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RESEARCH ARTICLE

Freeze-Thaw Effect in Granular Soil Reinforced with Calcareous Portland Cement

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HIGHLIGHTS

> Calcareous Portland cement was shown to have increased the unconfined compressive strengths of granular soil.

> Calcareous Portland cement, improving the resistance to freeze-thaw, can be used for stabilization of granular soil.

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ABSTRACT

The use of cement with additives to increase the strength values of fine and coarse-grained soils is becoming increasingly common today. Because cement with additives has become preferred in the construction industry due to the economy they provide and the low CO2 emissions in clinker production due to climatic changes. In this study, CEM II/A-LL 42.5 R, class limestone added cement produced according to the TS EN 197-1 standard was used in order to increase the freeze-thaw resistance of the granular soil. 5%, 10%, and 15% calcareous Portland cement (CPC) was added to the granular soil (GS) and compacted under standard proctor energy. After curing these three different rates for 1, 7, and 28 days, the freeze-thaw test was applied with -21°C, +21°C, 12 cycles, and 24 hours waiting time. As a result of freeze-thaw, the unconfined compressive strengths (UCS) of three different mixtures were determined with a uniaxial compression device according to three different curing times. As a result, the highest strength increase occurred in the 28-day cure and GS+5% CPC mixture of well over 100 percent. However, the lowest strength reduction rate before and after freezing-thawing was also found in the GS+5% CPC mixture with 9.30%.

Contents

1. Introduction

Today, natural, synthetic, chemical, or waste/waste materials are widely used in the improvement/reinforcement of fine or coarse-grained soils with poor physical and mechanical properties. Economy, sustainability, and environmental impact come to the fore as the main objectives in these improvement processes. Strengthening the weak geotechnical properties of soils used as foundation or sub-base material in the construction of many engineering structures (such as buildings, roads, pipelines) has now become a necessity. Because the deteriorations, collapses,

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settlements, and deformations on this ground adversely affect the engineering structures built on it.

Portland cement has been used for many years in soil reinforcement, concrete, or reinforced concrete material production [1–5]. However, today, the use of cement with additives has become preferred due to both the economic and technical advantages they provide and the indirect benefits of reducing CO_2 emissions by reducing clinker production [6, 7].

The swelling potential of expansive soils can be controlled by different methods including soil improvement by chemical additives, treatment by electro-osmosis application, compaction control, moisture control, rewetting, and thermal methods [8–13]. The application of both the traditional and non-traditional additives in treatment of expansive soils has been widely studied by various researchers from different parts of the world [14, 15]. Lime, cement, and gypsum are considered as traditional additives and are known as appropriate additives for reducing the swelling potential and increasing the strength of soils [16]. In the chemical stabilization, some additives such as lime, cement, fly ash, silica fume etc., are added, which physically interacts with the soil and change the index properties [13, 17–24].

Tsivilis et al. [2] investigated the effects of clinker and limestone quality on air permeability, water absorption, and pore structure of calcareous cement concrete. Portland limestone cement with different fineness and limestone content were produced by grinding clinker, gypsum, and limestone together. As a result, it was concluded that calcareous cement concrete with optimum limestone content can provide lower gas permeability and water absorption rate compared to pure cement concrete, depending on the clinker quality and cement fineness.

Tsivilis et al. [1] addressed the main factors affecting the properties of Portland limestone cement while also examining the hydration behavior of calcareous cement. The properties and behavior of calcareous cement concrete and the corrosion behavior of calcareous cement mortar were investigated. It was concluded that the fineness of clinker and limestone was strongly related to the limestone content and the fineness of the cement. Limestone cement shows satisfactory strength and generally requires less water than relatively pure cement. He also stated that Portland limestone cement improved the corrosion performance of concrete.

In an experimental study carried out by Voglis et al.[3], three Portland composite cement containing Portland cement and limestone, natural pozzolan, or fly ash were produced. The grinding process is designed to produce cement with the same 28-day compressive strength. Composite cement shows significant differences in terms of clinker fineness, strength development, water requirement, and hydration rate. It has been emphasized that while the production of Portland-limestone cement seems very difficult due to the low cost and high availability of limestone in Greece, calcareous cement has satisfactory properties. Tumluer [4], in his study, investigated the change of geotechnical properties of sand soils with slag additives, which are composite cement and iron residues at certain proportions. After all, it has been found that sand floors can be improved by using cement, and with the use of slag at the same rate as cement, results close to the strength obtained using only cement will be obtained in the increase of strength. It was also observed that curing had a significant effect on strength. In a study by Tosun et al. [6]; the problems encountered in the preparation of cement and the changes in the physical and mechanical properties of the prepared mortars by the limestone substitution were investigated. It was determined that the grain size distribution spread over a wider range with the increase in the limestone additive ratio. A stickiness and gumming occurred in the consistency of the prepared mortars. In addition, with the increase in the amount of limestone, a decrease in unit weight, an increase in water absorption values, and a decrease in compressive strength at all ages were observed.

As a result, mineral additives added to cement can be beneficial in such matters as: Economy and energy saving, protection of natural resources and environment, reduction of greenhouse gases, reduction of hydration heat, facilitating the processing of cement products, increasing durability and strength over time. The decrease in the early strengths can be solved by grinding the cement finer or by changing the clinker properties [25].

In this study, the effect of reinforcing granular soils with weak physical and mechanical properties with Portland calcareous cement on the change in strength values as a result of freeze-thaw was investigated.

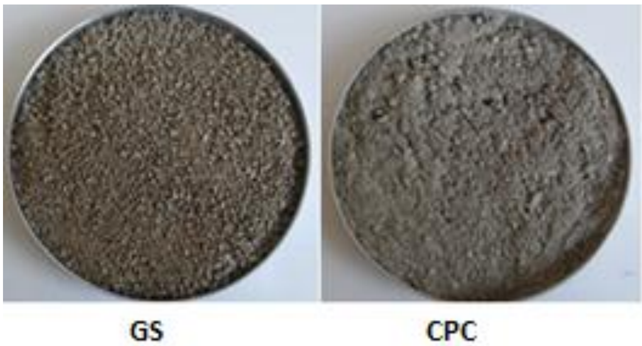
2. Materials and Method

2.1. Granular soil (GS)

The GS used in this study was obtained from the NESCE Group (Erzurum, NE Turkey), which is currently constructing the Erzurum-Oltu ring road (Figure 1). The GS was dried in an oven at 105 ºC and within 24 hours. After drying, sieve analysis of the granular material was performed (Figure 1). It is classified as SW (well graded sand) according to the Unified Soil Classification System (USCS). Experimental studies were performed according to BS 1377 (classification tests) standards. The physical and mechanical properties of GS are given in Table 1.

2.2. Calcareous Portland Cement (CPC)

The CPC was supplied in 50 kg bags from the cement factory in Van (Turkey). It is obtained by grinding together clinker and limestone and a small amount of gypsum. The CPC contains limestone between 6-20% by mass. The total amount of organic matter is 0.2%. The 28-day compressive strength is 42.5R [6].



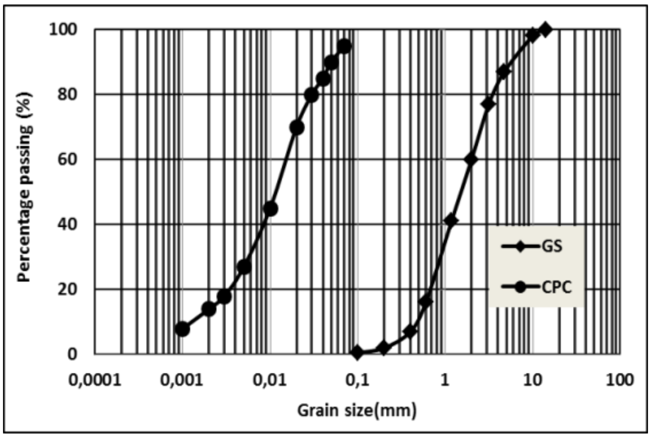


Figure 1 GS and CPC samples

Table 1 Physical and mechanical properties of GS

Properties	Value
Specific weight, Gs	2.58
Gravel (%)	30.00
Sand (%)	61.00
Silty (%)	5.80
Clay (%)	3.20
LL, %	26.10
PL, %	12.09
PI, %	14.01
Optimum water amount, %	10.50
Maximum dry weight, (kN/m^3)	19.33
Soil category	SW

2.3. Experimental procedure

The compression test, which constitutes an important part of this study, was performed on GS + CPC mixture samples prepared by compression under standard proctor energy according to ASTM [26].

The prepared samples are cylindrical samples with a diameter of 30 mm and a height of 70 mm, which are compressed in the optimum water content. A uniaxial compression test was performed in accordance with the ASTM [27] standard to determine the unlimited compressive strength of the test specimens at 1, 7, and 28-day curing times. The loading speed of the digital free pressure device is 0.5 mm/min was selected as.

Freeze and thaw tests were performed in accordance with ASTM [28] to investigate the effects of GS+CPC mixtures on freeze and thaw resistance. These tests were performed with a programmable freeze-thaw apparatus. For freeze-thaw cycles, -21 °C, +21 °C, the number of cycles is 12 and the waiting time is 24 hours.

3. Results and Discussion

3.1. Unconfined compressive strength (UCS)

When the UCS values of the GS soil samples equipped with CPC were examined, the highest strength value was observed in the GS+CPC mixture sample with 5% CPC at 28 days of curing (Figure 2). When the strength values after 28 days of curing before and after freezing-thawing were compared, the decrease in strength was 9.30% in the mixture with 5% CPC, while this decrease was 21.24% in the 10% mixture and 27.68% in the 15% CPC mixture.

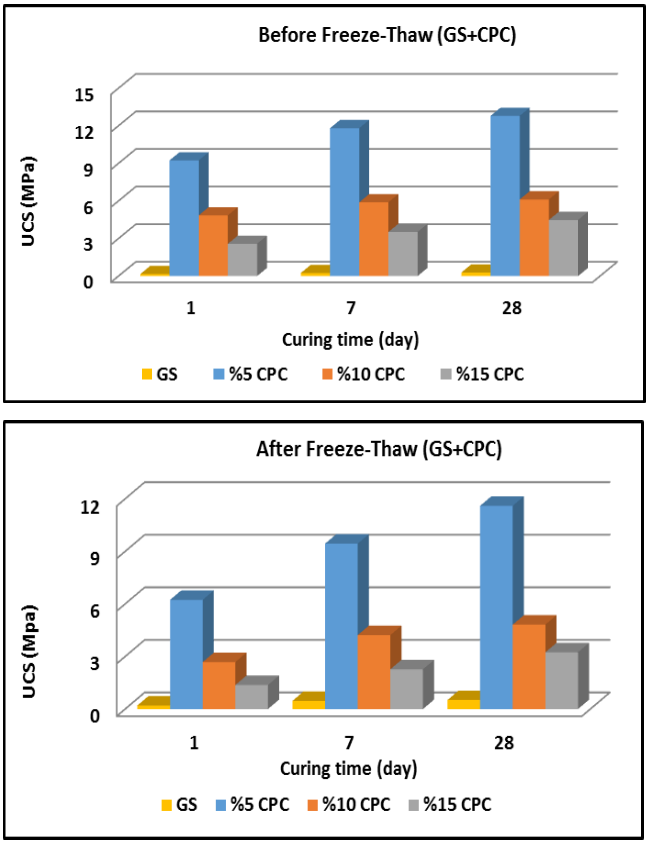


Figure 2 UCS graphs before and after freeze-thaw

Pozzolanic Substance (Puzolane) is a silica and/or aluminum silicate compound that does not have a binding feature on its own, but gains hydraulic binder feature when mixed with finely ground lime hydrate. In the past, the limestone additive, mostly with pozzolanic properties, was usually limited to 5% by weight as a minor component in cement. However, according to the TS EN 197-1 standard, the $CaCO_3$ ratio of the limestone to be used in the production of cement with additives should be at least 75% in the production of cement with limestone as the main additive. component. The clay content of the limestone should not exceed 1.2% [6]. Within the scope of this study, it was observed that there was a significant increase in the freeze-thaw resistance properties of the mixtures prepared with limestone-added cement, and a decrease of 9.30% in the strength loss as a result of freeze-thaw, especially in the GS+5% CPC mixture.

From these data, it is accepted that the limestone in CPC does not directly contribute to the compressive strength, it only serves as a filler and does not have pozzolanic properties [29]. It has been emphasized in many studies that 5% limestone additive can increase the early strength with its indirect effect by accelerating hydration, but that higher rates of limestone additive have a decreasing effect on the compressive strength [1, 2, 29].

4. Conclusion

In this study, the change in freeze-thaw strength of the mixtures in three different cures (1, 7, and 28 days) was applied on the GS reinforced with a cement type, CPC additives were investigated.

As a result of the experimental studies, the highest strength increase (28-day cure) and the lowest strength loss as a result of freeze-thaw occurred in the mixture with GS+5 CPC. However, as the CPC additive ratio increased, the strength values decreased (12.79 MPa in the mixture with 5% additive, 6.12 MPa in the mixture with 10% CPC, and 3.96 MPa in the mixture with 15% CPC). At the same time, strength loss rates increased as a result of freeze-thaw (the strength loss is 9.30% in the mixture with 5% additive, 21.24% in the mixture with 10% CPC, and 27.68% in the mixture with additives. 15% CPC).

As a result, when the compressive strength developments in GS+CPC mixtures are examined, it is seen that the limestone additive causes strength loss in the mixtures where the limestone additive ratio is above 5%.

Conflict of Interest

Authors declare that they have no conflict of interest with any person, institution, or company.

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