Reducing the environmental burden during the reconstruction of highways by extending their life cycle

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Abstract. The article presents the results of studies on assessing the effectiveness of using stabilizing additives of complex action (Chimston) to increase the bearing capacity of structural layers of the base of road pavements of the Far North highways due to its use in strengthening various types of non-cohesive soils in combination with an inorganic binder. It was found that the application of Chimston is unconditionally required, as the additive in the system allows one to obtain a material that meets the regulatory requirements for frost resistance and to ensure the reliable operation of the road structure in the conditions of the Far North. The maximum efficiency in terms of physical and mechanical characteristics with Chimston in the system was demonstrated by compositions based on crushed sand stabilized with 7 % cement, and for crushed stone-sand mixes of types C-7 and C-6 with 9 % cement. Based on the analysis of the obtained results, it can be assumed that the stabilizing additive Chimston, adsorbing on the surface of particles of sandy and coarse-grained soil, interacts with the inorganic binder of the composite. It affects the mechanism of its hydraulic activity in the process of gaining brand strength, which was most confirmed in the study of strength characteristics of samples based on coarse-grained soils. Thus, with an increase in the amount of binder in the presence of the Chimston additive, a higher increase in the compressive strength of the samples is observed. An increase in the amount of binder when adding an additive to the composition of samples based on coarse-grained soils contributes to the maximum gain in compressive strength of samples containing 9% cement. The obtained results allow for the conclusion that the technology of using the polymer stabilizer Chimston in the construction of structural layers of the base of road clothes based on loose soils can provide the required transport and operational condition of road structures with a life cycle of 24 years. It will also significantly reduce the volume of industrial waste used as pavement, as well as reduce the consumption of unsustainable Portland cement.

1 Introduction

The road transportation infrastructure in the Far North has been actively developed over the past 10 years. The key area of development is to increase the life cycle of roads. For areas with severe environmental conditions, the traditional approach to solving the problem by increasing the thickness of the structural layers of pavement is not economically feasible and it does not allow ensuring the load-bearing and service characteristics of the road as a whole during the period between repairs. This is due to the fact that materials used for structural layers do not have the full range of necessary physical and mechanical characteristics for a reliable functioning of the structure over an extensive period.

The most affordable technological solution to the problem lies in the creation of a rigid pavement structure by providing a strong foundation of reinforced and stabilized soils and stone materials using innovative additives of complex action [1–7].

Structural base layers of pavement require the use of an inorganic binder, namely cement. At the same time, the cement for road construction is required to not only be highly active chemically, but also to provide chemical and corrosion resistance. Unfortunately, to date, cement manufacturers do not pay the necessary attention to this requirement, causing concrete products for road construction to lose their operational reliability rapidly [7–11]. In this regard, the fragility of the resulting pavement leads to the need for its untimely repair or replacement. This leads to an increase in industrial waste, as well as an increase in the consumption of non-environmentally friendly binder – Portland cement.

The purpose of this research was to evaluate the effectiveness of Chimston complex-acting stabilizing additive in increasing the bearing capacity of the structural base layers of roads in the Far North, through its use in stabilization of various types of non-cohesive soils in combination with an inorganic binder.

2 Materials and Methods

In the study, the following stone materials of quarry No. 4 (Yamal Peninsula near Bovanenkovskoye oil and gas

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condensate field) were used as coarse clastic and sandy soils for structural layers of the road base: crushed sand of 0–5 mm fraction according to GOST 32730-2014, and crushed stone-sand mixes of types C-7 and C-6 according to GOST 25607-2009. Crushed sand samples were studied according to the following regulatory documents: GOST 32727-2014, GOST 32725-2014, GOST 32726-2014; crushed stone-sand mixes (C-6 and C-7) according to GOST 8269.0-97, GOST 25607-2009. Cement TsEM I 42.5 according to GOST 31108-2016 was used as the inorganic binder. Requirements for the Chimston polymeric stabilizer are provided in TU 2493-001-97980347-2016.

The maximum density and optimum moisture content of the studied soils were determined according to GOST 22733-2016. The maximum density of crushed sand was 1.49 g/cm^3 at an optimum moisture content of 8.2%; crushed stone-sand mix C-7—1.37 g/cm^3 at an optimum moisture content of 5.7 %; and crushed stone-sand mix C-6–1.41 g/cm^3 at an optimum moisture content of 4.5 %. Requirements for materials for the structural layers of road pavement on the basis of the studied sand and clastic soils, as well as methods of their study, are provided in GOST 23558-94. Strength parameters of composite material samples were determined according to GOST 10180-2012, and frost resistance – according to GOST 10060-2012.

When conducting research of the effect of Chimston-1 on the physical and mechanical properties of coarse clastic and sandy soils, several series of samples were molded differing in the amount of inorganic binder (5, 7 and 9 %) and with or without the use of additive. The content of Chimston-1 was constant and amounted to 0.007% of the soil mass, which was introduced into the mixing water to achieve maximum density of the samples.

3 Results and Discussions

Evaluation of the effectiveness of Chimston in soils was aimed to establish the feasibility of its use in the structural base layers of the road "Extended-use winter road Obskaya – 193 km". The winter road will be part of the construction project for the “New Obskaya - Bovanenkovo railway line”. The road is intended, in particular, for traffic access to Bovanenkoskoye, the largest oil and gas condensate field on the Yamal Peninsula, the operation of which began in 2012.

The resulting physical and mechanical characteristics of different mixes of the studied composites are presented in the diagrams in Fig. 1–2.

Analysis of the data presented in the diagrams indicates that crushed sand stabilized with 5% of TsEM 42.5 cement by weight of the mineral part fails to meet the requirements of GOST 23558 in terms of bending strength (actual value is 0.65 MPa; standard requirements are not less than 0.8 MPa). In terms of frost resistance, samples based on sand in combination with cement fail to meet the design requirements (required grade is not lower than F50; actual grade with the addition of 5% of inorganic binder is F15, 7% and 9% of cement is F25).

The use of Chimston in the amount of 0.007 % of the weight of the mineral part in crushed sand stabilized with 5 % of TsEM 42.5 cement allows one to increase its compressive strength by 39 %; bending strength by 78 %, increase the frost resistance grade from F15 to F25 compared with the control sample without the modifier. At the same time, samples fail to meet the design frost resistance grade of F50.

The use of Chimston in the amount of 0.007 % of the weight of the mineral part in crushed sand stabilized with 7 % cement allows one to increase its compressive strength by 42.4 %; bending strength by 107% compared with the control sample without the modifier. The frost resistance grade increases from F25 to F50.

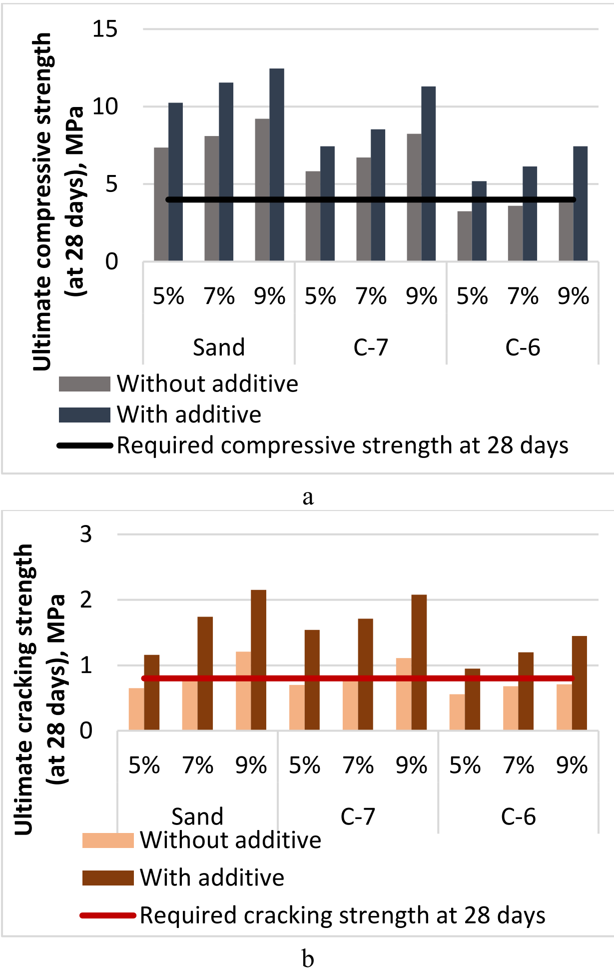

Fig. 1. Compressive strength (a) and cracking strength (b) of soil samples stabilized with different amounts of cement with and without Chimston

The use of Chimston in the amount of 0.007 % of the weight of the mineral part in crushed sand stabilized with 9 % cement allows one to increase its compressive strength by 35.1%; bending strength by 44% compared with the control sample without the modifier. The frost resistance grade increases from F25 to F50. In this way, Chimston allows one to obtain the compositions based on crushed sand stabilized with 7 and 9 % cement, which correspond to the requirements of GOST 23558 and the design requirements.

The analysis of results shown in Fig. 2 and 4 shows that C-7 crushed stone-sand mix stabilized with TsEM 42.5 cement in the amount of 5 and 7 % of the mineral mass fails to meet the requirements of GOST 23558 in terms of bending tensile strength. The actual value with the addition of cement 5 % is 0.70 MPa; 7 % is 0.77 MPa; standard requirement is not less than 0.8 MPa.

In terms of frost resistance, the studied compositions based on the crushed stone-sand mix SchPS-7 stabilized with cement in all quantities fail to meet the design requirements (the actual grade for samples with 5 and 7% of binder is F15, with 9 % of binder it is F25).

The use of Chimston in the amount of 0.007 % of the weight of the mineral part in the crushed stone-sand mix SchPS-7 stabilized with 5 % cement allows one to increase its compressive strength by 27.5 %; bending strength by 120 %, and to increase the frost resistance grade from F15 to F25 compared with the control sample without the modifier. At the same time, the frost resistance grade of the composition still fails to meet the design value and amounts to only F25.

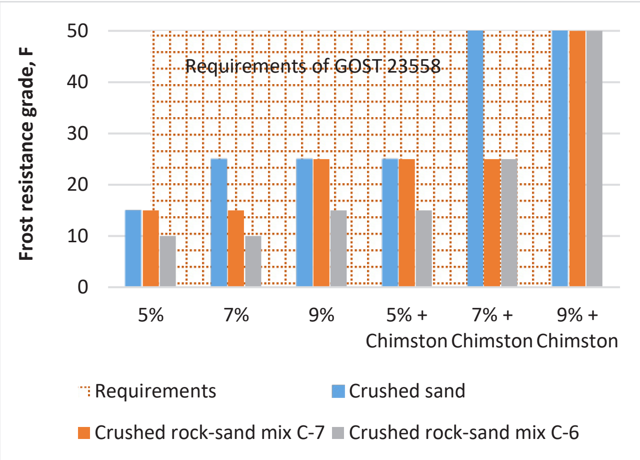

Fig. 2. Frost resistance of samples stabilized with cement with and without the use of Chimston

The use of Chimston in combination with 7 % cement allows one to increase the compressive strength by 31.2 %; bending strength by 122 % compared to the control sample without the modifier. The frost resistance grade increases from F15 to F25.

The use of Chimston in the amount of 0.007% of the weight of the mineral part in the crushed stone-sand mix of grade C-7 stabilized with 9 % cement allows one to increase its compressive strength by 37.2%; bending strength by 87.4 % compared with the control sample without the modifier. The frost resistance grade increases from F25 to F50. In terms of physical and mechanical characteristics and frost resistance, this composition meets the requirements of GOST 23558 and design requirements.

The analysis of the results presented in Fig. 3 and 4 shows that C-6 crushed stone-sand mixes stabilized with TsEM 42,5 cement in quantities of 5 %, 7% and 9% of the weight of the mineral part fail to meet GOST 23558 requirements by a number of indicators. The compressive strength as the actual value at 5% cement is 3.25 MPa; 7% cement is 3.61 MPa; 9 % cement – 3.81 MPa. The required value should be at least 4.0 MPa. The tensile strength during bending as the actual value when using 5% cement is 0.56 MPa, 7% – 0.68 MPa, 9 % - 0.71 MPa. The regulatory requirement is not less than 0.8 MPa). In terms of the frost resistance grade, the mix fails to meet the design requirements (the required grade is not lower than F50; actual grade is F10 with the addition of 5 and 7 % cement and F15 with 9% cement).

The use of Chimston in the amount of 0.007 % of the weight of the mineral part in the crushed stone-sand mix of grade C-6 stabilized with 5 % cement allows one to increase its compressive strength by 62 %; bending strength – by 69 %. And it increases the frost resistance grade from F10 to F15 compared to the control sample without the modifier.

The use of Chimston in the crushed stone-sand mix of C-6 grade stabilized with 7 % cement allows one to increase its compressive strength by 70.0 %; bending strength by 76% compared to the control sample without the modifier. The frost resistance grade increases from F10 to F25. Adding Chimston in the amount of 0.007 % to C-6 crushed stone-sand mixes stabilized with 9 % cement allows one to increase its compressive strength by 95 %; bending strength by 104.0% compared with the control sample without the modifier. The frost resistance grade increases from F15 to F50. Thus, according to the physical and mechanical characteristics and frost resistance, the composition using 9 % cement in combination with Chimston meets the requirements of GOST 23558 and design requirements.

Use of Chimston for stabilization of sandy and coarse clastic soils with inorganic cement-based binder for the construction of structural base layers of motor roads demonstrates high effectiveness. The following peculiarities can be noted regarding the strength gain dynamics for samples based on the studied loose soils with different fraction sizes, as shown in Fig. 3.

The maximum increase in strength characteristics of the samples consisting of the studied materials is observed in the stabilization of coarse clastic soils based on the C-6 crushed stone-sand mix with the fraction size from 0 to 20 mm. In particular, the increase in the compressive strength of the samples based on crushed sand, as well as C-7 crushed stone-sand mixes in the presence of Chimston at the age of 28 days, varies in the range of 28-39 %; and for samples based on C-6 crushed stone-sand mixes it is in the range of 60-95 %.

It is also important to note that the high rate of strength gain in the first 7 days is observed for samples based on C-7 crushed stone-sand mixes. The gained strength ranges from 60 % to 70 %. For samples of C-6 crushed stone-sand mixes, the increase in compressive strength on day 7 is less dynamic than that on day 28, ranging from 40 to 60 %, while for crushed sand it is from 32 to 50 %.

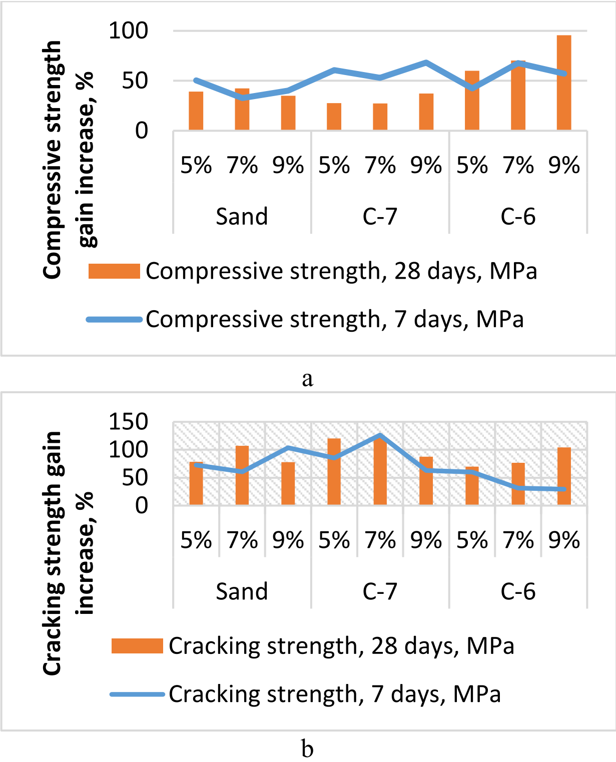

Fig. 3. Increase in the compressive strength (a) and cracking strength (b) of samples with the addition of Chimston polymeric stabilizer

Based on the analysis of the obtained results it can be assumed that Chimston, which is being adsorbed on the surface of the particles of sand and coarse clastic soil, interacts with the inorganic binder of the composite. It affects the mechanism of its hydraulic activity in the process of gaining strength, which was confirmed in the study of strength characteristics of samples based on the crushed stone-sand mix. In particular, with an increase in the amount of binder in the presence of Chimston a higher increase in the compressive strength of the samples is observed. Increasing the amount of binder when introducing the additive into the composition of samples based on crushed stone-sand mixes contributes to the maximum gain of compressive strength of samples containing 9 % cement.

Chemically active components of the additive affect the activity of cement, which contributes to the rapid increase in the compressive strength of samples based on sand with a minimum amount of cement (5 %) at the age of 28 days. However, as the amount of binder in the composition of the composite material based on crushed sand increases, the rate of compression strength gain of the samples changes insignificantly.

The introduction of Chimston leads to a significant increase in the ultimate cracking strength for all studied compositions compared with the ultimate compressive strength. High values of the ultimate cracking strength of modified samples characterize the stable resistance of the material to small plastic deformations typical of the base layers of road pavements, and contribute to an increase in the load-bearing capacity of the entire road structure.

The increase in cracking strength of samples at the age of 28 days prepared with the use of sand and the C-7 crushed stone-sand mix reaches its maximum at 7 % cement (being equal to 107 and 122 % respectively), while reaching 104 % for samples based on the C-6 crushed stone-sand mix stabilized with 9 % cement. The graph of change in the cracking strength (Fig. 3.7 (b)) demonstrates that the rate of cracking strength gain in samples during the first 7 days is minimal for porous mix of type C-6 among the studied compositions and varies in the range from 30 to 60%. However, by the age of 28 days, the rate of cracking strength gain in samples of this composition increases to 100 % (in the presence of 9 % cement). For samples of composite materials based on crushed sand and the C-7 crushed stone-sand mix, a significant increase in cracking strength is typical already in the first 7 days of strength gain. Perhaps, a denser packing of material particles contributes to the most intensive structure formation of the composite due to full interaction of the active components of Chimston and the inorganic binder in the first days of strength gain.

4 Conclusion

1. The use of the polymeric stabilizer "Chimston" is unconditionally required in the development of structural base layers of road pavement using coarse and sandy soils. Such presence of the additive in the system allows one to obtain material that meets the regulatory requirements for frost resistance and to ensure reliable operation of the structure in the conditions of the Far North.

2. The maximum efficiency in terms of physical and mechanical characteristics with Chimston added to the system was demonstrated by compositions based on crushed sand when using 7 % cement, and for crushed stone-sand mixes of types C-7 and C-6 it was in the amount of 9 %.

3. The use of this stabilizer will also significantly reduce the volume of industrial waste in the form of used pavement, as well as reduce the consumption of non-environmentally friendly Portland cement.

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