Dependence of Physical and Mechanical Characteristics on the Specific Surface of Mineral Particles in Asphalt Concrete

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Abstract. The ever-increasing intensity of traffic and axial loads from motor vehicles is forcing material scientists and road-building organizations to develop and use asphalt concrete with higher physical, mechanical and operational characteristics. An integral part, when creating new compositions of asphalt concrete mixtures, is the study of the processes going on at the phase boundary "surface of mineral particles - organic binder". In the presented studies, mineral materials with different specific surfaces were considered. To study the effect of the specific surface on the physical and mechanical properties of asphalt concrete, the following were used: natural sand, quartz sand, and waste foundry sand. To obtain an objective result of the study, all materials were selected with the same size modulus. The first stage of laboratory research was aimed at studying the structure and surface shape of the particles of stone materials. The second stage consisted of molding asphalt concrete samples and determining their physical and mechanical characteristics. Three compositions of asphalt concrete have been studied. The presented studies confirm the theory put forward earlier by the authors about the mechanism of interaction of the surface of mineral particles with an organic binder. An increase in the specific surface of stone materials increases the adhesion force of bitumen to the surface of stone materials. It has been established that a well-developed, rough surface of particles of mineral aggregate in asphalt concrete can act as an effective modifying element. An increase or decrease in the specific surface area of the particles of mineral aggregate, with the same modulus of fineness, it is possible to achieve a proportional change in the strength characteristics of asphalt concrete using bitumen. With an increase in the specific surface of the particles of mineral aggregate in the asphalt mix, it is possible to create asphalt concrete capable of resisting increasing loads from the rolling stock.
1. Introduction
The successful development of the state is largely determined by the development of transport highways. A strategy has been adopted in the Russian Federation to ensure an increase in the length of roads in the Russian Federation. At the same time, the national project “Safe and high-quality roads” is being implemented, according to which it is necessary to increase the length of regional roads and bring the technical condition of existing ones to the normative. The implementation of the above projects requires a large amount of raw materials for the production of road-building materials, in particular asphalt concrete, one of the main road-building materials used in the upper structural layers of pavement. The increase in traffic and axle loads require the use of asphalt concrete with improved physical, mechanical and operational performance. The development of new compositions of asphalt concrete capable of withstanding increasing loads requires the study of structure-forming processes, especially those going at the boundary of bitumen-mineral material.

Asphalt concrete used for road construction is an organic-mineral mixture consisting of a bituminous binder, mineral aggregate and fine aggregate. The properties of the resulting asphalt concrete depend on the physicochemical properties of the materials used.

The study of the theory of structure formation, the formation of physico-mechanical as well as physicochemical properties, asphalt concrete manufacturing technologies has been the subject of many scientific works by domestic and foreign scientists. [1-4]. It has been established that the stronger the bond at the interface between the binder and the mineral aggregate, the higher loads from rolling stock and the impact of negative external factors are ready to perceive asphalt during operation [5, 6].

2. Establishing the dependence of the specific surface on the physico-mechanical characteristics of asphalt concrete
It has been established that the structure and characteristics of bitumen-mineral mixtures depend on the following factors: quality of chemical bonds acting between the individual initial mineral particles; properties of bitumen binder; thickness of the bitumen film on the surface of crushed stone; the mechanism of interaction of the bitumen binder and the mineral part at the phase boundary. [7-9] The improvement of the physico-mechanical properties of asphalt concrete pavement can possibly be achieved through the use of materials that have a uniform and dense structure and are resistant to destructive loads of various nature. As shown by a number of studies conducted by Russian and foreign scientists, the presence on the surface of mineral particles of a well-developed rough surface (higher specific surface) contributes to the formation of strong bonds with an organic binder [10]. The shape of the mineral particles has a significant effect on the characteristics of the skeleton of asphalt concrete, lower angularity leads to weaker characteristics of the contact of the skeleton. [11] The technological properties of the asphalt mix depend on the contact action of the mineral aggregate and the organic binder, which has a significant effect on the compaction of the asphalt mix. [12]

A common technique for studying the structure and shape of particles of mineral aggregate is microtopography of the surface. Digital imaging is used to study microscopic changes on the surface of particles. Using a scanning electron microscope, it is possible to determine the penetration depth of bitumen into the body of a mineral particle. [thirteen]

The material presented above, collected from various sources, confirms that the shape and surface structure of mineral particles affect the physical and mechanical properties of asphalt concrete. Physical and chemical properties of the surface of mineral particles determine the adhesion forces of bitumen and mineral aggregate. However, currently there are no scientifically confirmed data on the degree of influence of the specific surface of mineral particles on the physical and mechanical properties of asphalt concrete. To establish the degree of influence of the specific surface of a fine mineral aggregate on the physico-mechanical properties of asphalt concrete, we conducted an experiment that made it possible to establish, as a first approximation, the above dependence.
3. Materials used in the study
Quartz sand, waste foundry sand (WFS), and natural sand with the same fineness modulus (Mk = 1.65) were used as materials with different specific surfaces. The same size modulus provided us with a uniform grain composition of mineral aggregates. The difference was in the specific surface of the materials, which was determined by the difference in the structure of the surface layer of particles. The specific surface of quartz sand is 0.29 m²/g, natural sand is 0.45 m²/g, WFS 0.79 m²/g. A more detailed study of the physico-mechanical properties of the samples was presented earlier. [14-21]

Crushed stone (fraction 10-20) was used as a large aggregate, from a quarry located in the Perm Territory, which in its physical and mechanical properties met the requirements of GOST 9128-2013 and GOST 8267-93. As an organic binder, bitumen grade BND 60/90 produced by PJSC Lukoil Oil Company, which meets the requirements of GOST 22245-90 “Road bitumen, was used. Technical conditions”.

4. Experiments
At the first stage of research, the shape and structure of the surface of the particles (natural sand, quartz sand, WFS) were determined. The studies were performed on a HITACHI S-3400N scanning electron microscope. The shape and surface of the particles are shown in figures 1-3.

![Figure 1](image1.png)
**Figure 1.** The shape and surface of the particles of natural sand: a - with an increase of 10 times; b - with an increase of 100 times.

![Figure 2](image2.png)
**Figure 2.** The shape and surface of the WFS particles: a — 10-fold increase; b - an increase of 100 times.
Figure 3. The shape and surface of the particles of quartz sand: a - with an increase of 10 times; b - with 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 WFS with the same particle size modulus of the starting materials. On a part of the surface of the OFS particles there is a porous layer formed during the technological operations of steel casting. WFS 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 aggregate (quartz sand). Using OFS and quartz sand in the compositions of the studied samples of asphalt concrete we obtained samples with guaranteed the same particle size distribution and particle shape.

At the second stage of the research, the indicators of physical and mechanical characteristics of 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 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 | Crushed stone, % | Screening crushing, % | Mineral powder, % | Bitumen, % | Natural sand, % | Quartz sand, % | WFS, % |
|-----------|------------------|----------------------|------------------|------------|----------------|---------------|--------|
| 1         | 46               | 39                   | 3                | 5.0        | 12             |               |        |
| 2         | 46               | 39                   | 3                | 5.0        | 12             |               |        |
| 3         | 46               | 39                   | 3                | 5.0        | 12             |               |        |

The studies showed that a number of physical and mechanical indicators unambiguously, although to varying degrees, showed the influence of the specific surface on their value. In particular, the specific gravity of samples, tensile strengths 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 in figures 4 and 5.
Figure 4. Indicators of ultimate compressive strength: a - at 50 °C; b - 20 °C, (MPa).

Figure 5. Comparative results of water resistance (a) and average density (b).

It was found that an increase in the specific area of fine aggregate by 2.7 times leads to an increase in the compressive strength at 50 °C and 20 °C by 1.6 and 1.98 times, respectively. The indicators of water resistance and average density are less dependent on the specific surface and showed an increase of 12% and 1%, respectively.

Other physical and mechanical indicators of asphalt concrete samples did not reveal a clear dependence on the specific surface area, which indicates the low significance of its formation of these indicators. These indicators included: tensile strength at 0 °C; crack resistance index; shear stability index and water saturation coefficient. The results of comparative tests are presented in figures 6 and 7.

Figure 6. Indicators of compressive strength at 0 °C (a) and fracture toughness index (b).
The obtained test data for asphalt concrete samples with different specific surfaces of fine aggregate, with the same fineness modulus, confirm the theory put forward by the authors of the interaction of an organic binder with a surface of particles of mineral aggregate. Mineral materials with a developed particle surface can be effectively used as modifiers of asphalt concrete mixtures with the achievement of specified parameters of physical and mechanical characteristics.

5. Conclusion
A change in the specific surface area of mineral particles, with the same particle size modulus, can proportionally change the compressive strength for asphalt concrete.

The use of mineral materials with a high specific particle area in the composition of the asphalt mix allows one to obtain asphalt concrete, which in its physical and mechanical properties satisfies increasing external loads.

It is possible to consider the specific surface area of stone materials used as a fine aggregate in organic-mineral mixtures as a modifier element for regulating the properties of the resulting asphalt concrete.

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