12th International Conference
ENVIRONMENTAL ENGINEERING
April 27–28, 2023, Vilnius, LITHUANIA

eISSN 2029-7092
eISBN 978-609-476-342-7
Article ID: enviro.2023.874
https://doi.org/10.3846/enviro.2023.874

THE EFFECT OF ION-EXCHANGE STABILIZER AND CEMENT AMOUNT ON IMPROVED ROAD SUBGRADE SOIL LABORATORY SPECIMENS COMPRESSIVE STRENGTH AND RESISTANCE TO FROST

Audrius VAITKUS, Deimantė KILAITĖ, Rafal MICKEVIČ, Ovidijus ŠERNAS*

Road Research Institute, Vilnius Gediminas Technical University, Vilnius, Lithuania

Received 16 January 2023; accepted 20 February 2023

Abstract. Due to high price of construction materials and earthworks, scientists are looking for cost-effective solutions, especially in roads that are sensitive to moisture fluctuations and frost. To improve the performance of weak soils, usually treatment with cement or lime is applied. However, in the most cases, treatment only with cement or lime only requires relatively high amount of these materials or do not ensure resistance to frost. Usually, to improve the performance of treated soils, various additives are applied. One of the most popular additives is ion-exchange stabilizers. However, the performance of additives depends on soil type and the composition of additive. The aim of this study is to evaluate the properties as compressive strength and resistance to frost of soil, treated with different additives. Research showed that the application of an ion-exchange stabilizer increases compressive strength of clay up to 12% and the compressive strength of sand up to 18%.

Keywords: compressive strength, ion-exchange, soil treatment, soil stabilization, resistance to frost.

JEL Classification: L7.

Introduction

The subgrade is the base structure of the pavement structure and, usually, the local soil is the main material of this layer. However, the subgrade of natural soil commonly cannot ensure sufficient bearing capacity due to moisture and frost fluctuations (Vaitkus et al., 2021). In Lithuania, national regulations proclaimed that the subgrade bearing capacity must be 45 MPa for roadways and 30 MPa for pathways with warrant that strength do not diminish (ĮT ŽS 17) (VĮ Lietuvos automobilių kelių direkcija, 2017). The bearing capacity of the subgrade significantly decreases during the spring thaw period. As a consequence, the deflection of the pavement structure becomes very high and road construction changes to deterioration. For that reason, several methods to achieve a higher quality subgrade layer are usually applied: weak soil replacement with a better quality soil or soil treatment. Moreover, soil stabilization is divided into different procedures: stabilisation, improvement, and qualified improvement. For these procedures to treat soil, research mostly apply soil treatment with cement or lime due the fact that these stabilizers improve soil performance such as strength, durability, and workability (Adeyanju & Okeke, 2019; Biswal et al., 2018; Celauro et al., 2012; Eisa et al., 2022; Ezreig et al., 2022; Firoozi et al., 2017; Jaffar et al., 2022; Jawad et al., 2014; Juodis, 2022; Karami et al., 2021; Nguyen & Phan, 2021; Pirouz & Arabani, 2022; Rahman et al., 2021).

However, in most cases, soil treatment only with cement or lime alone requires a relatively high amount of these materials. Furthermore, in some cases, the application of plain cement or lime does not guarantee the required resistance to frost. Therefore, to improve the performance of treated soils, various additives are applied. One of the most popular additives is ion-exchange stabilizers. Ion-exchange stabilizers cause soil to release weakly ionized water molecules from the soil matrix and replace the water with strongly ionized sulphate radicals. Ion-exchange stabilizers dissolve the mineral salts and natural cementitious properties of the soil. Mixing the soil disperses the dissolved material into the void spaces between the soil grains where it cures and crystallises. Commonly, the re-crystallized mineral salts and natural cements form an effective bond that results in improved strength, load-bearing capacity and durability (Gautam et al., 2020; He, 2019; He et al., 2018; Katz et al., 2001; Luo et al., 2020; Park & Park, 2018; Roshan et al., 2022; Tavakoli, 2016; Wang

* Corresponding author. E-mail: *ovidijus.sernas@vilniustech.lt*

et al., 2022; Zhang et al., 2019). However, it is important to note that the effects of additives depend on the type of the soil. Despite the fact that many studies have been conducted, there is still a lack of information on how ion-exchange stabilizers work in treated soil. Therefore, the aim of this study is to evaluate the properties of the soil, treated with cement only and a combination of cement and ion-exchange stabilizers.

1. Test materials and methods

1.1. Materials

Two types of soils were selected for this research: clay and sand. The particle distribution of clay and sand is given in Figure 1.

In this research, two additives were investigated.

Stabgrunt 1 – is a liquid whose color varies from colorless to yellow. It has a sharp, pungent odor. Boiling temperature is about 310 °C, density is 1.835 kg/l.

Stabgrunt 2 – is a liquid whose color varies from colorless to yellow. It has a sharp, pungent odor. Boiling temperature is about 147 °C, density – 1.300–1.385 kg/l.

1.2. Test methods

In this research compressive strength was determined by standard LST EN 13286-41:2022 "Unbound and hydraulically bound mixtures – Part 41: Test method for determining the compressive strength of hydraulically bound mixtures" (Lietuvos standartizacijos departamentas, 2022). Three different maintenance conditions were applied:

Specimens were stored in a humid environment for 6 days and 24 h before compression test- in water according to Lithuanian regulations "Lithuanian Methodological Instructions for the Improvements and Stabilization of Soils BN GPR 12, 2012" (Valstybės įmonė Lietuvos automobilių kelių direkcija, 2012). Compressive strength was determined after 7 days.

Specimens were stored in a humid environment for 14 days and in water for 14 days before the compression test. Compressive strength was determined after 28 days.

Specimens were stored in a humid environment for 13 days, then saturated with water for 24 h. After that, 14 cycles of freezing and thawing at −23 °C temperature were performed. 1 Cycle: 8 hours at −23 °C temperature air and 16 hours at ambient temperature water. After that, the compressive strength was determined. The resistance to frost was expressed as a ratio of the compressive strength after and before freezing and thawing cycles.

2. Experimental research

The aim of this study is to evaluate the properties of the soil, treated with only cement and a combination of cement and ion-exchange stabilizer. Due to the fact that the effect of ion-exchange stabilizer depends on the type of soil, to evaluate the influence of the ion-exchange stabilizer, clay and sand were treated with cement (3% and 5%) and two different types of additives (Stabgrunt 1 and Stabgrunt 2).

Two groups of specimens were made of different types of soil: clay and sand. Clay specimens: cement 3% with Stabgrunt 1 (0.15 L/m^3), plain cement 3%, cement 5% with Stabgrunt 1 (0.15 L/m^3) and plain cement 5%. The same amount of cement was used for the sand samples, the only one exception being Stabgrunt 2 (0.2 L/m^3) was used. Samples were prepared in this sequence – at

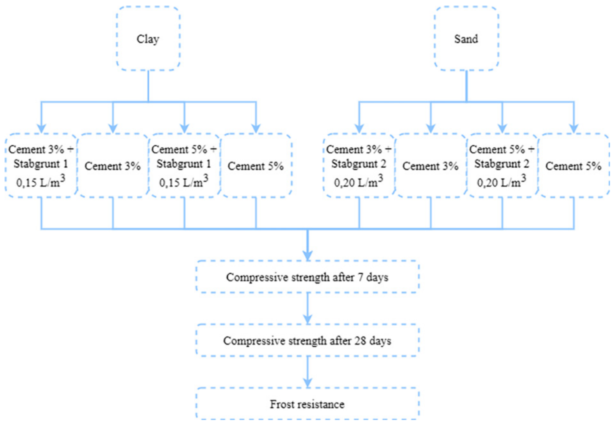

Figure 2. Flowchart of the Experiment

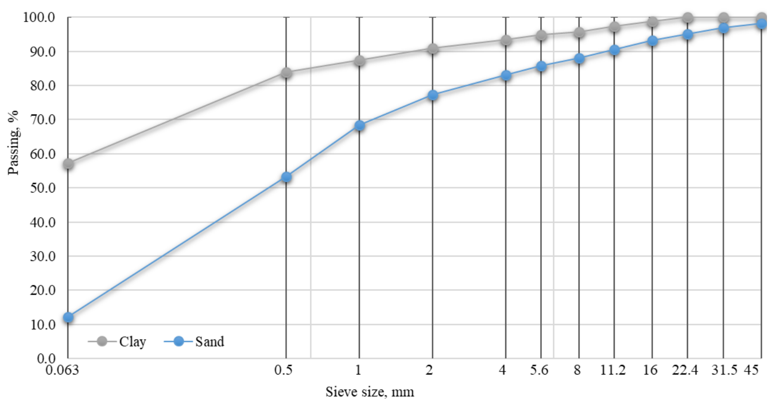

Figure 1. Particle size

first cement was incorporated to dry soil and homogenized, then the solution of water and additive was incorporated and mixed until full homogenization. For prepared samples, compressive strength was evaluated after 7 and 28 days after maintaining the samples under appropriate conditions, which are presented in test methods. Furthermore, the resistance to frost was evaluated. The research plan is given in Figure 2.

3. Results

The effect of additives on the compressive strength of the treated soil (Figure 3) after 7 and 28 days is shown in Figure 4. During a 7-day period, samples were stored in a humid environment for 6 days and 24 h before compression, in water. During the 28-day period, the samples were stored in a humid environment for 14 days and in water for 14 days.

Figure 3. Compressive Strength Test

As can be seen from Figure 4, treating clay with cement 3% and Stabgrunt 1 causes an increase of compressive strength up to 19% (from 0.47 MPa to 0.56 MPa) after 7 days, and up to 3% (from 0.64 MPa to 0.65 MPa) after 28 days compared to clay treated with cement only 3%. Using cement 5% and Stabgrunt 1 improves the compressive strength of clay by up to 11% (from 1.03 MPa to 1.15 MPa) after 7 days and up to 12% (from 1.46 MPa to 1.63 MPa) after 28 days compared to clay treated with cement 5% only. The application of Stabgrunt 1 and the increase in the amount of cement from 3% to 5% enhance compressive strength to 104% (from 0.56 MPa to 1.15 MPa) after 7 days and even to 150% (from 0.65 MPa to 1.63 MPa) after 28 days.

A similar tendency was obtained with a sample of sand. Treating sand with cement 3% and Stabgrunt 2 causes an increase of compressive strength up to 6% (from 1.18 MPa to 1.25 MPa) after 7 days and up to 18% (from 1.41 MPa to 1.66 MPa) after 28 days compared to sand treated with cement 3% only. Using cement 5% and Stabgrunt 2 benefits compressive strength of sand up to 9% (from 2.00 MPa to 2.18 MPa) after 7 days and up to 4% (from 2.79 MPa to 2.91 MPa) after 28 days compared to sand treated with cement 5% only. The use of Stabgrunt 2 and an increase in the amount of cement from 3% to 5% advantage compressive strength up to 75% (1.25 MPa to 2.18 MPa) after 7 days and up to 76% (from 1.66 MPa to 2.91 MPa) after 28 days.

Only one clay composition of Stabgrunt 1 with cement 5% with compressive strength 1.63 MPa after 28 days satisfies the requirement of compressive strength requirement (1.5 MPa) for the obtained value of the cement treated base layer. Treated sand with Stabgrunt 2 and cement satisfy this requirement for compressive strength regardless of the amount of cement 3% or 5%, values respectively are 1.66 MPa and 2.91 MPa.

The results shown in Figure 5 evaluate the effect of additives considering different maintenance conditions during the 28-day period. A group of specimens were stored in a humid environment for 14 days and in water for 14 days, another group of specimens were stored in a humid environment for 13 days, then saturated with water for 24 h and 14 cycles of freezing and thawing at

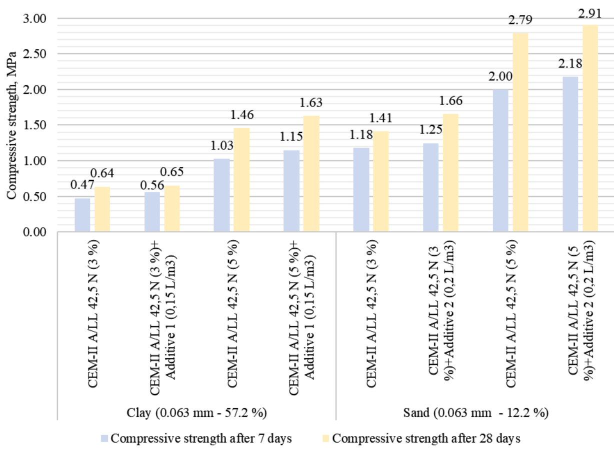

Figure 4. Compressive strength after 7 and 28 days

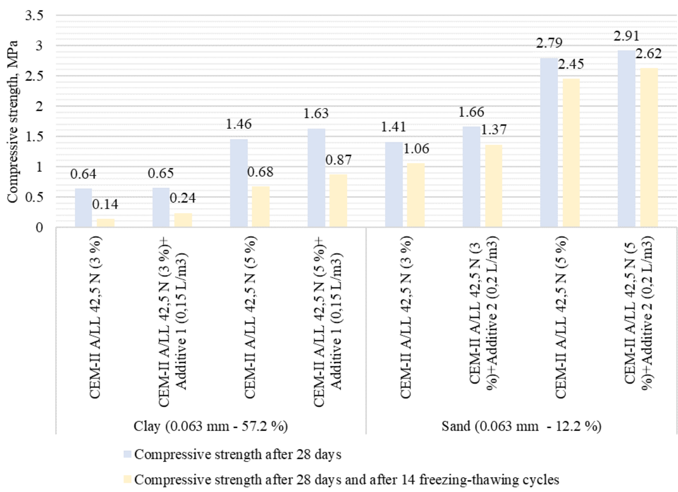

Figure 5. Compressive strength after 28 days, different maintenance conditions

–23 °C temperature were performed. Treating clay with cement 3% and Stabgrunt 1 cause an increase of compressive strength of up to 70% (from 0.14 MPa to 0.24 MPa) after 28 days and freeze-thaw cycles comparing to clay treated with cement 3% only. Using cement 5% and Stabgrunt 1 boost the compressive strength of clay by up to 29% (from 0.68 MPa to 0.87 MPa) after 28 days and freeze-thaw cycles comparing with clay treated with cement 5% only. Clay with the application of Stabgrunt 1 and an increased amount of cement from 3% to 5% advantage compressive strength even up to 268% (from 0.24 MPa to 0.87 MPa) after 28 days and freeze-thaw cycles. The effect of cement amount on freezing-thawing amount is represented in Figure 6. Matching tendency discovered with specimen of sand. Treating sand with cement 3% and Stabgrunt 2 causes an improvement of compressive strength of up to 29% (from 1.06 MPa to 1.37 MPa) after 28 days and freeze-thaw cycles comparing to sand treated with cement 3% only. Using cement 5% and Stabgrunt 2 benefit the compressive strength of sand by up to 7% (from 2.45 MPa to 2.62 MPa) after 28 days and freeze-thaw cycles comparing with sand treated with cement 5% only. Sand treatment with Stabgrunt 2 and increased amount of cement from 3% to 5% advantages compressive strength up to 92% (from 1.37 MPa to 2.62 MPa) after 28 days and freeze-thaw cycles.

The effect of additives on the resistance of treated soil to frost is shown in Figure 7. The addition of Stabgrunt 1 and cement 3% increases clay frost resistance ratio up to 66% (from a ratio of 0.22 to 0.36) compared to addition of plain cement 3% into clay. The use of Stabgrunt 1 and 5% cement improves clay resistance to frost up to 16% (from a ratio of 0.46 to 0.53) compared to using cement 5% only. The effect of clay treated with only cement or cement with additive is more efficient when considering a smaller amount of cement – 3%. Nevertheless, treating clay with Stabgrunt 1 and increasing the amount of cement from 3% to 5%, increases the frost resistance ratio 47% (from 0.36 to 0.53 ratio).

The use of Stabgrunt 2 and cement 3% increases sand frost resistance ratio by up to 10% (from 0.75 to 0.82 ratio) compared to treated sand only with cement 3%. The addition of Stabgrunt 2 and 5% cement boosts sand resistance to frost by up to 3% (from 0.88 to 0.90 ratio) comparing to soil treatment only with cement 5%. As with clay, the effect of treating sand only with cement or cement with additive is more efficient when considering

Figure 6. Treated clay specimens after freezing cycles before compressive strength test (3% of cement with 0.15 L/m^3 Stabgrunt 1 – on the left; 5% of cement with 0.15 L/m^3 Stabgrunt 1 – on the right)

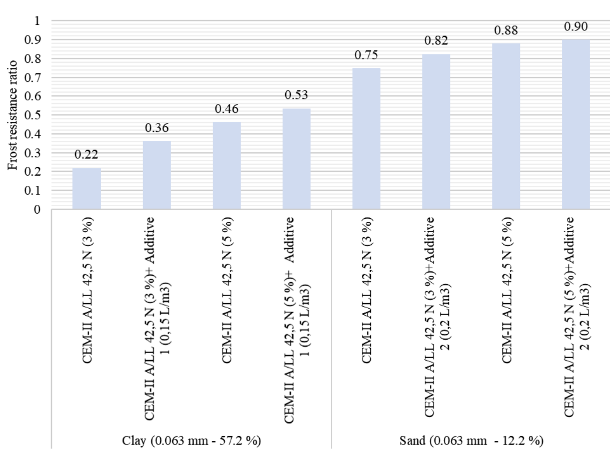

Figure 7. Frost resistance ratio

a smaller amount of cement – 3%. Regardless, treating sand with Stabgrunt 2 and adding a higher amount of cement from 3% to 5%, advance frost resistance ratio 9% (from 0.82 to 0.90 ratio).

Only treated sand specimen meets the frost resistance ratio for cement treated base (≥0.7), values are 7–29% higher than the requirement, while treated clay values are 10–69% lower. However, treated clay could be applied to cement-treated subgrade, where requirements for frost resistance are lower.

Conclusions

In this investigation, the effect of the ion-exchange stabilizer on the properties of the treated soil was determined. The following conclusions were drawn:

Natural soil usually does not ensure the sufficient bearing capacity of the subgrade. Therefore, natural soil treatment with stabilizers such as cement or lime is applied. However, achieving desired values of bearing capacity requires a relatively high amount (3% or more cement) of stabilizers and in some cases does not guarantee resistance to frost.

Clay (57.2% fines) treatment with combination of Stabgrunt 1 and 3–5% cement increase compressive strength up to 19% (from 0.47 MPa to 0.56 MPa using 3% cement and from 1.03 MPa to 1.15 MPa using 5% cement) after 7 days and up to 12% (from 0.64 MPa to 0.65 MPa using 3% cement and from 1.46 MPa to 1.63 MPa using 5% cement) after 28 days compared to treated soil with plain cement. The use of Stabgrunt 1 and increased amount of cement from 3% to 5% enhance compressive strength up to 104% (from 0.56 MPa to 1.15 MPa) after 7 days and even up to 150% (from 0.65 MPa to 1.63 MPa) after 28 days.

Sand (12.2% fines) treatment with combination of Stabgrunt 2 and 3–5% cement increases compressive strength up to 9% (from 1.18 MPa to 1.25 MPa using 3% cement and from 2.00 MPa to 2.18 MPa using 5% cement) after 7 days and up to 18% (from 1.41 MPa to 1.66 MPa using 3% cement and 2.79 MPa to 2.91 MPa using 5% cement) after 28 days comparing to treated soil with plain cement. The use of Stabgrunt 2 and increased amount of cement from 3% to 5% improves compressive strength to 75% (from 1.25 MPa to 2.18 MPa) after 7 days and to 76% (from 1.66 MPa to 2.91 MPa) after 28 days.

Clay (57.2% fines) treatment with the combination of Stabgrunt 1 and 3–5% cement increases frost resistance ratio, respectively, by 66% (from 0.22 to 0.36 ratio using 3% cement) and 16% (from 0.46 to 0.53 ratio using 5% cement) compared to the treated clay with the plain cement. The increase of the amount of cement from 3% to 5% along with the use of Stabgrunt 1 causes an increase in the frost resistance ratio of up to 47% (from 0.36 to 0.53 ratio). Whereas the treatment of sand (12.2% fines) with the combination of Stabgrunt 2 and 3–5% cement improves the frost resistance ratio, respectively, by up to 10% (from 0.75 to 0.82 ratio using 3% cement) and 3% (from 0.88 to 0.90 ratio using 5% cement) compared to the treated sand with the plain cement. Treatment of sand with Stabgrunt 2 and cement from 3% to 5% improves the frost resistance ratio by 9% (from a 0.82 to 0.90 ratio).

The use of ion-exchange stabilizer in combination with cement for soil treatment improves the compressive strength of the treated soil after 7 and 28 days under different conditions and also significantly increases the values of the frost resistance ratio.

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