Organic composite binder improving the physical and mechanical properties of low-strength stone materials

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Abstract. Based on the results of research and practical tests, the authors have developed a composition and proposed a technology for preparing an organic composite binder capable of deep penetration into pores of low-strength stone material with formation of a hydrophobic well-retained layer on its surface, which provides improvement of the main strength characteristics of the stone. Results of experimental studies are presented, optimal concentration of OCB and minimum processing time are determined. Practical recommendations are given for using the obtained strengthened material, which can act as a full-fledged independent working layer of road structure, as well as a component of asphalt concrete and cement concrete mixtures.

1. Introduction

Low-strength stone materials, according to the classification adopted in road construction, include easily compactible crushed stone from carbonate (limestone) and sandstone rocks of the 4 - 5th strength class, which is characterized by non-uniform structure, porosity, high water saturation and respectively low frost resistance. One of the main problems of using such a material is its failure to provide the required physical-mechanical and operational properties of road structures in an undetected form. A logical solution to this problem can be the development of technology of improvement of strength characteristics of low-strength crushed stone by its bulk penetration, followed by hydrophobization of grain surface composed of organic composite binder [1-3].

2. Relevance

Analysis of carried out studies [4-6] shows that one of the most effective directions of increasing the quality characteristics of low-strength stone materials is their preliminary bulk hydrophobization, which allows to significantly increase wear strength, and as a result also increase resistance against destruction during operation.

Bulk hydrophobization of porous material is carried out by preliminary penetration with bitumen with surfactants, oils, sodium silicate solution, molten liquid sulphur, and various organic and inorganic compositions [7-10]. Anionic substances are also used for the treatment of crushed stone, the role of which is to soften the wetting by bitumen of the outer and inner surfaces of the grains of the material, as well as to form chemo absorption bonds on the separation line phase. The efficiency of hydrophobization is increased by the presence of a bitumen film on the surface of mineral grains, which serves as a barrier that protects the crushed stone from moisture ingress during operation.
shown by practical studies [11-14], the wear of penetrated crushed limestone in the abrasion machine is reduced by 2-2.5 times compared to the raw material.

3. Body of work

Proposed method of increasing strength characteristics of low-strength crushed limestone is based on hydrophobization of material by penetration with aqueous solution based on composite binder. Penetration of crushed stone is carried out under natural conditions, at which OCB penetrates into pores of crushed limestone, where in process of natural (or forced) drying of penetrated material hydrophobic, well-retained layer is adsorbed, providing improvement of basic strength characteristics (strength, abrasion, water absorption, frost resistance). A series of experiments made it possible to determine the optimum concentration of OCB in water, the solution temperature and the minimum volume penetration time in order to obtain the maximum strength of the crushed stone to be treated.

Crushed limestone of fractions 40-70, 20-40 and 10-20 mm with fractionability grade М400, crushing strength and wear resistance grade LA 50, water-dispersion 4.2% and frost resistance grade F50 was used as an initial material. Penetration of crushed stone in aqueous solution of OCB with ratio of 1/12 (OCB/WATER) was carried out at temperature of 50-60° C with maintenance of material in vacuum unit with residual pressure of 2000 Pa. After 60 minutes the pressure was brought to atmospheric pressure and the samples were kept for 30 minutes. Drying of the samples to a constant weight was carried out at 105 ± 5 °C.

Analysis of the results of the experiments showed that the preheated OCB solution helps to increase the opening of pores and microcracks of crushed stone, and the vacuum compaction process leads to an increase in the depth of penetration. Depth of penetration was estimated by means of a metalgraphic microscope "Olympus BX-61" for filling bricks of the maximum size of the penetration fraction (Figure 1) with fixing of microstructures of the OCB components and weak-strong stone material by means of the digital camera microscope DP12 with magnification ×(50-500).

![Figure 1. Optical pictures of penetration depth of crushed stone from a metalgraphic microscope "Olympus BX-61": 1) Crushed stone fineness of 10 mm; 2) Crushed stone fineness of 40 mm; 3) Crushed stone fineness of 70 mm.](image-url)
Processing of digital photographs and measurement of various parameters of the structure of the tested samples were carried out on a computer using a software complex AnalySIS® by Soft Imaging System GmbH. Measurement of the porosity of the material was carried out using digital photographs with magnification ×100, by coloring pores and determining their percentage over the entire area of the photograph. The accuracy of measurements was ensured by the high capabilities of the modern equipment and software used for it.

By the nature of penetration of OCB into crushed stone samples, coarse-grained sections of rock with impurity of pulverized substance are more subjected to treatment, at the same time zones of developed porosity and weakened sections of rock are involved. Uniform penetration of crushed stone samples is achieved throughout the whole volume [15-17]. The hydrophobizing properties of the treated low strength material are shown in the formation of a dense and uniform structure of the generated OCB on the surface of the crushed stone grains. The number and size of micropores is reduced resulting in a contact having a reverse angle at which surface tension forces push water out of the pores. This effect is shown as a result of various physical processes taking place in the hardening system due to chemical processes at the phase interface "crushed limestone - pore structure filled with OCB" [18-20].

For three-dimensional visualization of crushed limestone grains treated with an aqueous solution of OCB, a universal two-beam Versa 3D system was used to obtain clear, electronic images of the samples under study (Figure 2 and Figure 3).

![Figure 2. Microscopic three-dimensional image of control samples of crushed limestone grains: 1) Untreated crushed stone; 2) Crushed stone with size of 10 mm.](image-url)
During the analysis of the three-dimensional image, it was found that the grain structure of the penetrated crushed stone differs from the control raw sample (M400) by the presence of an additional number of neoplasms in cracks and pores in the form of dense clusters of cemented rock debris, 0.5 to 10 mcm long, 0.3 to 1.0 mcm wide, with crystallized pore space.

Measurements of microhardness of crushed stone grains were carried out on a microhardness tester by a recover imprint method, which consists in applying an imprint to the test surface after applying to the diamond tip a static load of 0.5 N. The value of microhardness was determined by dividing the normal load applied to the diamond tip by the conventional area of the side surface of the imprint. This study of the microhardness of the non-OCB treated crushed stone samples showed an average hardness of 0.5 GPa. After the hydrophobization process the microhardness of 40-70 mm crushed stone sample was 0.8 GPa, for 20-40 mm and 10-20 mm it was 1.1 GPa, which indicates twofold increase in hardness in comparison with the original untreated sample.

Table 1 shows the physical and mechanical properties of the initial and penetrated crushed stone samples of the considered fractions.

Analysis of the obtained experimental data showed that the crushed limestone with OCB penetration, fractions of 10-20 mm increased its strength by 4 times and from the brand M400
transferred to the brand M1200 (weight loss during the test was - 10.95%). For 20-40 mm fraction - 11.82% (M1000); fractions 40-70 mm - 12.25% (M1000), water absorption decreases from 4.2% to 0.78%, the value of crushed stone grade in resistance to crushing and wear from LA50 to LA15 and frost resistance increase.

Table 1. Physical and mechanical properties of the initial and penetrated crushed stone samples.

| №   | Indicators                              | Initial  | OCB penetrated |
|-----|-----------------------------------------|----------|----------------|
|     | Size of fraction, mm                    | 40-70 | 20-40 | 10-20 | 40-70 | 20-40 | 10-20 |
| 1   | Crushed stone grade by fractionability  | 400    | 400   | 400   | 1000  | 1000  | 1200  |
| 2   | Crushed stone grade by resistance to    |        |       |       |       |       |       |
|     | crushing and wear                       | LA50   | LA50  | LA50  | LA20  | LA20  | LA15  |
| 3   | Grade of crushed stone by frost         | F50    | F50   | F50   | F150  | F150  | F200  |
|     | resistance                              |        |       |       |       |       |       |
| 4   | Water absorption of crushed stone, %    | 4,2    | 3,8   | 3,7   | 1,52  | 1,3   | 0,78  |

Low-strength crushed limestone strengthened with organic composite binder can act as independent material of working layer of road structure, as well as component of asphalt concrete and cement concrete mixtures. This will expand the raw materials base of regions that do not have sufficient stocks of strong stone materials, reduce the cost of their delivery and allow its use for the construction of roads with low traffic intensity, thus ensuring low cost of construction.

4. Conclusions

1. Proposed method of treatment of low-strength crushed limestone based on hydrophobization of material by penetration with aqueous solution of organic composite binder provides improvement of basic strength characteristics.
2. When the crushed stone surface is treated with OCB solution with concentration of 1/12, the grade of strength of crushed stone increases from M400 to M1000 (M1200), water emission decreases by 70%, grade of crushed stone increases in frost resistance and resistance to crushing and wear.
3. Reinforced low-grade and low-strength stone material can act as an independent material of the working layer of the road structure, as well as a component of asphalt concrete and cement concrete mixtures.

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