Development of road soil cement compositions modified with complex additive based on polycarboxylic ether

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Abstract. The paper is focused on the research results of the main physical and technical properties of the cement-stabilized polymineral clay modified with a complex hydrophobic plasticizer based on polycarboxylate and octyltriethoxysilane ethers. A graphical result interpretation of the mathematic model which shows the influence of the complex hydrophobic plasticizer components on the cement-stabilized polymineral clay, containing more than 85% of relict minerals, has been designed. The research significance for the building sector lies in the fact that applying a complex hydrophobic plasticizer provides increasing the compressive strength of the cement-stabilized polymineral clay up to 102%, the tensile bending strength – up to 88%, the freeze-thaw resistance – up to 114%.

1. Introduction

The development history of using binding agents to enhance the service properties of soils for road building can be traced back to the distant past. The stabilized soil roads existed in Ancient Mesopotamia, Egypt and Rome [1].

Clay rocks are one of the most widespread soils. They take 270 million km³ out of the total volume of sedimentary rocks amounting 340 million km³ (5 % lithosphere). They include clays, clay loams, loess, argillite and others. [2].

According to D.T. Bergado, L.R. Anderson, N. Miura, A.S. Balasubramaniam [3], there are 2 basic chemical reactions which regulate physical and mechanical properties of soils stabilized with cement (soil cement): a primary hydration reaction between cement and water, a secondary pozzolanic reaction between Portlandite, formed as a result of Portland cement hydration, and clay minerals. A hydration reaction causes the formation of primary hydration products of Portland cement that explains comparatively high strength and freeze-thaw resistance of soil cement. A secondary pozzolanic reaction occurs when the concentration of Ca(OH)₂ reaches the certain limit in pore water [3, 4]. It is possible that a pozzolanic reaction occurs between silicon and aluminium oxides, which are present in the clay, and calcium ions in the Portland cement forming hydrated calcium aluminates, hydrated calcium silicates and hydrated calcium silicoaluminates [5].

D.T. Bergado, L.R. Anderson, N. Miura, A.S. Balasubramaniam [3] suggested that the dependence of ultimate compressive strength (Rₘ) on Portland cement content can be divided into 3 zones: an
inactive zone, an active zone, an inert or quasi-inert zone, as it is presented in Figure 1. The given behaviour conforms to the results obtained by other scientists [6-8]. However, K.Q. Lin and I.H. Wong [9] specified the parabolic relation between the ultimate compressive strength of soil cement and Portland cement content (Figure 2).

The linear dependence of the strength variation of the stabilized soil is shown in scientific studies of American Concrete Institute [10].

![Figure 1. The dependence of the ultimate compressive strength of the stabilized soils on Portland cement content according to D.T. Bergado, L.R. Anderson, N. Miura, A.S. Balasubramaniam (1) and K.Q. Lin and I.H. Wong (2)](image)

As it was stated earlier, to enhance the strength of soil cement it is reasonable to apply polycarboxylate superplasticizers [11], and to improve freeze-thaw resistance it is reasonable to apply organosilicon water-repellent octyltriethoxysilane [12]. However, a possibility of combined application of these additives when modifying soil cements of different mineral compositions has not been explored. In this connection, the aim of this paper is to obtain an optimal composition of a hydrophobic plasticizer based on polycarboxylate and octyltriethoxysilane ethers and to study its influence on physical and mechanical properties of cement-stabilized polyminal clay.

2. Materials and methods

To make the soil cement samples and conduct the research, the authors used the soil picked at the borrow pit of Sakharovskoye deposit of Alekseevsky District of the Republic of Tatarstan. The reserves of the given soil are 2.102 million m$^3$ out of 180.1 million m$^3$. By its mineral content the soil refers to polymineral clay, in accordance with the State Standard 9169-75, as well as to light silt clay loam in accordance with the State Standard 25100-2011. The content of relict minerals is more than 85 % (52.49 % quartz).

To stabilize the clay soil, the authors used Portland cement CEM I 42,5H by ZAO «Ulyanovskcement». Portland cement was placed into clay soils by adding 6 %, 10 % and 14 %.

As a soil cement modifier, the authors used the polycarboxylate superplasticizer (PSP) PantarbitPC 160 Plv and organosilicon water-repellent octyltriethoxysilane (OTES). PSP dosage amounted to 0.05-0.15 %, OTES dosage amounted to 0.015-0.045 %.

The ultimate compressive strength ($R_{cm}$) of soil cements was determined by using samples 10x10x10 cm in size, the ultimate tensile bending strength ($R_{ten}$) was determined using samples 10x10x40 cm in size in water saturated (for a period of 2 days) condition according to the State Standard 10180-90. The freeze-thaw resistance was studied according to the State Standard 10060.3-91 by using samples in the form of a cube with 10 cm on the edge after 28 days of standard curing. The freezing time took not less than 2,5 hours at temperature (18±2) °C below zero, the thawing time ...
took 2±0.5 hours in water at temperature (18±2) °С above zero. The coefficient of freeze-thaw resistance (К_{frz}) was determined as a ratio of the sample resistance after testing for repeated cycles of freezing and thawing to the sample resistance before the trial. The coefficient of freeze-thaw resistance was determined after 15 cycles of freezing and thawing that meets the requirement of the State Standard 23558-94 for pavement surfacing of intermediate type for regions with average monthly atmospheric temperature of the coldest month reaching 15 °C.

Taking into account the fact that the dependence of construction material properties on its composition is described by equations which are not higher than the second order, the rotatable design of the second order was chosen to conduct the experimental study. The given method is characterized by good features: orthogonality and compositionality. On the ground of the adopted design, it was possible to perform a full factorial experiment: 20 tests were conducted depending on three factors: 8 tests were carried out at the cube corner, 6 tests – at star points with axial distance 1.682, 6 tests – in the cube centre.

The following factors were determined as original independent variables: Portland cement content (X₁), polycarboxylate superplasticizer (X₂) and organosilicon water-repellent octyltriethoxysilane (X₃).

3. Results and discussion

As it can be seen in Figure 2, in the soil cement the increase of strength is observed with the increase of Portland cement consumption. However, the intensity of strengthening is various. The obtained results have the most similarity with the dependence shown by D.T. Bergado, L.R. Anderson, N. Miura, A.S. Balasubramaniam [3], where 3 activity zones of the binding agent in cement soils are represented, i.e. the zones of Portland cement content are influencing on the cement soil strength.

![Figure 2](image)

**Figure 2.** The dependence of the ultimate compressive strength of the stabilized polymineral clay on the Portland cement content with indicating the most active zone

The graph analysis (Figure 2) showed that in polymineral clay stabilized with Portland cement (CSPC), the curve piece with the consumption of the binding agent 2-6 % corresponds to the low-active zone, with 6-14 % – corresponds to the active zone, with more than 14 % – corresponds to the quasi-inert zone. Therefore, the content of Portland cement is accepted to be 6-14 % for further studies.
Figure 3 showed the influence of the polycarboxylate superplasticizers and organosilicon water-repellent octyltriethoxysilane on the change of the main physical and technical properties of cement-stabilized polymineral clay (CSPC) when the consumption of Portland cement is 6, 10 and 14 %.

![Graph showing the ultimate compressive strength and the freeze-thaw resistance coefficient of soil cements using optimal dosages of PSP and OTES additives with different cement consumption.](image)

**Figure 3.** The ultimate compressive strength and the freeze-thaw resistance coefficient of soil cements using optimal dosages of PSP and OTES additives with different cement consumption.

When putting a multicomponent mix ranging from 0.025 to 0.200 % depending on the polymineral clay mass and adding 6% of Portland cement into the cement-stabilized polymineral clay, the ultimate compressive strength increases up to 15-65 %, the ultimate tensile bending strength – up to 10-39 %, the freeze-thaw resistance coefficient after 15 cycles of freezing and thawing – up to 5-23 %. The optimal dosage of the multicomponent mix was chosen according to the criterion of achieving the maximum strength by the cement-stabilized polymineral clay which amounted to 0.1 % when consuming 6% of Portland cement.

When putting a multicomponent mix ranging from 0.025 to 0.200 % depending on the polymineral clay mass and adding 10% Portland cement into the cement-stabilized polymineral clay, the ultimate compressive strength increases up to 17-78 %, the ultimate tensile bending strength – up to 32-76 %, the freeze-thaw resistance coefficient after 15 cycles of freezing and thawing – up to 5-30 %. The optimal dosage of the multicomponent mix in the cement-stabilized polymineral clay amounts to 0.1 % when consuming 10% Portland cement.

When putting a multicomponent mix ranging from 0.025 to 0.200 % depending on the polymineral clay mass and adding 14% Portland cement into the cement-stabilized polymineral clay, the ultimate compressive strength increases up to 16-81 %, the ultimate tensile bending strength – up to 32-76 %, the freeze-thaw resistance coefficient after 15 cycles of freezing and thawing – up to 5-35 %. The optimal dosage of the multicomponent mix in the cement-stabilized polymineral clay amounts to 0.125 % when consuming 14% Portland cement.

When putting OTES (Figure 3) ranging from 0.015 to 0.045 % depending on the polymineral clay mass, the ultimate compressive strength increases when adding 6% Portland cement up to 19-32%, when adding 10% Portland cement – up to 11-26%, when adding 14% Portland cement – up to 9-20%. The ultimate tensile bending strength in the cement-stabilized polymineral clay increases when adding 6% Portland cement up to 12-19%, when adding 10% of Portland cement – up to 11-18%, when adding 14% Portland cement – up to 10-16%. After 15 cycles of freezing and thawing, the freeze-thaw resistance coefficient increases when adding 6% of Portland cement up to 20-59%, when adding 10% of Portland cement – up to 50-86%, when adding 14% of Portland cement – up to 35-107%. The
optimal dosage of OTES in the cement-stabilized polymineral clay amounts to 0.03 % when consuming 6, 10 and 14% Portland cement.

Analyzing the results obtained when applying a design matrix of the experiment allowed us to get a graphical result interpretation of the mathematic model (Figure 4) which shows the influence of the complex hydrophobic plasticizer components on the physical and technical properties of the clay soils stabilized with Portland cement.

The ultimate compressive strength of the cement-stabilized polymineral clay modified with the complex hydrophobic plasticizer in comparison with the check composition of the cement-stabilized polymineral clay increases when adding 6% Portland cement up to 85%, when adding 10% Portland cement – up to 72%, when adding 14% Portland cement – up to 102%. The ultimate tensile bending strength increases when adding 6% Portland cement up to 77%, when adding 10% Portland cement – up to 98%, when adding 14% Portland cement – up to 88%. Besides, the freeze-thaw resistance coefficient after 15 cycles of freezing and thawing increases 65 %, 113 % and 114 % respectively.

The obtained results allowed suggesting that the strength increase of the cement-stabilized clay soil happens due to the peptization of cement floculi when a great number of newgrowths appear because of the immobilized water release, the decrease of internal-friction coefficient, the increase of electrostatic repulsion of particles as a result of significant changes of their electrokinetic potential [13], as well as a result of adsorption and chemisorption of the components of the complex hydrophobic plasticizer on the surface of aluminum silicate layers of clay minerals. Adsorption probably leads to decreasing moisture content of the optimum mix with increasing the strength, and chemisorption – to forming organo-mineral bonds in much the same way as it was noticed by different authors in the publications [13-23]. The increase of freeze-thaw resistance of the stabilized soil is achieved due to integral waterproofing of pore and capillary walls with the organic silicone compound and due to denser and more homogeneous structure [12].

![Figure 4](image-url)

**Figure 4.** The influence of the composition of the complex hydrophobic plasticizer on the physical and technical properties of the cement-stabilized polymineral clay when adding cement amounting to 10% depending on the polymineral clay mass: a) $R_{cu}$; b) $R_{tem}$; c) $K_{frz}$

### 4. Conclusion

Thus, it has been stated that applying the complex hydrophobic plasticizer provides increasing in compressive strength of the cement-stabilized polymineral clay up to 102%, in tensile bending strength – up to 88%, in freeze-thaw resistance – up to 114%.

The authors have determined the dependence of the influence of the cement consumption, the composition and dosage of the complex hydrophobic plasticizer based on polycarboxylic and octyltriethoxysilane ethers on the physical and technical properties of the polymineral clay. They have optimized the composition of the cement-stabilized polymineral clay modified with the complex hydrophobic plasticizer taking into consideration its range of use in pavement surfacing.
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