Freeze-Thaw Behaviors of Sandy Soils Modified by Mixtures of PET Fiber and Marble Dust

Necmi Yarbaşı[1], Ekrem Kalkan[2*]
[1,2]Ataturk University, Oltu Earth Sciences Faculty, Geological Engineering Department, 25400 Erzurum, Turkey
[*]Corresponding author

***Abstract*—The sandy soils generally are soft and low strength and these properties of the cause to differential settlements, less shear strength and high compressibility in the soils. It is difficult to find natural soil that provided high strength and high durability in practice. Hence it is necessary to improve the engineering properties of soil. Modification techniques are applied to increase the physical and mechanical properties of the soils to the desired level. In this study, sandy soil was modified by using mixtures of waste materials such as PET fiber and marble dust. For the modification of sandy soil, PET fiber content was selected as 0.1%, 0.2% and 0.3% of the total weight of sandy soil samples. The contents of marble dust were 5%, 10% and 15% of the total weight of sandy soil samples. The modified sandy soil samples were subjected to the unconfined compression test and freeze-thaw test under laboratory conditions to investigate the freeze-thaw behaviors of modified sandy soil samples. The results show that the modified sandy soil samples with the mixtures of wastes have high resistance to the freeze-thaw cycles when compare with the unmodified sandy soil samples. Consequently, it is concluded that the mixtures of wastes such as PET and marble dust can be successfully used for the modification of sandy soils in the geotechnical applications.**

***Keywords*— Sandy soil,waste material, PET fiber, marble dust, soil modification, freeze-thaw**

I. INTRODUCTION

The use of waste/residual natural or synthetic materials in the modification of soils is an economic, sustainable and favorable contribution to the environment. There is growing interest in the use of waste plastic PET fibers, PETE-PET (Polyethylene Terephthalate) and marble quarry wastes for the treatment of coarse or fine-grained soils. Sand is usually easily destroyed due to its low strength and cohesion and most of natural sand needs to be modified to meet the engineering requirements in the application of geotechnical engineering (Lui et al., 2017). In order to enhance properties of weak soil formations such as loose sand deposits a wide range of ground improvement techniques have been introduced over the past decades. Majority of these ground modification techniques utilize mechanical energy and fabricated binder materials. Nowadays, there is a high demand for new sustainable methods to improve soils. The extensive research has been undertaken to find alternative soil binders to replace high cost materials. The engineering properties of the soils are important not only in foundation materials for the projects, but also as materials for construction in embankments, dams, and other works (Yarbaşı and Kalkan, 2019a).

Soil modification techniques used to change the characteristics of soil for modifying the physical and mechanical properties of soil, and these techniques have been widely used. Soil modification techniques are growing since they are feasible, sustainable and economical. Soil modification (also known as soil improvement or soil stabilization) is the change of properties of the soil to improve its engineering performance (Lambe and Whitman, 1979; Cuisinier et al., 2011; Jorat et al., 2013). The main properties of soil which are of interest to engineers are the strength, the durability, the volume stability, the compressibility and the permeability (Ingles and Metcalf, 1977; Sherwood, 1993; Shooshpasha and Shirvani, 2015; Rahmannejad and Toufigh, 2018).

Many investigators have studied natural, fabricated, and by-product materials and their use as additives for the stabilization of coarse or fine-grained soils. All these methods may have the disadvantages of being ineffective and expensive. Therefore, new methods are still being researched to increase the strength properties and to reduce the swell potential of expansive soils (Asavasipit et al., 2001; Puppala and Musenda, 2002; Prabakar et al., 2003; Kalkan, 2003; YetimogluandSalbas, 2003; Kalkan and Akbulut, 2004; Al-Rawas et al., 2005; Kolias et al., 2005; Cetin et al., 2006; Senol et al., 2006; Sezer et al., 2006; Akbulut et al., 2007; Guney et al., 2007; Moavenian and Yasrobi, 2008; Kalkan, 2011; Kalkan, 2012;Mohamedgread et. al., 2019; Yarbaşı and Kalkan, 2019a; Yarbaşı and Kalkan, 2019b).

In this study, the mixtures of wastes such as PET fiber and marble dust were used as additive material to modify the sandy soils. To investigate the effects of waste mixtures on the freeze-thaw resistance, modified sandy soil samples were subjected the unconfined compression tests and freeze-thaw tests. The results obtained experimental study showed that the mixtures of wastes such as PET fiber and marble dust can be used as additive material for modification of sandy soils.

II. MATERIAL AND METHOD

2.1. Sandy Soil

Soil is called sandy soil when the percentage of sand is high in a specific soil. Sandy soil is also known as light soil. The sandy soil generally composed of- 33.21% gravel, 62.37% sand and 4.42% silt and clay. In sandy soil, most of the soil particulars are bigger than 2 mm in diameter and it has the largest particle among different soil particles. The sandy soil material used in this experimental study was supplied from Oltudistrict of Erzurum, NE Turkey. This material is classified as poorly graded sand (SP) according to the Unified Soil Classification System (USCS). The photo of sandy soil material was given in the Fig. 1 and its grain size distribution was given in the Fig. 2. Also, physical and mechanical properties of sandy soil were summarized in the Table 1.

Fig. 1. Photos of sandy soil, marble dust and PET fiber

2.2. Marble Dust

The marble dust waste material was obtained in wet form as an industrial by-product directly from the deposits of marble factories, which forms during the sawing, shaping and polishing processes of marble in Afyon (Turkey) region. The wet marble sludge was dried up prior to the preparation of the samples. The dried material was sieved through a 0.25 mm sieve to remove the coarse particle. Finally, the marble dust waste material was obtained to use in the experimental studies as additive material for the modification of fine-grained soils (Kalkan and Yarbaşı, 2013). The photo of marble dust waste material was given in the Fig. 1 and its grain size distribution was given in the Fig. 2. Also, the chemical properties of the marble dust waste material are given in Table 2.

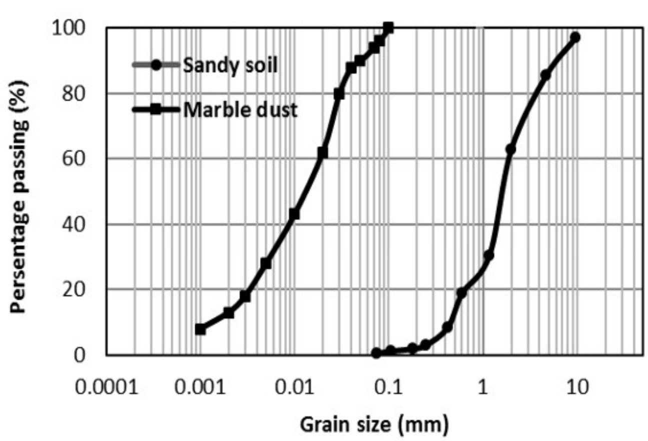

Fig. 2. Grain size distribution of sandy soil and marble dust

Table 1.Physical and mechanical properties of sandy soil

Properties	Value
Specific gravity, Gs	2.63
Gravel (%)	33.21
Sand (%)	62.37
Silty (%)	3.42
Clay (%)	1.00
Liquid limit (L_L, %)	35.00
Plastic limit (P_L, %)	NP
Maximum void rate (%)	89.00
Minimum void rate (%)	40.60
Optimum water content, w_{opt} (%)	16.00
Maximum dry unit volume weight, γ_{kmax} (kN/m^3)	17.60
Soil classification	SP

Table 2. Chemical properties of marble dust

Components	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

2.3. PET Fiber

The PET fiber used in this study were obtained from Ertona Textile (Bursa, W Turkey) which provides raw materials to the textile market. The photo of PBW fiber material used in this study was given in the Fig. 1. The PET fiber has a length of 20 mm, diameter of 0.035 mm. The physical and chemical properties of PET was given in the Table 3.

Table 3. Physical and chemical properties of PET fiber (Anabal, 2007)

Parameters	**Value**
Density, g cm^{-3}	1.41
Melting temperature, °C	265
Breaking force, MPa	50
Tensile strength, MPa	1700
The lowest stress value that can be deformed, %	4
Impact strength, J m^{-1}	90
Water absorption (after 24h), %	0.5

III. EXPERIMENTAL PROSEDURE

3.1. Preparation of sandy soil-marble dust-PET fibermixtures

The sandy soil was dried in an oven at approximately 105 °C and then ground before using in the mixtures. First, the required amounts of sandy soil material, marble dust waste material and PET fiber material were blended together under dry conditions. As the fiber tended to lump together, considerable care and time were spent to get a homogeneous distribution of the fibers in the mixtures. Then the mixtures of sandy soil-marble dust-PET fiber were mixed with the required amount of water according to the optimum moisture content.For the modification of sandy soil, PET content was selected as 0.1%, 0.2% and 0.3% of total weight of modified sandy soil samples. The contents of marble dust were 5%, 10% and 15% of total weight of modified sandy soil samples. The ratios of mixtures used the experimental study were summarized in the Table 4.

Table 4. Mixture ratios by weight

Mixtures	**Sandy soil (%)**	**Marble dust (%)**	**PET (%)**	**Total (%)**
MIX0	100	--	--	100
MIX1	94.9	5	0.1	100
MIX2	94.8	5	0.2	100
MIX3	94.7	5	0.3	100
MIX4	89.9	10	0.1	100
MIX5	89.8	10	0.2	100
MIX6	89.7	10	0.3	100
MIX7	84.9	15	0.1	100
MIX8	84.8	15	0.2	100
MIX9	84.7	15	0.3	100

3.2. Compaction tests

The Standard Proctor tests were carried out to determine the optimum water contents of samples and to prepare the samples for the unconfined compression and freeze-thaw tests. During the compaction process, a soil at selected water content was placed in three layers into a mold of standard dimensions. The compaction curves were plotted from the data and the values of optimum water content and maximum dry unit weight were determined from the compaction curves. The mixtures of sandy soil-marble dust-PET fiber were compacted at the optimum water content to prepare samples for the tests. For unconfined compression test and freeze-thaw test, samples were prepared with static compaction method based on ASTM standards. Three-layered compaction was adopted to keep the uniformity of test samples with the 35 mm diameter and 70 mm height.

3.3. Unconfined compression tests

The unconfined compressive strength (UCS) values of unmodified sandy soil samples and modified samples with the mixtures of sandy soil-marble dust-PET fiber were determined from the unconfined compressive tests in accordance with ASTM D 2166. This test is widely used as a quick and economical method of obtaining the approximate compressive strength of the soils. In this study, three cylindrical samples were prepared and tested for each combination of mixtures. These tests were repeated at the 7^{th}, 14^{th} and 28^{th} of curing period of the samples. These tests were carried out at the loading rate of 0.5 mm/min until samples failed.

3.4. Freeze-thaw tests

To obtain the freeze-thaw resistance of the modified sandy soil samples with the mixtures of sandy soil-marble dust-PET fiber, the freeze-thaw tests were performed under laboratory conditions. This tests were performed by a programmable freeze-thaw apparatus. The samples with an age of 28 days were subjected to freeze-thaw tests in accordance with ASTM C 666. In the freeze-thaw apparatus, the samples were conditioned at -20 °C for 2.30 h. After freeze-thaw process, they were transferred into a test room at 20 °C to thaw for 2.30 h. This process was repeated for 10 times of freeze-thaw cycles at the 7^{th}, 14^{th} and 28^{th} of curing period of the unmodified and modified samples with the marble dust-PET fiber mixtures.

IV. RESULTS AND DISCUSSION

4.1. Effects of Marble Dust-PET Fiber Mixtures on the UCS of Sandy Soils

The unconfined compression tests were performed to investigate the effect of marble dust-PET fiber mixtures on the UCS values of the samples unexposed freeze-thaw process. The results obtained from tests were illustrated on the Fig. 3. The test results showed that the marble dust-PET fiber mixtures improved the UCS values of sandy soil samples. The sandy soil has low cohesion between the soil particles resulting in its loose structure. The mechanism of modification with marble dust-PET fiber mixtures in sand mainly includes that the fiber and sand particles constrain each other to produce interface force and marble particles serve as binder material between grains. This interface force is mainly caused by the extrusion pressure and in the form of cohesion and friction (Liu et al., 2017). The maximum values of the UCS were obtained from modified sample defined as MIX7 at the 28 days of curing time. The same results were obtained from some experimental studies carried out in the past (Ranjan et. al., 1994; Prabakar and Sridhar, 2002; Akbulut et al., 2007; Zaimoglu, 2010; Hejazi et al., 2012; Muntohar et al., 2013; Lv and Zhou, 2019; Benziane et al., 2019).

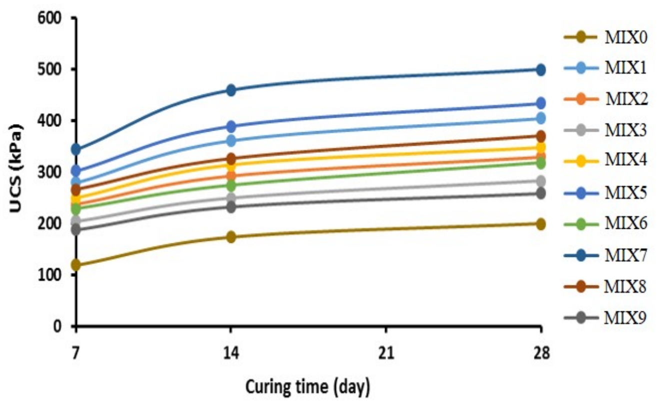

Fig. 3. The effects of marble dust-PET fiber mixtures on the UCS values of sandy soil

4.2. Effects of Marble Dust-PET Fiber Mixtures on the Freeze-Thaw Resistance of Sandy Soils

The unmodified and modified samples with marble dust-PET fiber mixtures were subjected to the freeze-thaw tests to investigate the freeze-thaw resistance of sandy soil samples. For this purpose, all samples were exposed to the freeze-thaw cycles and then these samples were subjected to the unconfined compression tests. The results obtained from tests were illustrated on the Fig. 4. The test results showed that the marble dust-PET fiber mixtures improved the freeze-thaw resistance of the sandy soil samples.

After the freeze-thaw cycles, decrease in the UCS values of modified samples with marble dust-PET fiber mixtures was lowest level compared to the unmodified sandy soil samples. The lowest strength loss was observed from the modified sample defined as MIX7 at the 28 days of curing time. The effects of freeze-thaw cycles on the deterioration degree vary depending on the material properties. The main mechanism governing the alteration of soil behavior caused by the freeze-thaw cycles appears to be changes in the soil structures. The decrease in the compressive strength of modified samples is attributed to the changes in soil sample structure due to particle rearrangements and the initiation of cracks (Cruzda and Hohmann, 1997; Viklander, 1997; Viklander and Eigenbrod, 2000).

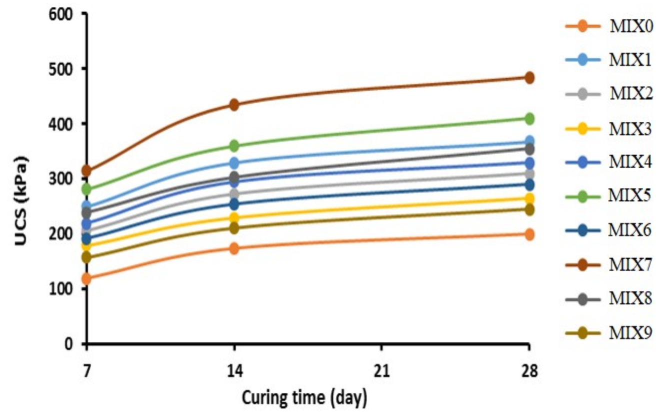

Fig. 4. The effects of marble dust-PET fiber mixtures on the UCS values of sandy soil exposed to freeze-thaw cycles

V. CONCLUSIONS

In this study, the effects of marble dust-PET fiber mixtures on the UCS values and the freeze-thaw resistances of sandy soil samples modified with marble dust-PET fiber mixtures. According to the test results, marble dust-PET fiber mixtures improved the strength properties of sandy soils. Also, the marble dust-PET fiber mixtures enhanced the freeze-thaw resistances of sandy soil samples modified with marble dust-PET fiber mixtures. As a result, the marble dust-PET fiber mixtures can use as an alternative waste material for the modification of the sandy soils.

REFERENCES

[1] Akbulut, S., Arasan, S. Kalkan, E., 2007. Modification of clayey soils using scrap tire rubber and synthetic fibers. Applied Clay Science 38, 23-32.

[2] Al-Rawas, A.A., Hago, A.W., Al-Sarmi, 2005. Effect of lime, cement and sarooj (artificial pozzolan) on the swelling potential of an expansive soil from Oman. Building and Environment 40, 681-687.

[3] Asavasipit, S., Nanthamontry, W., Polprasert, C., 2001. Influence of condensed silica fume on the properties of cement based solidified wastes. Cement and Concrete Research 31, 1147-1152.

[4] Benziane, M.M., Della, N., Denine, S., Sert, S., Nouri, S., 2019. Effect of randomly distributed polypropylene fiber reinforcement on the shear behavior of sandy soil. StudiaGeotechnica et Mechanica, 1-9.

[5] Cetin, H., Fener, M., Gunaydin, O., 2006. Geotechnical properties of tire-cohesive clayey soil mixtures as a fill material. Engineering Geology 88, 110-120.

[6] Cruzda, K.A., Hohmann, M., 1997. Freezing effect on strength of clayey soils. Applied Clay Science 12, 165-187.

[7] Cuisinier, O., Le Borgne, T., Deneele, D. and Masrouri, F., 2011. Quantification of the effects of nitrates, phosphates and chlorides on soil stabilization with lime and cement. Engineering Geology 117 (3-4), 229-235.

[8] Guney, Y., Sari, D., Cetin, M., Tuncan, M., 2007. Impact of cyclic wetting-drying on swelling behavior of lime-stabilized soil. Building and Environment 42, 681-688.

[9] Hejazi, S.M., Sheikhzadeh, M., Abtahi, S.M., Zadhoush, A., 2012. A Simple Review of Soil Reinforcment by Using Natural and Synthetic Fibers, Construction and Building Materials, 30, 100-116.
[10] Ingles, O.G, Metcalf, J.B., 1977. Soil Stabilization Principles and practice, 2nd ed, Australia Butterworths.
[11] Jorat, M.E., Kreiter, S., Moerz, T., Moon, V., de Lange, W., 2013. Strength and compressibility characteristics of peat stabilized with sand columns. Journal of Geomechanics and Engineering 5 (6), 575-594.
[12] Kalkan, E., 2011. Impact of Impact of wetting-drying cycles on swelling behavior of clayey soils modified by silica fume. Applied Clay Science 52 (4), 345-352.
[13] Kalkan, E., 2012. Effects of waste material-lime additive mixtures on mechanical properties of granular soils. Bulletin of Engineering Geology and the Environment 71 (1), 99-103
[14] Kalkan, 2013. Preparation of scrap tire rubber fiber–silica fume mixtures for modification of clayey soils. Applied Clay Science 80-81, 117-125.
[15] Kalkan, E., Akbulut, S., 2004. The positive effects of silica fume on the permeability, swelling pressure and compressive strength of natural clay liners. Engineering Geology 73, 145-156.
[16] Kalkan, E., Yarbaşı, N., 2013. Use of marble dust waste material for stabilization of compacted clayey soils. Jökull Journal 63 (5), 322-344.
[17] Kolias, S., Kasselouri-Rigopoulou, V., Karahalios, A., 2005. Stabilization of clayey soils with high calcium fly ash and cement. Cement and Concrete Composites 27, 301-313.
[18] Lambe, T.W., Whitman, R.V., 1979. Soil Mechanics, SI version, New York, Wiley.
[19] Liu, J., Feng, Q., Wang, Y., Bai, Y., Wei, J., Song, Z., 2017. The Effect of Polymer-Fiber Stabilization on the Unconfined Compressive Strength and Shear Strength of Sand. Advances in Materials Science and Engineering 2017, 1-9.
[20] Lv, X., Zhou, H., 2019. Shear Characteristics of Cement-Stabilized Sand Reinforced with Waste Polyester Fiber Fabric Blocks. Advances in Materials Science and Engineering 1-12.
[21] Moavenian, M.H., Yasrobi, S.S., 2008. Volume change behavior of compacted clay due to organic liquids as permeant. Applied Clay Science 39, 60-71.
[22] Mohamedgread, F., Yarbaşi, N., Kalkan, E., 2019. Reinforce in Engineering Properties of Clayey Soils Using Cigarette Butts and Marble Dust. European Journal of Advances in Engineering and Technology 6(8), 31-37.
[23] Muntohar, A.S., Wıdıantı, A., Hartono, E., Dıana, W., 2013. Engineering Properties of Silty Soil Stabilized with Lime and Rice Husk Ash and Reinforced with Waste Plastic Fiber. J. Mater. Civ. Eng. 25:1260-1270.
[24] Prabakar, J., Sridhar, R.S., 2002. Effect of Random Inclusion of Sisal Fibre On Strength Behavior of Soil. Construction and Building Materials, 16, 123-131.
[25] Prabakar, J., Dendorkar, N., Morchhale, R.K., 2003. Influence of fly ash on strength behavior of typical soils. Construction and Building Materials 18, 263-267.
[26] Puppala, A.J., Musenda, C., 2002. Effects of fiber reinforcement on strength and volume change in expansive soils. Transportation Research Record 134-140 (Paper No: 00-0716).
[27] Rahmannejad, M., Toufigh, V., 2018. Influence of Curing Time and Water Content on Unconfined Compressive Strength of Sand Stabilized Using Epoxy Resin. International Journal of Engineering 31 (8), 1187-1195.
[28] Ranjan, G., Vasan, R.M., Charan, H.D., 1994. Behaviour of Plastic fibre-Reinforced Sand. Geotextiles and Geomembranes 13 (8), 555-565.
[29] Senol, A., Edil, T.B., Benson, C.H., 2006. Soft subgrades' stabilization by using various fly ashes. Resources Conservation and Recycling 46 (4), 365-376.
[30] Sezer, A., Inan, G., Yilmaz, H.R., Ramyar, K., 2006. Utilization of a very high lime fly ash for improvement of Izmir clay. Building and Environment 41, 150-155.
[31] Sherwood, P., 1993. Soil stabilization with cement and lime. State of the art review. London: Transport research laboratory, HMSO.
[32] Shooshpasha, I., Shirvani, R.A., 2015. Effect of cement stabilization on geotechnical properties of sandy soils. Geomechanics and Engineering 8 (1), 17-31.
[33] Viklander, P., 1997. Compaction and thaw deformation of frozen soil, permeability and structural effects due to freezing and thawing. PhD Thesis, Luea University of Technology, Luea, Sweden.
[34] Viklander, P., Eigenbrod, D., 2000. Stone movements and permeability changes in till caused by freezing and thawing. Cold Regions Science and Technology 31, 151-162.
[35] Yarbaşı, N., Kalkan, E., 2019a. The Stabilization of Sandy Soils by Using the Plastic Bottle Waste. International Journal of Advance Engineering and Research Development 6 (11), 140-144.
[36] Yarbaşı, N., Kalkan, E., 2019b. Use of Waste Material (Oltu Stone Waste) for Soil Stabilization. International Journal of Latest Technology in Engineering, Management & Applied Science 8 (11), 102-107.
[37] Yetimoglu, T., Salbas, O., 2003. A study on shear strength of sands reinforced with randomly distributed discrete fibers. Geotextiles and Geomembranes 21, 103-110.
[38] Zaimoglu, A.S., 2010. Freezing-Thawing Behavior of Fine-Grained Soils Reinforced with Polypropylene Fibers. Cold Regions Science and Technology 60, 63-65.