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FREEZING-THAWING BEHAVIOR OF CLAYEY SOILS REINFORCED WITH PINE TREE SAWDUST AND MARBLE DUST

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Abstract

In this study, the change of freeze-thaw test result of unconfined compressive strength of clayey soils reinforced with pine tree sawdust and marble dust was investigated. Mixtures containing 5%, 10% and 15% marble dust and 0.5%, 1% and 1.5% pine tree sawdust were compressed by standard Proctor test with optimum moisture content. After curing the mixture samples for 1, 7 and 28 days at a working room temperature of +21°C, they were subjected to the freeze-thaw test at -21°C, +21°C for 12 hours and 12 cycles. In the test results of the unconfined compressive strength test applied to the samples, the highest strength increase was determined in clayey soil+%15 marble dust+1% pine tree sawdust mixtures before and after freezing thawing. The strength increases before and after freeze-thaw was 54.80% and 31.56%, respectively. According to SEM analyses, structural changes in clayey soil reinforced with pine tree sawdust and marble dust were examined before and after freeze-thaw. It has been determined that the mixture of pine tree sawdust and marble dust can be applied in the treatment of clayey soils.

Key words: clay, freeze-thaw, marble dust, pine tree, strength

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1. Introduction

In areas where temperature differences occur frequently, soil is subjected to freeze-thaw cycles. Engineering properties, strong forces, and deformation of the soil are affected under different external forces as well as different loads. These mechanical properties depend on the internal structure of the soil. Therefore, properties such as ductility, strength, and hardness, which represent the deformation and strength of the soils, depend on the internal structure. If the internal structure of the soil is well known, the necessary changes can be made regarding the interior structure and the soil properties can be adapted to the proper application on purpose (Akbulut et al., 2007; Kalkan, 2011, 2013; Yarbaşı et al., 2007; Zhou and Keeling, 2013). In the studies, especially the researches dealing with the marble waste, strength is increased and brittle fractures are observed in fine-grained soils reinforced with marble dust. Ductile fractures were observed in fine-grained soils reinforced with pinewood sawdust, an organic residual material. The strength of the clayey soils, which are reinforced by the addition of these two materials at the same time, the strength and duration of breakage are extended and the two properties are used together in a positive way (Koteswara et al., 2012; Shawl et al., 2017) Studies have been carried out on the use of pine tree sawdust as a building material or as a sub-base material, especially in civil engineering. As a result of these studies, it was used as a wall material due to its feature of being a light material. It can be used as foundation and sub-base material especially in road constructions (Karafakı, 2009; Okagbue, 2007; Oyedepo et al., 2014; Rodrigues et al., 2015; Shawl et al., 2017; Taşpolat et

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al., 2006; Udoeyo and Dashibil, 2014; Yarbaşı and Kalkan, 2016; Yarbaşı, 2018; Zorluer and Usta, 2003).

In this study, these two properties were evaluated together by assessing both brittleness (marble powder) and ductility (pine wood shavings) together, increasing the strength and resistance of clayey soils against freezing and thawing.

2. Material and methods

2.1. Materials

2.1.1. Green clay (GC)

Within this paper, the green clay (GC) soil sample was obtained from the Oligocene sedimentary unit located in the west of Oltu (Erzurum) district and excavated from a depth of 0.80 m from the surface (Fig. 1). The GC soil brought to the laboratory was dried in the oven at a temperature of 105 ± 5°C for 24 hours and then the hardened grains were milled in the Los Angeles Abrasion Machine at 4000 rpm. Los Angeles Abrasion Machine is used to determine the fragmentation resistance in aggregates and the percentage of light material in the aggregate. It is also used as a grinder. The device consists of a cylindrical steel tambour with an inner diameter of 711 mm and an inner length of 508 mm, 12 wear balls and an electronic control unit. When the speed set by the user is reached, the automatic counter on the device automatically stops the machine. According to the United Soil Classification System, GC are inorganic clays of high plasticity (CH). These soils have high expansion potential as a result of over-consolidation, high-very high plasticity, and montmorillonite clay content (Kalkan and Bayraktutan, 2008). The particle size distribution, physical-mechanical features and elemental analyses are given in Fig. 2, Table 1 and Table 2, respectively.

Fig. 1. Green clay, pine tree sawdust and marble dust materials

2.1.2. Pine tree sawdust (PTS)

PTS, the second important element of this study, was obtained from the carpenters in the industrial area of Oltu-Erzurum (Fig. 1). About 140 tons of pine tree shavings are released per year from these carpenters. The systematic location of the yellow pine (*Pinus silvestris L.*), which extends over an extremely wide area in the world, is a species of the genus Pinus (Pine) from the Gymnospermae class and the Pinaceae family. The area covered by yellow pine forests (*Pinus sylvetris* L.), which is commonly found in North East Anatolia Region, is 1.961.660 ha and the ratio to total forest area is 9.00% (Atalay et al., 1985; CABI, 2002). Particle size distribution and elemental analysis of PTS are given in Fig. 2 and Table 3, respectively.

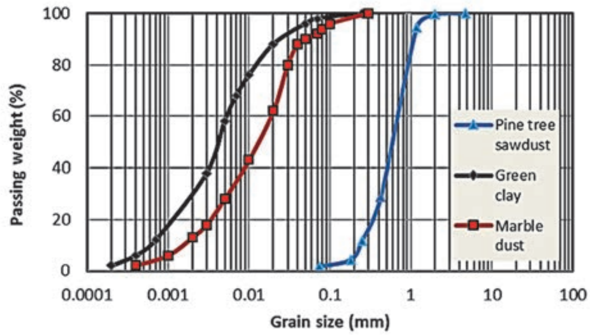


Fig. 2. The particle size distribution of the green clay, pine tree sawdust and marble dust

Table 1. Physical and mechanical properties of the GC

Property	*Value*
Soil unit weight (kN/m^3)	26
Sand (2000-75 μm) (%)	10.0
Silt (2-75 μm) (%)	58.0
Clay (<75 μm) (%)	32.0
Liquid limit (%)	68
Plastic limit (%)	28
Plasticity index (%)	40
[1]Optimum water content, w_{opt} (%)	25.8
[1]Max. Dry Unit Volume Weight, γ_{kmax} (kN/m^3)	14.1
[2]Soil classification	CH

[1]Standard Proctor Test is applied, [2]Unified Soil Classification System (USCS)

Table 2. Elemental analyses of the GC

Elements	*Weigth (%)*
O	50.55
Na	4.11
Mg	4.26
Al	6.75
Si	22.33
K	1.46
Ca	6.93
Fe	3.62

Table 3. Elemental analyses of the PTS

Element	*Weigth (%)*
Soil unit weight, (kN/m^3)	12
C	50.1
O	46
Si	0.1
Ca	0.3
Others	3.5

2.1.3. Marble dust (MD)

MD, the third component of this study, was obtained from the marbles of Afyon region, as a result of polishing, scraping and engraving processes, in a dry form. 0.125 mm sieve was used to remove the coarse grains in the dry MD (Fig. 1). The grain-size distribution, and elemental analyses are given in Fig. 2 and Table 4, respectively.

Table 4. Elemental analyse of the MD

Component	***Value (%)***
SiO_2	0.36
Al_2O_3	0.28
Fe_2O_3	0.04
CaO	54.98
MgO	0.62
Na_2O_3	0.03
K_2O	0.07
SO_3	0.06
CaO_2	43.56

2.2. Methods

The first step of this study was the standard compaction test in order to determine the optimum water content (w_{opt}) and the maximum dry unit weight (γk_{max}). The samples were prepared by compressing the cylindrical sample containers with a diameter of 38 mm and 76 mm in the optimum water content. 3 (three) samples were prepared to determine the cure time of each type of mixture and the average of the results were obtained. Experimental studies were performed according to ASTM-D 2166 (2006), ASTM-D 698-78 (2012), ASTM D 560 (2003) and BS. 1377 Part 2. (1990). Sieve analysis was performed to determine the particle size distribution. Sieve wrapping device and ASTM standard sieves were used for this analysis. Sieve analysis was performed to determine the particle size distribution. Sieve wrapping device and ASTM standard sieves were used for this analysis. These tests were carried out at Atatürk University Faculty of Earth Sciences, soil mechanics laboratory. Elemental analysis was performed with Zeiss Sigma 300 equipped with EDAX analyzer (Zeiss, Germany) found in Atatürk University Central Laboratory. For SEM analysis, Sigma 300 Zeiss Gemini FE-SEM device was used at the Atatürk University Center Laboratories.

The samples were prepared with ratios of GC, GC+5%, 10%, 15% MD and 0.5%, 1%, 1.5% PTS. These mixing ratios are 100% GC (MIX0), 94.5% GC+5% MD+0.5% PTS (MIX1), 94% GC+5% MD+1% PTS (MIX2), 93.5% GC+5% MD+1.5% PTS (MIX3), 89.5% GC+10% MD+0.5% PTS (MIX4), 89% GC+10% MD+1% PTS (MIX5), 88.5% GC+10% MD+1.5% PTS (MIX6), 84.5% GC+15% MD+0.5% PTS (MIX7), 84% GC+15% MD+1% PTS (MIX8), 83.5% GC+15% MD+1.5% PTS (MIX9).

Samples were cured at room temperature (+21°C) for 1, 7 and 28 days. At the end of the cure time, the samples were subjected to unconfined compression test to determine the strength values of the samples. The uniaxial compressive device and samples in which the loading speed is selected as 0.8 mm/min are shown in Fig. 3. A deep-freeze refrigerator was used for the freeze-thaw test. The freezer was set to -21°C and freezing process was applied. Thawing process was applied at +21°C operating room temperature. The number of freeze-thaw cycles was 12 and the waiting time at each temperature was chosen as 12 hours.

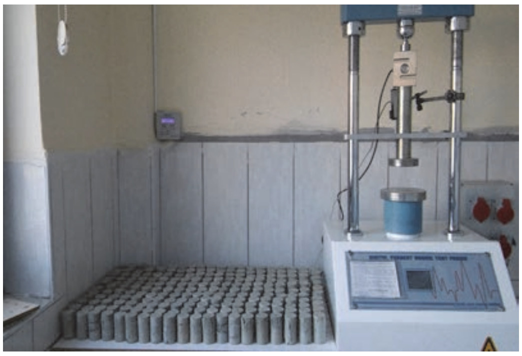


Fig. 3. Uniaxial compressive device and the samples

3. Results and discussion

3.1. Unconfined compressive strength (UCS)

UCS values of GC soil samples reinforced with MD and PTS before and after freezing-thawing were determined according to ASTM D 2166 Standards.

Before freeze-thaw, for the mixture of MIX8, the highest UCS values obtained at the end of 28-days curing strength values were compared with GC soil (main material). According to the test results, the strength increase rate is 54.80%. The other highest strengths following this mixture were 23.40% in the MIX4 mixture and 9.42% in the MIX2 mixture (Fig. 4).

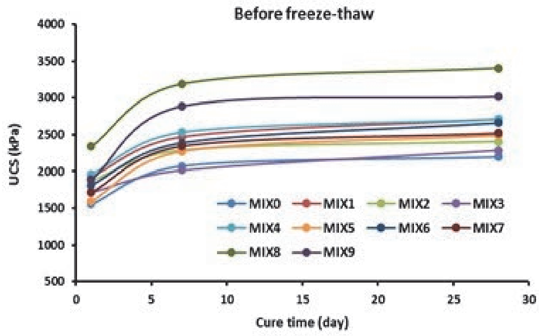
After freeze-thaw, for the mixture of MIX8, the highest UCS values obtained at the end of 28-days curing strength values were compared with GC soil (main material). According to the test results, the strength increase rate is 31.56%. This mixture was followed by MIX6 mixture with an increase of 21.52% and MIX2 mixture with an increase of 9.00% (Fig. 4). Test results showed that MD was an important factor in increasing the strength of GC soil before and after freeze- thaw. The UCS values generally increased with the increase in the MD ratio up 15%. This was also observed in the strength values before and after the freeze-thaw. The mechanical resistance increases with curing time. Among the different variables affecting the UCS of MD-stabilized clay soil, curing time is of major importance (Okagbue, 2007; Okyay and Dias, 2010; Yarbaşı, 2018). MD effect on UCS is a function of time, temperature and relative humidity (Bell, 1996). An increase in the MD content in the GC soil increased the strength compared to the natural compacted GC soil sample, which made the mixture more brittle. PTS used to make this fragility more ductile was effective in this case. Reducing the permeability of PTS adds a significant positive property to the mixture. Increases in the ratios of MD and PTS were effective in strength increases before and after freeze thaw. Similar results were reported by Okagbue, (2007); Shawl et al., (2017); Taşpolat et al., (2006); Yarbaşı and Kalkan, (2016); Yarbaşı, (2018); Yarbaşı, (2019), Zorluer and Usta, (2003).

3.2. SEM analyses

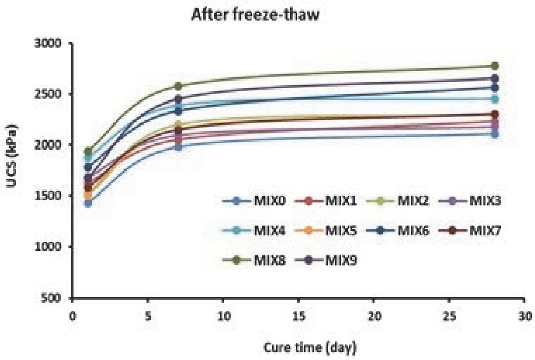
3.2.1. Before freeze-thaw analyses

The SEM image indicates a layered structure and clay minerals were observed in accordance with the green clay internal structure (Fig. 5a). In the SEM image of the addition of MD into the GC soil material, the material has become more compact and the porous structure has disappeared (Fig. 5b). When the 100 µm scaled morphological appearance is examined, it can be said that the structure is more rigid and flat. Again, the morphological appearance of this mixture can be said to have gained a hard and complete structure with the addition of MD.

In Fig. 5c, the morphological image was obtained by adding PTS to GC before freezing and thawing. When the SEM image scaled as 2 µm was examined, it was clear that the structure of the mixture changed, but it was also observed that the structure did not gain hardness like it did in MD. The reason for this is due to the natural structure of PTS. Therefore, it is seen that even if PTS changes the structure of the mixture, it does not give enough strength. Fig. 5d shows the morphology regarding the GC+MD+PTS mixture prior to the freeze-thaw process. The MD and PTS material added to the clay soil from the images caused significant textural changes in the clay structure, resulting in significant increases in strength values.



(a)



(b)

Fig. 4. UCS graphics of the mixtures before freeze-thaw (a) and after freeze-thaw (b) process

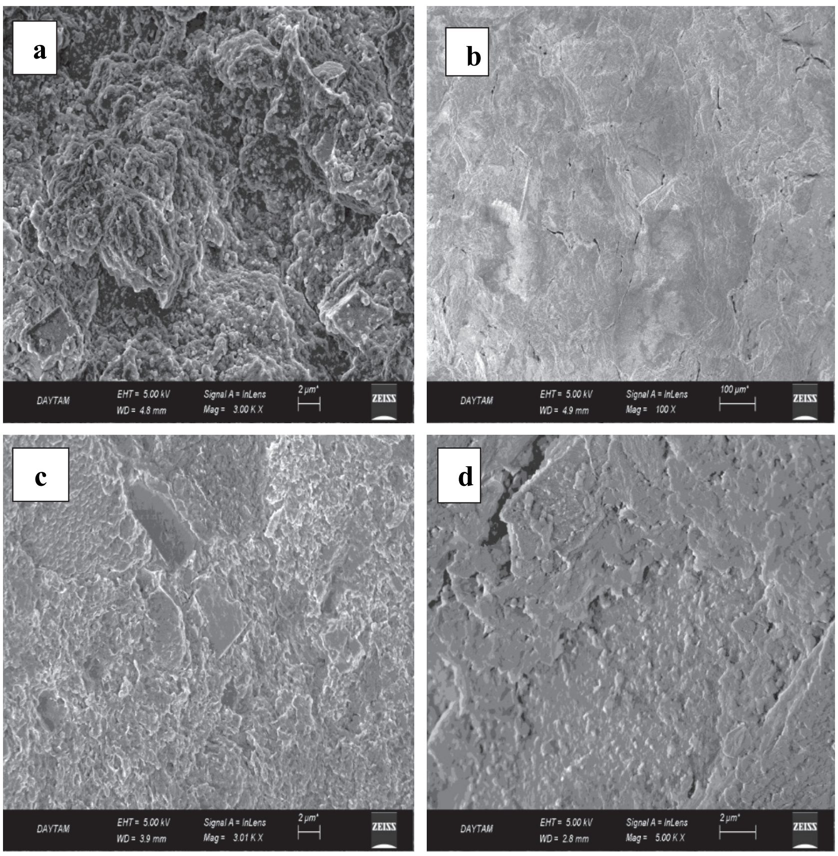


Fig. 5. Before freeze-thaw, variation in the microstructure with MD+PTS content: (a) stabilized GC sample, (b) stabilized GC sample with MD, (c) stabilized GC sample with PTS and (d) stabilized GC sample with MD+PTS

3.2.2. After freeze-thaw analyses

In the SEM image shown in Fig. 6a, it was observed that the layer in the inner structure of the clay decreased relatively. A change was observed in the volume of the existing clay by the effect of both air and water molecules on the structure dissolving at +21°C and the structure moved away from its former state as understood from its morphology, indicating that freeze-thaw process affects the structure of the material. In the SEM image of the addition of MD into the GC material, the material has become much flatter and the porous structure in the material has become apparent (Fig. 6b). The morphological image scaled as 2 μm indicate that the structure could have a smooth state and slits and cracks could occur in the mixture. In the SEM image of the mixture scaled as 10 μm, taken after the freeze-thaw process, in which PTS was added to the GC, it is observed that there is a change in the structure of the mixture and significant voids are formed in the structure due to the natural structure of the PTS (Fig. 6c).

PTS is an organic material and water molecules formed by the evaporation temperature in the media after the freeze-thaw process greatly affect the structure of it. Because of the absorbent properties of the water molecules within its structure, PTS reduces the permeability while absorbing water in the structure of the mixture that can be considered as an advantage. As we examine the morphological image structures as shallow depth basic and sub-base materials of the mixture (GC+MD+PTS) taken after the freeze-thaw process (Fig. 6d), it is observed that the MD and PTS added to the material have significantly changed the structure of the material. It was observed that the MD and PTS materials present in the mixture after the freeze-thaw process did not reduce the strength in the structure much, but they caused textural changes in the structure. However, cracks in the morphological image, fissure and aggregation of the structure can be considered as evidence of a relatively low resistance as seen in UCS measurement.

4. Conclusions

The effects of pine tree sawdust (PTS) and marble dust (MD) on the strength properties of green clayey soil (GC) were investigated and the results obtained within this experimental study were given below. A significant change in unconfined compressive strengths of the reinforced mixtures obtained by the addition of 0.5%, 1%, 1.5% PTS and 5%, 10% and 15% MD to the GC soil was observed before and after freezing-thawing.

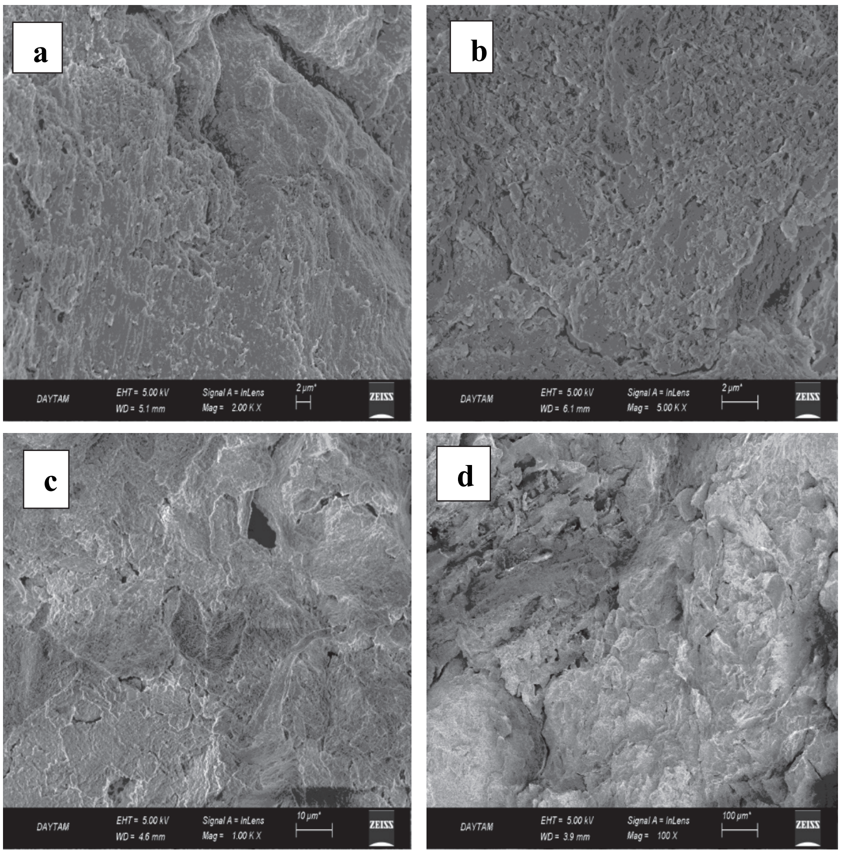


Fig. 6. After freeze-thaw, variation in the microstructure with MD+PTS content: (a) stabilized GC sample, (b) stabilized GC sample with MD, (c) stabilized GC sample with PTS and (d) stabilized GC sample with MD+PTS

The highest increase in strength was recorded as 54.8% and 31.56% in the MIX8 mixture after 28 days of curing, before and after freezing-thawing, respectively. Structural analysis of GC soil to which PTS and MD was added was analyzed by SEM. Prior to freeze-thaw, the addition of PTS and MD to the GC material was observed to be more compact and tighter in SEM images.

However, it has been observed that cracks and fissures occur in the structure after freezing and thawing. These adverse structures are thought to adversely affect the mixture and cause loss of strength. Therefore, it should be used carefully in regions where temperature differences are frequent. As a result, it was concluded that clay soils reinforced with waste PTS and MD can be used for soil improvement and engineering structures as shallow depth basic and sub-base materials

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