties of asphalt concrete. Were considered fine mineral materials with different specific surface (natural sand, quartz sand, waste molding sand). They were matched with the same size modulus. At the first stage, the structure and shape of the surfaces of the particles of mineral materials were determined. At the second stage, the physical and mechanical characteristics of three asphalt concrete compositions were determined. It was established that a well-developed, rough surface of mineral aggregate particles in asphalt concrete can act as an effective modifying element in the composition of asphalt concrete and achieve the desired physical and mechanical characteristics. An increase in the specific surface area of the mineral aggregate particles, with the same size modulus, makes it possible to proportionally increase the strength characteristics of asphalt concrete.

1. Introduction

Currently, asphalt concrete remains the main material for the construction of the upper structural layers of highways. The increase in the length of highways, the volume of repair work associated with the restoration of their operational characteristics require a large amount of raw materials. The growth of traffic intensity of vehicles of various carrying capacities and an increase in axle loads of certain categories of vehicles require the use of asphalt concrete with improved operational and physical and mechanical properties. Asphalt concrete is a rationally selected and compacted mixture of mineral materials with bitumen. Natural stone or man-made materials are used as mineral materials. The use of asphalt concrete in different climatic zones imposes special conditions on the selection of mineral materials and the grade of bitumen used. This is due to a change in the main physical and mechanical parameters of asphalt concrete with a change in temperature, ambient humidity, precipitation, which leads to accelerated aging and loss of operational properties of the coating. [1-4] Obtaining effective asphalt concrete compositions capable of withstanding increasing loads under unfavorable climatic influences, possibly by analyzing the structure-forming processes occurring during the formation of an asphalt concrete pavement from an asphalt concrete mixture. One of these processes is the interaction of the surface of a mineral material with bitumen. Earlier it was found that the stronger the bond at the
interface between the bitumen and mineral material, the higher the loads from road transport, and negative external natural factors can be perceived by asphalt concrete during its operation [5, 6].

A large number of scientific works by domestic and foreign scientists are devoted to the study of the processes of structure formation in asphalt concrete, the development of theoretical prerequisites to explain the obtained dependences of the physical-mechanical, operational and technological properties of asphalt concrete with a change in the parameters of the feedstock. [1-4]. However, a large number of scientific works mainly focus on optimizing the composition of the asphalt concrete mixture, do not analyze laboratory tests to establish theoretical dependencies that could indicate at an early stage the possibility of using mineral raw materials or man-made material in the composition of asphalt concrete with the achievement of target performance indicators. The establishment of the laws of structure formation in organic-mineral mixtures, the establishment of the degrees of influence of individual factors on the target indicators of asphalt concrete can reduce the number of expensive laboratory tests.

Previously, it was found that the structure and physical and mechanical characteristics of asphalt concrete depend on the quality and amount of bonds formed between mineral particles and bitumen. [7-9] As shown by a number of studies carried out by Russian and foreign scientists, the presence of a rough surface on the surface of mineral particles contributes to the formation of strong bonds with organic binder [10-15]. Establishing the degree of influence makes it possible to assess the boundary conditions for the use of mineral material in the composition of asphalt concrete. To establish the influence of the quality indicators of the surface of mineral particles on the physical and mechanical properties of asphalt concrete, the planning of experimental studies was carried out, which made it possible, in a first approximation, to establish the effect of the specific surface area of the mineral material on the properties of asphalt concrete.

To obtain objective data, mineral materials with the same particle size distribution, particle shape, and the same chemical composition were used. The variable parameter was the specific surface area of the fine mineral material. With the same particle size, an increase in the specific surface of the material is provided by a more porous surface of the material particles. To ensure the same particle size distribution, three types of sand were used: natural (river) sand, quartz sand and spent molding sand. The spent molding sand is quartz sand after being used as a mold. The use of three types of sand made it possible to withstand the necessary conditions for ensuring the homogeneity of the physical and mechanical characteristics of the mineral material.

2. Methods and materials used

Surface microtopography was used to study the surface structure of mineral particles. Investigations of the surface and the elemental composition of mineral materials were carried out on an S-3400N "HITACHI" scanning electron microscope equipped with an XFlashDetektor 4010 spectrometer, which allows X-ray spectral microanalysis of materials surfaces. The adhesion of bitumen to stone materials was established in accordance with GOST 11508-74. Determination of the specific surface area of mineral materials was determined using a Sorbi®-MS device. Determination of the bitumen content of sand and spent molding sand was determined in accordance with GOST 32766-2014. The determination of the grain size composition of the sands was carried out using a standard set of sieves. The determination of the true density of materials was carried out by the pycnometric method. Tests of the obtained asphalt concrete samples were carried out in accordance with GOST 12801-98 "Materials based on organic binders for road and airfield construction. Test methods ". To determine the physicomechanical, physicochemical characteristics of the mineral materials used, as well as samples of asphalt concrete, we used standard laboratory equipment used in road laboratories, which has passed the necessary verification and certification. The determination of the ultimate strength in compression of asphalt concrete samples was carried out on a Tecnotest T052 / E installation. The obtained results of a series of laboratory tests of materials and samples were mathematically processed for adequacy using the STATISTICA software.
For the formation of laboratory samples of asphalt concrete, crushed stone of the Zagotovka quarry was used as a large mineral aggregate, the quarry is located in the Perm Territory, fraction 5-20mm, crusher grade M1000, abrasion grade I-1, frost resistance grade F100. As a fine mineral aggregate, crushing screenings were used from the White Stone quarry, the quarry is located in the Perm Territory, fraction 0-5mm with a fineness modulus Mk = 2.83, true density 2.77 g / cm3. Used non-activated mineral powder of JSC "Gornozavodskcement" Perm region. Sand natural open pit "Port Perm" Perm region, with a modulus of size Mk = 1.6 and a true density of 2.67 g / cm3. Spent molding sand of JSC "Blagoveshchensk reinforcement plant", with a size modulus Mk = 1.6, true density 2.70 g / cm3. Quartz sand of JSC "Balasheiskiye Peski" with a particle size modulus Mk = 1.6, true density 2.68 g / cm3. The fractional composition of sands and spent molding sand was artificially leveled to create conditions for one-factor modeling. The binder used was BND 90/130 bitumen produced by PJSC Oil Company Lukoil).

3. Experiments performed
To determine the influence of the quality indicators of the surface of mineral particles on the properties of asphalt concrete, an experiment was planned. The specific surface area of mineral materials was used as a variable parameter in the composition of asphalt concrete. Quartz and natural (river) sand, waste molding sand (OFS) with the same size modulus were used as mineral materials with different specific surface areas. The same size modulus ensured the uniformity of the grain size composition of the mineral aggregates. The change in the specific surface area of materials was provided by the difference in the structure of the surface layer of sand particles.

It was found that the specific surface area of quartz sand is 0.29 m2 / g, natural sand is 0.40 m2 / g, and the specific surface area is 0.79 m2 / g. A more detailed study of the physical and mechanical properties of the samples was presented earlier. [16-18] At the first stage of research, the shape and structure of the surface of particles (natural sand, quartz sand, OFS) were determined. The shape and surface of the particles can be estimated in Figures 1, 2.

![Figure 1. Spent molding sand (OFS): a - an increase of 10 times](image-url)
Figure 2. Spent molding sand (OFS): an increase of 100 times

The analysis of the obtained images of the particle surfaces made it possible to substantiate the increased specific surface area of the OFS. On a part of the surface of the OFS particles there is a porous layer formed in the course of technological operations of steel casting. OFS is a production waste based on quartz sand. The same quartz sand, which was not used in the technological operations of casting, and was used as one of the options for fine mineral filler (quartz sand). Using OFS and quartz sand in the compositions of the studied asphalt concrete samples, we obtained samples with guaranteed the same grain size distribution and particle shape.

At the second stage of the research, the indicators of the physical and mechanical characteristics of the obtained asphalt concrete samples were determined. Laboratory studies were carried out in the laboratory of the Department of Roads and Bridges, Perm National Research Polytechnic University. The studied samples in composition corresponded to hot dense fine-grained asphalt concrete of type B grade I. Three compositions of asphalt concrete mixtures were used, the content of mineral components and binder are presented in table. 1.

| Structure | Crushedstone, % | Screeningcrushing, % | Mineralpowder, % | Bitumen, % | Naturalsand, d, % | Quartzsand, d, % | WF, % |
|-----------|-----------------|---------------------|-----------------|-----------|-----------------|-----------------|-------|
| 1         | 46              | 39                  | 3               | 5,0       | 12              |                 |       |
| 2         | 46              | 39                  | 3               | 5,0       | 12              |                 |       |
| 3         | 46              | 39                  | 3               | 5,0       | 12              |                 |       |

The studies carried out have shown that a number of physical and mechanical indicators unambiguously, although to varying degrees, showed the effect of the specific surface area of mineral fillers on their value. In particular, the values of the specific density of the samples, the ultimate strength at 50 °C, 20 °C and water resistance showed a clear increase in their values with an increase in the specific area of the fine aggregate table. 2
Table 2. Physical and mechanical properties of asphalt concrete

| 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  |

Studies have shown that the specific surface area of a mineral aggregate, in particular a fine aggregate, has a significant effect on most of the indicators specified by GOST. An increase in specific surface area by 2.7 times leads to an increase in the ultimate strength in compression at 50 °C and 20 °C by 1.6 and 1.98 times, respectively. Water resistance and average density of the obtained asphalt concrete samples are less dependent on the specific surface area and showed a change of 12% and 10%.

The remaining physical and mechanical indicators of asphalt concrete samples regulated by GOST did not reveal a clear dependence on the specific surface area of fine mineral aggregates, which indicates a low significance for the formation of these indicators. These indicators included: ultimate strength at 0 °C; crack resistance index; shear stability index and water saturation coefficient.

4. Conclusion

The physical and mechanical properties of asphalt concrete depend on a large number of factors. The quality indicators of the surface of mineral aggregates in the asphalt concrete mixture play a significant role in the formation of the strength and performance indicators of the pavement. An increase in the specific surface area of mineral particles, while maintaining the modulus of size, makes it possible to proportionally increase the value of the ultimate strength in compression.

The use of industrial waste, when obtaining target products in demand on the market, allows you to resolve the issue of their disposal.

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