Bitlis Eren Üniversitesi Fen Bilimleri Dergisi
BİTLİS EREN UNIVERSITY JOURNAL OF SCIENCE
ISSN: 2147-3129/e-ISSN: 2147-3188
VOLUME: 13 NO: 2 PAGE: 400-407 YEAR: 2024
DOI:10.17798/bitlisfen.1404308

Evaluation of the Contribution of Bayburt Tuffite (Bayburt Stone) Dust to the After Freeze-Thaw Strength Values of High Plasticity Clay Soils

Rıdvan KUL[1], Necmi YARBAŞI[2*]

[1] *Atatürk University, Graduate School of Sciences, Graduate student, Erzurum, Turkey*
[2] *Atatürk University, Faculty of Engineering, Civil Engineering Department, Erzurum, Turkey.*

(ORCID: 0000-0003-1336-4471) (ORCID: 0000-0003-4259-1278)

Keywords: Clay soil, Bayburt tuffite, strength, freeze-thaw

Abstract

In parallel with the increasing housing need in parallel with the population growth and the changing needs of the society depending on the continuous technological developments, the strength properties of the soils considered problematic such as high plasticity clay should be improved. In the last twenties when global climate changes started to be experienced, the improvement of the geotechnical properties of such soils that form the basis of engineering structures has become an important issue. Today, natural rocks are one step ahead of other additives in terms of being economical, sustainable and environmentally friendly. Based on this basic idea, in our study, Bayburt tuffite was added to the clay soil by powdering it at the rates of 5%, 10%, and 15% and the strength change after freezing-thawing was examined. The clay soil (CS) + Bayburt tuffite powder (BTP) mixture samples obtained at three different rates were cured in the laboratory environment for 7, 14 and 28 days. At the end of the curing period, the samples were subjected to +20ºC, -20ºC, 12 hours and 10 cycles in the freeze-thaw cabin and then the strength values were obtained with the Uniaxial pressure tester. The highest strength value after freezing-thawing was observed to increase by 29.55% in the CS + 5% BTP mixture cured for 28 days. As a result, in the light of the obtained data, it was concluded that this mixture ratio can be used as a foundation material in cold climate regions, shallow foundation depths and high plasticity clay soils.

1. Introduction

The strength properties of clayey soils that have not been sufficiently consolidated in the geological process and have weak geo-engineering properties can vary significantly under seasonal freeze-thaw cycles. Therefore, such clayey soils, which form the foundation or sub-base of engineering structures, have properties such as low bearing capacity, high plasticity, swelling, shrinkage, compressibility and low permeability due to the presence of the montmorillonite minera[1]. For this reason, the geotechnical properties of such high plasticity clay soils, which form the basis of engineering structures, need to be improved. In the last twenties, waste/residue materials, natural rocks and minerals, in addition to various chemicals and synthetic materials, have begun to be used significantly as additives in the improvement or strengthening of such soils.

In the modification of clay soils, waste/residue materials and natural rocks or minerals are widely used today as additives, both because they can reduce environmental pollution by reducing carbon dioxide emissions, which is a global problem, during production, and because they are economical and environmentally friendly [2-10].

In addition to natural, synthetic or various chemicals used within the scope of ground improvement, natural rocks and minerals are now frequently used in civil engineering because they are economical, sustainable, strength-increasing and environmentally friendly materials.

For this purpose, Tekin et al. (2012) in their study titled The Use of Bayburt Stone as an Improvement Material in Road Infrastructures,

---

[*] Corresponding author: nyarbasi@atuni.edu.tr

Received:13.12.2023 Accepted:10.06.2024

determined that Bayburt stone residue + Lime mixtures can be used as stabilization material in the sub-base layers of highways [11]. Yılmaz et al. (2015) used green Bayburt Stone mixtures to improve the usage properties of clay subbase layers [12], while Tekin (2016) created geopolymer composites using NaOH and marble, travertine, and volcanic tuff wastes as alkaline activators [13]. Additionally, Aykut (2017) used Bayburt Stone waste in the production of high-strength building bricks using the alkaline activator Sodium Hydroxide (NaOH) and geopolymerization method [14], while Taş et al. (2018) Bayburt tuffite obtained from fly ash and industrial wastes is used both as a material and to increase the strength of coarse or fine-grained materials with weak strength [15]. Tekin et al. (2018). In their study, it was determined that polynaphthalene sulfonate based superplasticizer can be used as a material in cements with white Bayburt stone addition [16].

The Bayburt Tuffite (Bayburt stone) powder used in this study is important in that it can be used to increase the strength of clayey soils, which are considered problematic soils, and to observe the change in strength values as a result of freezing and thawing.

It is of particular importance due to its contributions to today's world, especially where global climate changes have begun to take effect. The positive effect of the freeze-thaw effect on the strength (strengthening) of soils will make it possible to use it as both a building material and a shallow foundation material for engineering structures, especially in cold climate regions.

2. Material and Method

2.1. Clayey soil (CS)

CS materials were taken from the Oligocene aged unit of Oltu district of Erzurum province, northeastern Turkey. It is green in color and has the characteristics of a consolidated clayey rock [15].CS sample and granulometry graph in Figure 1, XRD and SEM images in Figure 2, and geotechnical properties are given in Table 1.

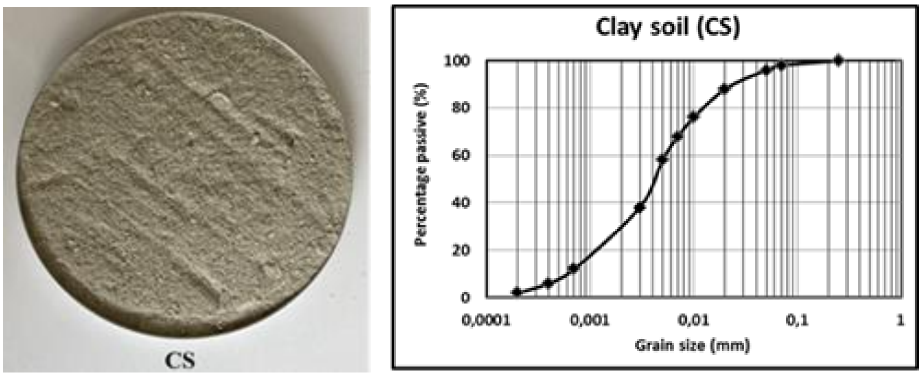

Figure 1. CS sample and granulometry

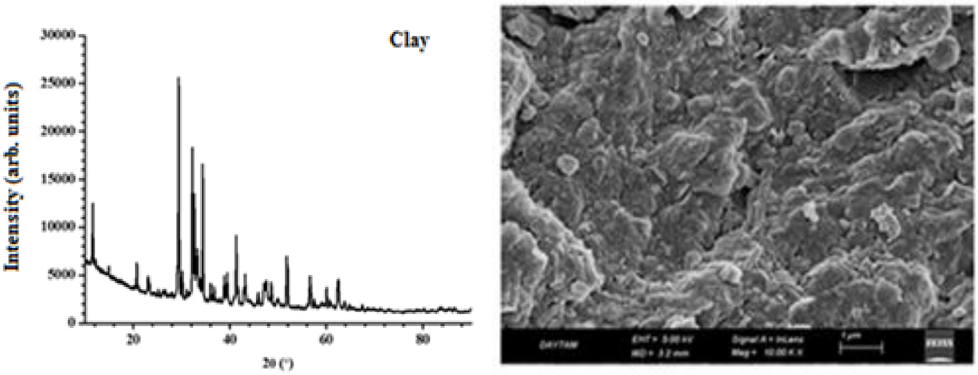

Figure 2. XRD graph and SEM image of CS

Tablo 1. Geotechnical properties of CS [17]

Basic characteristics	Data
Specific weight	2,64
Sand (%)	10,0
Silt (%)	58,0
Clay (%)	32,0
WL (%)	68
PL (%)	28
PI (%)	40
[1]Optimum water amount, (%)	25,8
[1]Max. dry weight, (kN/m^3)	14,1
[2]Soil category	CH

[1] Obtained from Standard Proctor Test.

[2] Soil class according to Unified Soil classification System (USCS)

2.2. Bayburt tuffite powder (BTP)

BTP is located as tuffite layers within the Yazyurdu Formation, which consists of Eocene-aged volcano-sedimentaries and carbonate units unconformably located on Jurassic-aged units cropping out in Bayburt province and its surroundings. It can be seen in yellowish, green spotted, yellow and green wavy colors. Bayburt stone has low hardness (2-3 on the Mohs scale) and chemically contains high amounts of silica ($Na_2(SiO_2)nO$) [11].

BTP sample and its granulometry are shown in Figure 3, XRD and SEM images are shown in Figure 4, and physico-chemical properties are shown in Table 2.

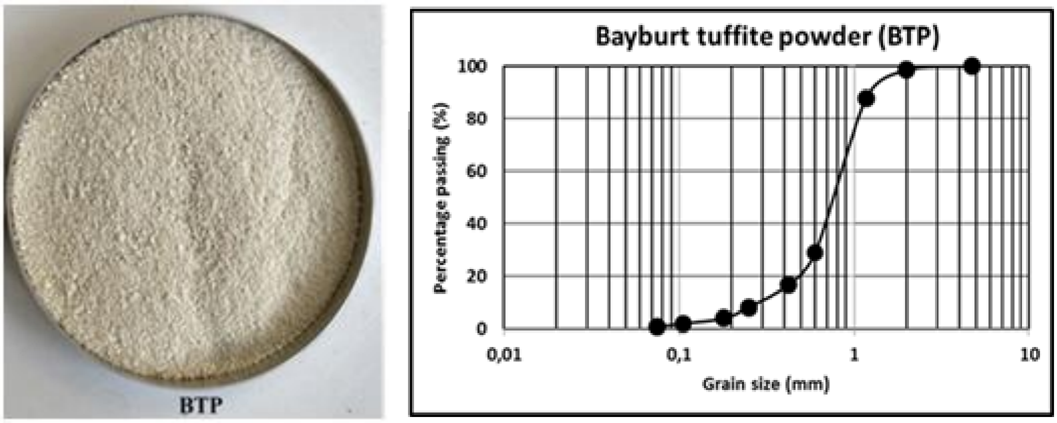

Figure 3. The BTP sample and granulometry

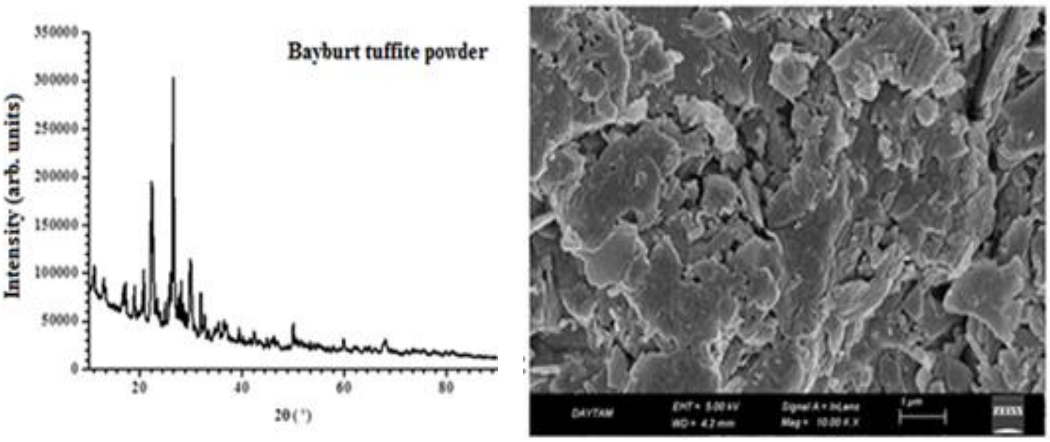

Figure 4. XRD and SEM images of BTP sample

Tablo 2. Physico-chemical properties of BTP [12]

Chemical properties	Data (%)
Total SiO_2	69,96
Al_2O_3	12,25
Fe_2O_3	0,33
CaO	2,52
MgO	1,20
SO_3	0,05
K_2O	2,43
Na_2O	0,57
Cl	0,0280
Physical properties	**Data**
Specific weight (g/cm^3)	2,31
Surface area (cm^2/g)	7193
Activation	8,8

2.3. Testing Procedures

The CS samples used in this study were obtained by excavating from the Oligocene-aged sedimentary unit in the west of the Oltu (Erzurum) district, from a depth of 0.75 m from the surface. The clay soil samples brought to the laboratory environment were dried in an oven at 105±5°C for 24 hours, and then the hardened grains were ground in the Los Angeles machine at 6000 rpm.

Bayburt tuffite (Bayburt stone), which constitutes the second important element of this study, was obtained from rocks deposited in Eocene-aged lacustrine basins that crop out in large areas in Bayburt province and its immediate surroundings. After the yellow-white colored (yellowish) BTP was broken and disintegrated, it was ground into powder at 6000 rpm in the abrasion device.

CS and BTP mixture samples were obtained under dry environmental conditions by adding BTP at the rates of 5%, 10%, and 15% of the dry weight of the CS sample. Mixing proportions are shown in Table 3. The mixtures were mixed manually for at least 3 minutes with the necessary precision. Each mixture was compacted under standard proctor energy at the optimum water content determined by the compaction test. The compaction test results of the mixture samples are shown in Table 4.

Table 3. Mixing and ratios

Mixtures/Ratios	CS (%)	BTP (%)
MIX0 (CS)	100	---
MIX1 (CS+5% BTP)	95	5
MIX2 (CS+10% BTP)	90	10
MIX3 (CS+15% BTP)	85	15

Table 4. Compaction test results of mixtures

Samples	Max. dry weight (g/cm^3)	Opt. water amount (%)
MIX1	1,330	35,7
MIX2	1,294	34,2
MIX3	1,328	35,0

2.3.1. Compaction (Standard proctor) test

Standard proctor testing was performed according to ASTM D 698-12 (2021) [18] standards. In this test, optimum moisture content and maximum dry volume weight values are determined from the graph obtained from the relationship between dry unit volume weight and moisture content.

2.3.2. Uniaxial compressive strength (UCS) test

UCS values of BTP-doped CS samples were obtained according to ASTM D 2166-06 (2010) [19] standards. Determination of strength values was carried out in a uniaxial compression device on cylindrical samples (35 mm-70 mm) compressed at optimum moisture content.

2.3.3. Freezing and thawing (F-T) test

F-T tests were performed with a programmable freeze-thaw cabinet according to ASTM D 559-03 (2012) [20]. The samples were subjected to F-T tests at +20°C, -20°C, 12 hours, and 10 cycles.

2.3.4. Image analyzes

In order to see and evaluate the interaction between CS and BTP, XRD and SEM image analysis of natural CS and BTP reinforced mixture samples were performed using a scanning electron microscope D8 AXS XRD Spectrometer and Sigma 300 Zeiss Gemini FE-SEM instruments. These analyzes were carried out in the DAYTAM Laboratory established at Atatürk University.

2.3.5. Brunauer-Emmett-Teller (BET) analysis

The surface area and micropore size distribution of CS+BTP mixture samples were determined by BET analysis. These analyzes were performed with Micromeriti CS 3-Flex version 5.00 device in Atatürk University DAYTAM Laboratory.

3. Results and Discussion

3.1. Before-After F-T, UCS analysis

As shown in Table 3, UCS values were obtained after CS soil mixtures reinforced with three different ratios of BTP were cured in a +20^{o}C laboratory environment for 7, 14 and 28 days and with a uniaxial compressive device. When the UCS values were compared with the material (witness) MIX0, it was seen that the highest strength was reached in the MIX1 mixture with a strength increase of 34.38% at the end of 28 days of curing. This mixture was followed by the MIX2 mixture with an increase of 18.75% and the MIX3 mixture with a 10.94% increase under the same conditions. The UCS graph of CS soil mixtures reinforced with BTP before freeze-thaw is shown in Figure 5 [21].

F-T tests were performed with a programmable freeze-thaw cabinet. CS soil mixtures reinforced with BTP at three different rates (5%, 10%, and 15%) were cured for 7, 14, and 28 days and then subjected to F-T test for 12 hours and 10 cycles at +20^{o}C, -20^{o}C. At the end of this test, UCS values were obtained with a uniaxial free pressure device. It was observed that the highest UCS strength value of BTP added CS samples after F-T was in the MIX1 mixture with an increase rate of 29.55%. This mixture is followed by the MIX2 mixture with 13.18% and the MIX3 mixture with 2.73%. The UCS distribution of CS + BTP mixture samples after F-T is Show in figure 5.

When the strength values before and after freeze-thaw were compared, it was seen that the lowest strength loss occurred in the MIX1 mixture with 4.83% after 28 days of curing. The other lowest strength losses following this mixture were 5.57% in the MIX2 mixture and 8.21% in the MIX3 mixture after 28 days of curing. In addition, the strength values obtained with a 28-day cure and 5% BTP mixture showed that the strength values both before and after F-T were the highest. It was seen in the data that increasing the BTP ratio (10%, 15%) in clayey soils caused a decrease in the strength of the mixtures.

Increases were observed in the strength values of the CS+BTP mixture both before and after freezing-thawing. In the graphical representations in Figure 5, it is seen that adding 5% BTP to CS significantly increases the strength of the sample, and the strength values in CS mixtures with 10% and 15% BTP addition decrease compared to CS. Mixture with 5% BTP addition. While the curing period had a positive effect on the development of this situation, the increase in the BTP rate caused strength decreases. However, when compared to the CS values, which is the main material, it is seen that the increase in strength values occurs at three different rates. As a result, the addition of 5% BTP material to CS material is the mixture in which the highest strength values are obtained before and after freezing-thawing.

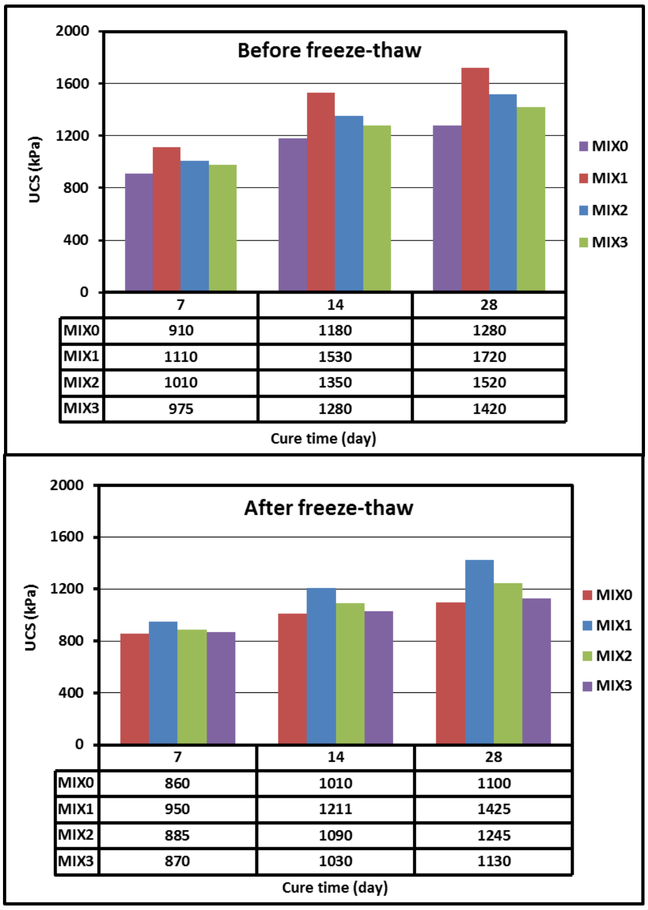

Figure 5. UCS distribution of samples before-after F-T

4.2. XRD analyzes

XRD plots of BTP-reinforced CS samples after F-T are shown in Figure 6. In the after F-T graphs of MIX0, MIX1, MIX2 and MIX3 samples, peaks are observed at the angles corresponding to 16^{o}, 26^{o}, 28^{o} and 30^{o}. It is thought that the changes in the intensity of these peaks are caused by the Si (silicon) mineral (approximately 70% SiO2), which is proportionally more abundant in BTP. Because the effect of the silicon mineral is observed in the XRD graphs after F-T, which reduces the peak intensities of the minerals in the clayey soil.

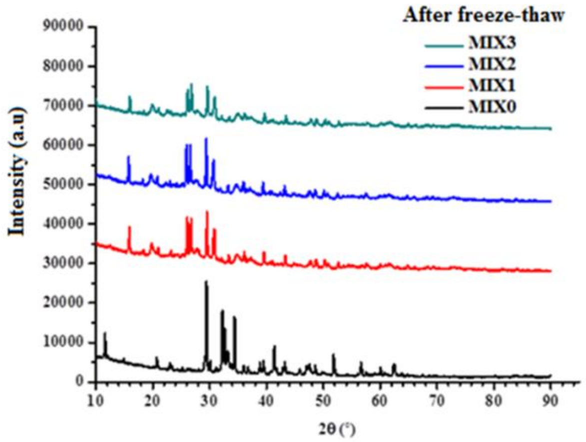

Figure 6. XRD graphs of samples after F-T

4.3. SEM analyzes

SEM images of BTP-enhanced CS mix samples (MIX0-2, MIX1-2, MIX2-2, MIX3-2) after FT are shown in Figure 7. In the SEM image of CS shown in MIX0-2 after FT, it is seen that the effect of F-T causes fractures and cracks in the internal structure of CS. BTP contribution to CS In parallel with the increase in BTP ratio, it was observed that fractures and cracks were more prominent in MIX2-2 and MIX3-2 mixtures after F-T, but this effect was much less in the MIX1-2 mixture. The reason why the highest strength values in unconfined compressive strength are obtained in MIX1-2 is also revealed in SEM images.

4.5. Brunauer-Emmett-Teller (BET) analysis

The surface area measurements, micropore size, and pore size distribution of pelleted mixture samples after F-T was determined by the BET analysis method. With this method, the surface area (m^2/g) was calculated by determining the amount of nitrogen gas required to cover the sample surface with a single molecular layer. The surface area measurements of the mixtures after F-T are shown in Table 5 and the pore size distribution graph is shown in Figure 8. When the surface area data of the mixture samples in Table 5 are examined; It was observed that as the BTP ratio in the CS increased, the surface areas decreased. When the pore distribution graph shown in Figure 8 is examined; It has been observed that the pore distributions of the mixture samples have a concentrated micro and mesoporous structure in the range of 1-20 nm.

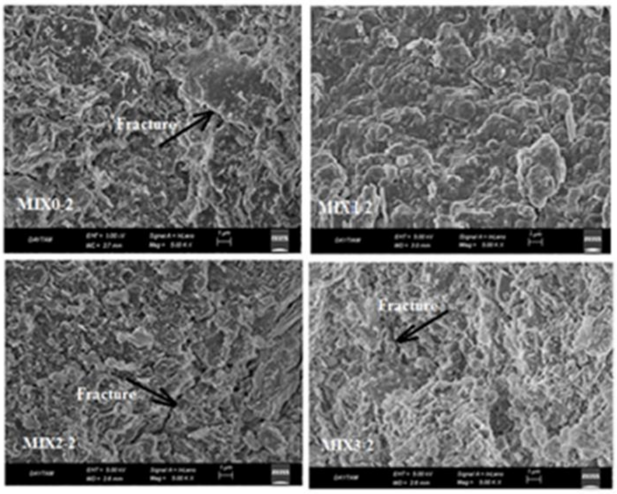

Figure 7. SEM images of the samples after F-T

Table 5. BET surface area measurement results of the mixtures after F-T

Mixtures	BET Surface area (m^2/g)
MIX1	43.8546
MIX2	40.5498
MIX3	40.3348

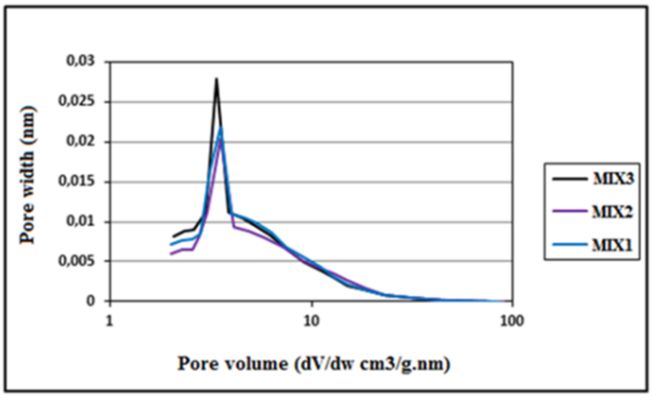

Figure 8. The pore distributions of the mixtures after F-T

5. Conclusion and Suggestions

The effects of three different mixture samples of BTP reinforced CS on strength after F-T were determined with a UCS device. The structural properties of the samples under the influence of F-T were investigated by XRD and SEM analysis, and their surface areas and pore structure were examined by BET analysis.

The highest strength value of CS soil reinforced with BTP before F-T occurred in the MIX1 mixture with an increase rate of 34.38%. This mixture was followed by MIX2 with an increase rate of 18.75% and MIX3 with an increase rate of 10.94%. After F-T, the highest strength increase occurred in the MIX1 mixture with 29.55%, followed by the MIX2 mixture with a 13.18% increase rate and the MIX3 mixture with a 2.73% increase rate.

BTP added to CS affected the main structure of the clay. This effect is achieved by Si (Silicon), the dominant mineral of BTP. As a result of this effect, it has been observed that the structure of the clay soil becomes more compact as a result of the decrease in porosity. The compact structure is clearly seen in the reduction of the intensity of the peaks in both XRD graphs and SEM images.

In addition, when the surface area and pore distributions of the mixture samples after F-T were examined by BET analysis, it was observed that as the BTP mixture ratio increased in CS, the surface areas decreased and the pore distributions had a concentrated micro and mesoporous structure in the range of 1-20 nm.

As a result, it was concluded that BTP-added CS soils can be used as base or subbase material, especially in cold climate regions and engineering applications. It is evaluated that this study will contribute to future studies on the changes in the strength values of CS+BTP mixtures, especially under the freeze-thaw effect.

Contributions of the authors

Author 1: Experimental study.

Author 2: Methodology, writing, supervising, reviewing and editing.

Conflict of Interest Statement

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics

Acknowledgment

This experimental research was supported by Atatürk University BAP unit with ID number 10401 and code FYL-2022-10401.

References

[1] J. Zhang, X. Cao, “Stabilization of expansive soil by lime and fly ash”. *J. Wuhan Univ. Technol.* Vol. 17, no. 4, pp.73–77. 2022. Doi:10.1007/BF02838423.

[2] A.J. Puppala, C. Musenda, “Effects of fiber reinforcement on strength and volume change in expansive soils”. *Transportation Research Record* 134-140 (Paper No: 00-0716). 2002.

[3] S.M. Hejazi, M. Sheikhzadeh, S.M. Abtahi, and A. Zadhoush, “A Simple Review of Soil Reinforcement by Using Natural and Synthetic Fibers”, *Construction and Building Materials,* vol. 30, pp.100-116. 2012. Doi: 10.1016/j.conbuildmat.2011.11.045.

[4] N. Yarbasi, “Performance of granular soils reinforced with obsidian (volcanic glass) additives in different proportions subjected to freeze-thaw”, *Pamukkale University Journal of Engineering Sciences* vol. 25, no.6, pp.764-767. 2019. Doi:10.5505/pajes.2019.39049.

[5] N. Yarbaşı, E. Kalkan, “Use of Waste Material (Oltu Stone Waste) for Soil Stabilization”. *International Journal of Latest Technology in Engineering, Management & Applied Science (IJLTEMAS)* Volume VIII, Issue XI, November 2019 | ISSN 2278-2540. 2019.

[6] E. Kalkan, N. Yarbasi, Ö. Bilici,“The Effects of Quartzite on the Swelling Behaviors of Compacted Clayey Soils”. *International Journal of Earth Sciences Knowledge and Applications* vol. 2, no. 2 pp. 92-101. 2020.

[7] N. Yarbaşi, “Effect of Freezing-Thawing on Clayey Soils Reinforced with Human Hair Fibers”. *Journal of Natural Fibers,* vol.17, no. 6, pp. 921-931.2020. https://doi.org/10.1080/15440478.2019.1690614.

[8]. N. Yarbasi, E. Kalkan, “The Mechanical Performance of Clayey Soils Reinforced with Waste PET Fibers”. *International Journal of Earth Sciences Knowledge and Applications* vol. 2, no. , pp. 19-26. 2020.

[9] C. Ince, S. Derogar, N.T. Tiryakiog, Y.C. Toklu, “The influence of zeolite and powdered Bayburt stones on the water transport kinetics and mechanical properties of hydrated lime mortars”. *Construction and Building Materials* vol. 98, pp. 345–352. 2015. https://doi.org/10.1016/j.conbuildmat.2015.08.118.

[10] A.O. Yılmaz, İ. Alp, C. Demir, M. Arslan, H. Kolaylı,“Physical, Mechanical, Petrographic Properties of Bayburt Tuff (Bayburt Stone)”, *TMMOB, Chamber of Mining Engineers*. 2005.

[11] Tekin, H.A. Kamiloglu, E. Yurdagül, “Usage Of Bayburt Stone In Road Infrastructures As A Improvement Material” Conference: *International Conference On Traffic And Transport Engineering,* Belgrade, Volume: 1, October 2012.

[12] F. Yılmaz, H.A. Kamiloglu, and E. Sadoglu, “Soil Stabilization with Using Waste Materials against Freezing Thawing Effect”. *Acta Physica Polonica* A, Vol. 128, Special issue of the International Conference on Computational and Experimental Science and Engineering (ICCESEN 2014). 2015.

[13] I. Tekin, “Properties of NaOH activated geopolymer with marble, travertine and volcanic tuff wastes”. *Construction and Building Materials* vol. 127, pp. 607–617. 2016. http://dx.doi.org/10.1016/j.conbuildmat.2016.10.038.

[14] C. Aykut, “Investigation of the usability of Bayburt stone waste in the production of geopolymer bricks”. Master's thesis, Bayburt University (Turkey), Institute of Science and Technology. 2017.

[15] M. Taş, D. Fidan, F. Yılmaz, “Soil Stabilization with Fly Ash and Bayburt Stone”, *Bayburt University (Turkey) Journal of Science* vol 1, no. 1., 2018.

[16] I. Tekin, D. Tekin. “ Effect Of The Polynaphtalene Sulfonate Based Superplasticizer On Mechanical And Physical Properties Of Blended Cement Replaced With Bayburt Stone At Different Fineness”, *Pamukkale Univ Muh Bilim Derg,* vol. 24, no. 3, pp. 419-425, 2018.

[17] E. Kalkan, M.S. Bayraktutan, “Geotechnical evaluation of Turkish clay deposits”: a case study in Northern Turkey. *Environmental Geology* vol. 55, no.5, pp. 937-950. Doi: 10.1007/s00254-007-1044-8. 2008.

[18] ASTM D 698-12, “Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort” (12,400 ft-lbf/ft^3 (600 kN-m/m^3). 2021.

[19] ASTM D 2166-06, “Standard Test Method for Unconfined Compressive Strength of Cohesive Soil”. 2010.

[20] ASTM D 559-03, “Standard Test Methods for Wetting and Drying Compacted Soil-Cement Mixtures” (Withdrawn 2012).

[21] N. Yarbaşı, R.Kul, “Compressive Strength Of Clayey Soils Reinforced With Bayburt Stone (Bayburt Tuffite)”, International Congress on Innovation Technologies & Engineering "On the occasion of the 40th Anniversary of Ege University, Graduate School of Natural and Applied Sciences" 207-211, Ege University, Izmir, Türkiye, 2022.