Fine-grained concrete modified with a multifunctional additive

Eugene Pyataev, Vyacheslav Semenov, Elen Bilonda Tregubova and Denis Kirushok

Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, Russia

E-mail: pyatay92@mail.ru

Abstract. The article presents the results of comparative tests of samples of fine-grained vibropressed concrete for paving blocks with modifiers for volumetric hydrophobization based on a dispersion of calcium stearate, an emulsion of polysiloxane and an additive based on a mixture of a dispersion of calcium stearate and an emulsion of polysiloxane. To increase the operational reliability and durability of the vibropressed paving slab an important role is played by properties such as water absorption, frost resistance and corrosion resistance. The aim of the work is to research of the effectiveness of complex modifying additives to increase the frost resistance and corrosion resistance of fine-grained concrete for paving slabs. The researches were carried out according to standard methods in accordance with current regulatory documents. It was revealed that the additive based on a mixture of a dispersion of calcium stearate and polysiloxane had the greatest hydrophobic effect. Concrete products based on these modifiers have shown significant improvement in properties such as water absorption, frost resistance and corrosion resistance compared to an unadulterated sample and samples based on calcium stearate.

1. Introduction

Vibropressed products made of hard concrete (paving slabs) laid in the middle zone and the north of Russia are subject to constant aggressive environmental influences, including anti-icing reagents. Therefore, to increase the operational reliability and durability of the vibropressed paving slabs, frost resistance and salt resistance are important. The main reason for the destruction of concrete in such conditions is the pressure on the walls of the pores and the mouth of the microcracks created by water during freezing. Cyclical freezing and thawing leads to a gradual loss of strength of the concrete structure and its destruction [1...4].

High hydrophilicity of the surface of vibropressed concrete products leads to increased water absorption. The appearance of efflorescence on the surface of products is also one of the problems for paving concrete. This is caused by moisture passing through the capillaries and carrying calcium hydroxide formed as a result of cement hydration to the surface. The carbonization of calcium hydroxide on the surface leads to the efflorescence of insoluble calcium carbonate, which negatively affects the decorativeness of products.

Hydrophobization of the inner surface of pores and capillaries of cement stone in concrete achieved by the chemisorption interaction of organic compounds with hydrated formations of cement reduces the probability of formation and growth of salt crystals which combined with the effect of...
plasticization and reduction of the water demand of the concrete mixture, also increases the resistance of concrete and its durability [4…6].

The following requirements are imposed on vibropressed paving slabs in accordance with GOST 17608-2017:

- Strength class – at least B30;
- Class of frost resistance – at least F2,200;
- Water absorption – no more than 6%.

Currently there are two methods for the production of vibropressed paving slabs - single-layer pressing and two-layer pressing. In the single-layer method the main components of the concrete mixture are cement and sand, in the two-layer method the main layer is cement, sand and gravel, the front layer is cement and sand. The main layer of concrete is responsible for the strength and durability of the entire structure, and the front layer is responsible for the decorativeness and abrasion resistance [7, 8].

The aim of the work is to research of the effectiveness of complex modifying additives to increase the frost resistance and corrosion resistance of fine-grained concrete for paving slabs.

The combined use of organic modifiers of various functionalities for concrete will significantly increase the index of frost resistance due to the formation of a dense structure of cement stone and the formation of an additional volume of small conditionally closed pores through the combined use of organosilicon compounds and surface-active agent [9…12].

The article presents the results of comparative tests of samples of fine-grained vibropressed concrete with modifiers for volumetric hydrophobization based on a dispersion of calcium stearate, an emulsion of polysiloxane and an additive based on a mixture of a dispersion of calcium stearate and an emulsion of polysiloxane.

2. Material and methods
In this work, comparative tests of additives based on organosilicon compounds (polysiloxane emulsions) and calcium stearate dispersion on the properties of fine-grained concrete were carried out. Obtaining fine-grained concrete with enhanced operational properties is possible by modifying the structure of cement stone. According to the results of physical and mechanical tests, the concrete composition of the base layer for vibropressed concrete paving slabs was selected, presented in table 1. For the tests for frost resistance, water absorption and corrosion resistance, samples 10 × 10 × 10 cm in size were made. Hardness of concrete was 50 seconds. A disturbing vibration force of 350...400 N/kg was chosen, and the vibration frequency for full-body products was 47 Hz (2800 rpm).

| Concrete layer | Material, kg |
|----------------|--------------|
|                | Cement       | Sand | Aggregate 3-10 mm | Water | W/C |
| main           | 340          | 920  | 1038               | 129   | 0,38|

Used materials:
- Portland cement PC 500 D0 with a specific surface of 3465 cm²/g, normal cement paste consistency of 26.8%, setting time: beginning - 166 min, end - 220 min, average activity of cement after 3 days - 44.9 MPa, at 28 days - 57.9 MPa;
- Sand with a true density of 2570 kg/m³, bulk density 1550 kg/m³, particle size module Mkr - 2.39;
Aggregate of a granite with a fraction of 3-10 mm with a true density of 2610 kg/m³, bulk density 1400 kg/m³, the content of flaky and vane-type grains 12.1%, the content of dusty and clay particles 0.3%; crushability class 1400; frost resistance F300;

Dispersion of calcium stearate (Ca(C₁₇H₃₅COO)₂) with dosage 1.3%.
Dosage of polysiloxane emulsion 0.05%.
Additive consisting of a mixture of polysiloxane emulsion (0.03%) and a calcium stearate dispersion (0.6%).

Frost resistance was tested by the 3rd accelerated method in accordance with GOST 10060-2012, which provides for the saturation of concrete samples in a 5% solution of sodium chloride and next periodic freezing at minus (50 ± 5) °C and thawing in the same solution at plus (20 ± 5)°C. Concrete cubes with sizes 10 × 10 × 10 cm were used as samples. The required concrete grade for frost resistance F₂₀₀ corresponds to 20 test cycles according to the 3rd accelerated method.

Durability tests were performed using an accelerated salt erosion test. Concrete samples of 10 × 10 × 10 cm were kept in a 10% sodium sulfate solution for 12 hours and then were dried at a temperature of 80 °C in an oven for 12 hours. After 15 cycles weight loss was measured.

3. Results and discussion

We studied different samples of fine-grained vibropressed concrete with the following compositions and dosages of modifiers:

- Control (without adding a modifier);
- Samples with a dispersion of calcium stearate (1.3%);
- Samples with an emulsion of polysiloxane (0.05%);
- Samples with an additive based on both a dispersion of calcium stearate (0.6%) and polysiloxane emulsion (0.03%).

The incorporated proportion of additives was selected, analysing the value of the water absorption. The selected values are shown in Table 2 and Figure 1. The quantities used for the mixture added to the last sample group data (0.03% polysiloxane emulsion and 0.6% calcium stearate dispersion) were determined experimentally. Despite the decrease in the value of the water absorption with increasing dosages of modifiers, it was decided to settle for 0.03% + 0.6%. Since with higher dosages, the stamp began to get stick to the concrete’s body and also plasticization was increased, an undesirable property when molding products for paving slabs.

Table 2. The results of the selection of the proportion of polysiloxane and calcium stearate used based on water absorption

| Polysiloxane proportion, % | Calcium Stearate proportion, % | Water absorption of concrete by weight, % |
|---------------------------|-------------------------------|-----------------------------------------|
| 0,005                     | 0,1                           | 3,2                                     |
| 0,01                      | 0,2                           | 3                                       |
| 0,015                     | 0,3                           | 3                                       |
| 0,02                      | 0,4                           | 2,1                                     |
| 0,025                     | 0,5                           | 1,5                                     |
| 0,03                      | 0,6                           | 1,1                                     |
| 0,035                     | 0,7                           | 0,8                                     |
| 0,04                      | 0,8                           | 0,7                                     |
Figure 1. Experimental selection of the consumption rate of a mixture of polysiloxane + calcium stearate

The water absorption test was carried out on 10 × 10 × 10 cm cubic samples. The results obtained after 24 hours of water saturation are shown in Figure 2. It appears as obvious, that the water absorption of the tested samples containing the additive based on the dispersion of calcium stearate (0.6%) and polysiloxane emulsion (0.03 %), drastically decreases in comparison with the control sample and the sample with the dispersion of calcium stearate. However, the values for this sample and the one containing a 0.05% polysiloxane emulsion differ only slightly.

Figure 2. Water absorption of the concrete.

We also tested the frost resistance on a different group of samples:
- Control (without adding a modifier);
- Samples using a modifier based on calcium stearate (7% dispersion of calcium stearate, 93% water), added in a proportion of 1.3% of the mass of cement.
Samples with polysiloxane, added in a proportion of 0.05% of the mass of cement
Sampling with an additive based on a mixture of a polysiloxane emulsion (0.03%) and a calcium stearate dispersion (0.6%).

The results of the frost resistance tests according to the 3rd accelerated method after 20 cycles of freezing and thawing in saturated saline solution, which corresponds to the frost resistance grade F2200 are shown in Table 3 and Figure 3.

Table 3. The results of tests for frost resistance after 20 cycles in a 5% solution of sodium chloride (grade F2200)

| Modifier (% by mass of cement) | Compressive strength, MPa | Losses after test, % strength | mass |
|-------------------------------|---------------------------|-------------------------------|------|
| Control                       | 2.7                       | 93                            | 9    |
| Stearate Ca (1.3)             | 28.0                      | 27.8                          | 4    |
| Polysiloxane (0.05)           | 31.6                      | 8                             | 3    |
| Polysiloxane (0.03) + Stearate (0.6) | 36.9                    | 2.9                           | 3    |

![Figure 3. Test results for frost resistance after 20 cycles (grade F2200)](image)

Focusing on the results obtained, we can conclude that the samples with an additive based on a dispersion of calcium stearate do not present a hydrophobic effect high enough, in comparison with polysiloxane, to be sufficient.

Regarding the second experiment, concrete samples based on a combination of a polysiloxane emulsion and a calcium stearate dispersion showed the best frost resistance results.

Lastly, samples were also tested by being cyclically soaked in a 10% sodium sulfate solution and dried. The data obtained, is shown in Table 4 and Figure 4. We can observe the high corrosion resistance of concrete modified with polysiloxanes compared to the control samples and samples containing an additive based on a calcium stearate dispersion. Samples with a 0.05% polysiloxane...
content and samples with a modifier based on a mixture of polysiloxane (0.03%) and a dispersion of calcium stearate (0.6%) showed very similar results.

Table 4. Test results for corrosion resistance after 15 cycles in a 10% sodium sulfate solution

| Modifier (% by mass of cement) | Losses, % |
|-------------------------------|-----------|
| Control                       | 13        |
| Stearate Ca (1.3)             | 8         |
| Polysiloxane (0.05)           | 1         |
| Polysiloxane (0.03) + Stearate (0.6) | 1 |

4. Conclusions

Studies have shown that samples modified by the additive based on a dispersion of calcium stearate (0.6%) and polysiloxane (0.03%) had the greatest hydrophobic effect. Concrete containing these modifiers have shown significant improvement in properties such as water absorption, frost resistance and corrosion resistance compared to samples with calcium stearate. However, samples with the addition of polysiloxane emulsion (0.05%) also have showed very similar results. It can be concluded that the presence of organosilicon polysiloxane significantly affects the volumetric hydrophobization and increase the operational properties of vibropressed fine-grained concrete.

The formation of gases, in particular hydrogen, as a result of the interaction of hydrogen-containing oligomers with Ca(OH)$_2$, forms closed porosity in the concrete body. With proper management of this gasification process, it is possible to influence the creation of a durable concrete structure. Thus, the modification of concrete with organosilicon compounds containing active functional groups will significantly improve the complex of properties of concrete and, first of all, their frost resistance, which is especially important when operating in harsh climatic conditions of the north or in arid regions where there is a risk of corrosion concrete under conditions of capillary suction effect and evaporation of salt solutions.

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