Use of Waste Material (Oltu Stone Waste) for Soil Stabilization

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***Abstract*: It is difficult to find natural soil that provided high strength and high durability in practice. Construction on the soils of this type cause difficulties and problematic because of soft soils is less stable and massive primary and long term consolidation settlements when subjected to even moderate load increases. To get stronger soil, unbound materials can be stabilized with cementitious materials such as cement, lime, fly ash, bitumen or combination of these. The stabilized soil materials have a higher strength, lower permeability and lower compressibility than the native soil. In this study, waste material emerged from Oltu Stone was used as additive material for stabilization of sandy soil. The Oltu Stone is an organic matter known as geological material. When it is taken from the quarry as raw material and converted into product, a large part of it turns into waste. Therefore, this work aims to research the usability of the Oltu Stone waste to stabilize the grained soils. In the experimental study, 0,5%, 1% and 2% percentages of Oltu Stone waste were added to the grained soils and prepared samples were subjected to related tests. The test results show that the grained soil samples stabilized by Oltu Stone waste have a high compressive strength as compared to natural grained soil samples. Consequently, it is concluded that Oltu Stone waste materials can be successfully used for the stabilization of the grained soils in geotechnical applications.**

***Keywords*: Oltu Stone, Waste material, Grained soil, Soil stabilization, Freeze and thaw**

I. INTRODUCTION

Soil is a natural body consisting of layers of mineral constituents of variable thickness, which differ from the parent materials in their morphological, physical, chemical, and mineralogical characteristics. Most of the constructions in engineering structures especially the construction of buildings and roads are preferably build on the soil that is strong and stable. Nevertheless, in practice, it is difficult to find natural soil that provided high strength and high durability. The problem of high compressibility is now becoming a major issue when construction built on soft soil terrain. Some types of soil can be classified as soft soil such as peat, clay, organic soil and others. Construction on the soils of this type cause difficulties and problematic because of soft soils is less stable and massive primary and long term consolidation settlements when subjected to even moderate load increases (Makusa, 2012; Hamzah et. al., 2015).

Construction of buildings and other civil engineering structures on weak or soft soil is highly risky because such soil is susceptible to differential settlements due to its poor shear strength and high compressibility. Improvement of certain desired properties like bearing capacity, shear strength parameters and permeability characteristics of soil can be undertaken by a variety of round improvement techniques such as the use of prefabricated vertical drains or soil stabilization (Abuel-Naga et al., 2006; Chu et al., 2006; Tang et al., 2007; Yarbaşıand Kalkan, 2019).

Generally, soil stabilization is a method of improving soil properties by blending and mixing other materials. Improvements include increasing the dry unit weight, bearing capabilities, volume changes, the performance of in situ subsoils, sands, and other waste materials in order to strengthen road surfaces and other geotechnical applications (Firoozi et. al., 2017). The concept of stabilization is 5000 years old. The stabilized earth roads were used in ancient Egypt and Mesopotamia and that the Greeks and Romans used lime as a stabilizer (McDowell, 1959). However, recent heaving and premature pavement failures in lime and cement-treated subgrades containing sulfates led to questioning the validity of calcium-based stabilization. When expansive soils containing sulfates are treated with calcium-based stabilizers, the calcium from the stabilizer reacts with soil sulfates and alumina to form the expansive mineral ettringite(Puppala et. al., 1999; Kaminskas and Barauskas, 2014; Saussaye et. al., 2015; Mohamedgread et. al., 2019).

Soil stabilization is the process of improving the load bearing capacity and engineering properties of subgrade soil to support pavements and structures. In last decades, using of natural or synthetic materials in the field of soil stabilization especially for coarse or fine-grained soils with poor physical and mechanical properties becomes very common. It is considered as the main condition that these materials, generated as waste or residual, have economic, sustainable and environmental importance (Ogundare et. al., 2018; Mohamedgread et. al., 2019).

Several soil stabilization methods are available for stabilization of expansive clayey soils. These methods include the use of chemical additives, rewetting, soil replacement, compaction control, moisture control, surcharge loading, and thermal methods (Chen, 1988; Nelson and Miller, 1992; Yong and Ouhadi, 2007). Many investigators have studied natural, fabricated, and by-product materials and their use as additives for the stabilization of clayey 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 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; Mohamedgread et. al., 2019; Yarbaşı and Kalkan, 2019).

Oltu stone is one of the best examples of semi-precious stones. As a natural, fossilized product, amber is accepted as an organic material in view of different science disciplines and arts (Buchberger et al., 1997). It is considered to be a geologic material but not accepted as a real mineral. Therefore, it is a mineraloid that's obtained from decomposing trees. Oltu stone is formed under excessive pressure, from there it does not crystallized as natural carbon material. As a stiff and similar to mineral, Oltu stone is usually black but sometimes it found in blackish, greyish or greenish colors. The most interesting feature of Oltu stone is, when it's become contacted to air, it becomes harden and therefore it becomes easier to process it (Kalkan et al., 2012).

The Oltu stone waste emerges as a by-product from its taken from the quarry as raw material and converting into product. The biggest reservoir of Oltu stone is located in the Oltu district of Erzurum, NE Turkey and Each year, tons of waste emerge as by-product of Oltu stone in the result of both processes. Geological, physical and mechanical properties of this type of material studied with many scientific researches (Buchberger et al., 1997; DonmezandIsık, 1999; Parlak, 2001; Ciftçi et al., 2002; Elagok, 2002; Ciftçi et al., 2004; Karayigit, 2007; Bilgin et al., 2011; Hatipoğlu et al., 2012; Kalkan et al., 2012. But there is not any scientific publication found about the effects of the Oltu stone waste on the engineering properties of sandy soils. This study was conducted to investigate the use of the Oltu stone waste as an additive material for the stabilization of sandy soils to improve the engineering properties.

The main objectives of this research were to produce different utilization areas for Oltu stone waste in geotechnical applications and investigate the effects of it's on the mechanical properties of grained soils. To accomplish these objectives, natural clay material was stabilized by using Oltu stone waste with different contents and the mechanical properties of grained soils were determined in laboratory tests.

II. MATERIAL AND METHOD

2.1. Grained soil

The grained soil used in this research was taken from the corporation of NESCE Group (Erzurum, NE Turkey) which currently operates Erzurum-Oltu road construction. Granular soil was kept for 24 hours in oven at 105 ^{o}C to remove its moisture. After drying procedure, the material was tested for sieve analysis and particles smaller than 4.76 mm was gathered to use for tests (Fig. 1). Grained soil is classified as SW according to the Unified Soil Classification System (USCS). The grain size distribution curve was shown in the Fig. 2. Also, its engineering and index properties was given in the Table 1.

2.2. Oltu stone waste

Oltu stone waste used in this this research was gathered from the Oltu stone processing workshops near the Oltu/Erzurum. Oltu stone sometimes called as black amber, is extracted from the Northeastern region of Oltu district of Erzurum, NE Turkey. The grain size distribution curve was shown in the Fig. 2. Engineering and index properties of Oltu stone waste was given in the Table 2. Oltu stone waste consist of 57.72% of carbon, 38.31% of oxygen and 3.97% of other elements.

Fig. 1. Grained soil and Oltu stone waste

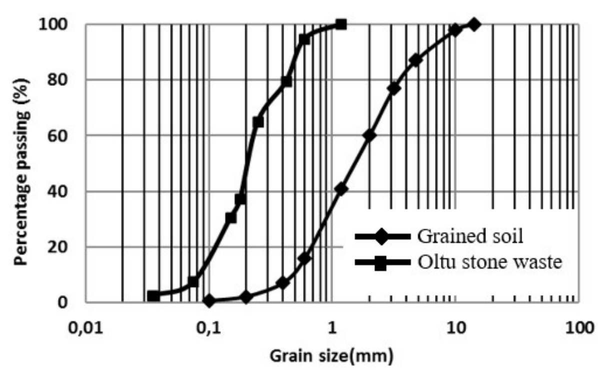

Fig. 2.Grain size distribution curves of grained soil and Oltu stone waste

Table 1.Engineering and index properties of grained soil

Properties	Value	Standard
Specific weight (Gs)	2.58	ASTM D854-00
Gravel (%)	30.0	
Sand (%)	61.0	
Silty (%)	5.80	

Clay (%)	3.20	
Liquid limit (%)	26.10	ASTM 423-66
Plastic limit (%)	12.09	ASTM D424-59
Plasticity index (%)	14.01	
Optimum moisture content (%)	10.50	ASTM D698-78
Maximum dry unit weight (kN/m^3)	19.33	ASTM D698-78
Soil class (USCS)	SW	

Table 2. Engineering and index properties of Oltu stone waste (Kalkan et al., 2012)

Properties	**Value**
Chemical structure	$C_{10}H_{16}0$. Succinic acid
Crystalsystem	Amorphous
Hardness	3 (Mohs)
Specific gravity	1.26
Density(g/cm^3)	1.5
C (%)	78
H_2 (%)	6.72
S (%)	0.9
Ash (%)	0.3
Moisture (%)	2.18
Calorie (Kcal/g)	8064

III. EXPERIMENTAL PROSEDURE

The samples of Oltu stone waste were subjected to characterization analysis for the determination of its characteristic properties. Analysis of Oltu stone waste were performed in Central Laboratories of Ataturk University named East Anatolia High Technology Application and Research Center ((DAYTAM). The structure of granular soil stabilized with Oltu stone waste, is analyzed with XRD and SEM methods. Images taken before and after freeze and thaw cycles. XRD analysis has performed with D8 Phaser AXS spectrometry device, EDX and SEM analysis was has performed with Sigma 300 Zeiss Gemini FE-SEM device.

For the preparation of grained soil-Oltu stone waste mixtures, the grained soil sample was dried in an oven at approximately 105 °C before mixing procedure. Then, the grained soil and Oltu stone waste were blended to prepare mixtures under dry conditions. The amounts of Oltu stone waste were selected to be 0, 5%, 1% and 2% of the total dry weight of samples.

The compaction parameters of samples such as the maximum dry unit weight and the optimum moisture content were obtained by Standard Proctor tests in accordance with ASTM D 698. To determine the compaction parameters, mixtures of grained soil-Oltu stone waste were blended with various amounts of water. Each material was evaluated at six different water concentrations in three steps (Kalkan, 2009). Samples were compacted in molds according to Standard Proctor Compaction in order to obtain undisturbed samples. The samples were extracted from molds by pushing a cylindrical tube. The dimensions of sample are 38 mm in diameter and 76 mm in height.

In order to determine the unconfined compressive strength (UCS) values, the samples were subjected to the unconfined compression tests in accordance with ASTM2166. At least three samples were tested for each combination of variables at a deformation rate of 0.16 mm/min.

The freezing and thawing tests were carried out in accordance with ASTM C 666 to investigate the effects of Oltu stone waste on the freezing and thawing resistance. These tests were performed by a programmable freezing apparatus. For freeze cycles freezer set to -21 °C and for thaw cycles it is set for 21 °C. 12 is selected as cycle count and 24 h is selected for waiting time. Humidity on the freeze-thaw area was 55%.

IV. RESULTS AND DISCUSSION

4.1. Effects of Oltu stone waste on the UCS

The UCS values of the stabilized samples prepared by the addition of various amounts of Oltu stone waste were investigated by unconfined compressive tests. The addition of Oltu stone waste increased the UCS values of stabilized samples (Fig. 3). Also, the natural and the stabilized samples were cured for 1, 7 and 28 days to investigate the effects of curing times on the UCS. As seen in Fig. 3, curing increases the UCS, notably in the first 28 days, as recorded by Thompson (1968) for lime-stabilized soils, by Okagbue and Onyeobi (1999) for marble dust-stabilized soils and by Kalkan (2012) for mixture of waste material and lime-stabilized soils.

The highest UCS results that got from the 28 days of waiting stabilized samples with 0,5%, 1% and 2% Oltu stone waste was compared to untouched sample of natural grained soils. The unconfined compressive tests results showed that stabilized samples containing 0,5%, 1% and 2% Oltu stone waste has increased strength about 68.93%, 84.47% and 52.43%, respectively. In literature, Ola (1978) and Gillot (1968) have reported that soil type, composition, mineralogy, particle shape, and particle size distribution influence the results of soil stabilizations. The extremely fine SF particles, in addition to being a high pozzolanic material, improve the packing of the soil matrix at the interfaces with the soil grains, resulting in a denser stabilized soil sample (Neville and Aitcin, 1998; Hassan et al., 2005; Yarbaşı et al., 2007; Kalkan, 2012).

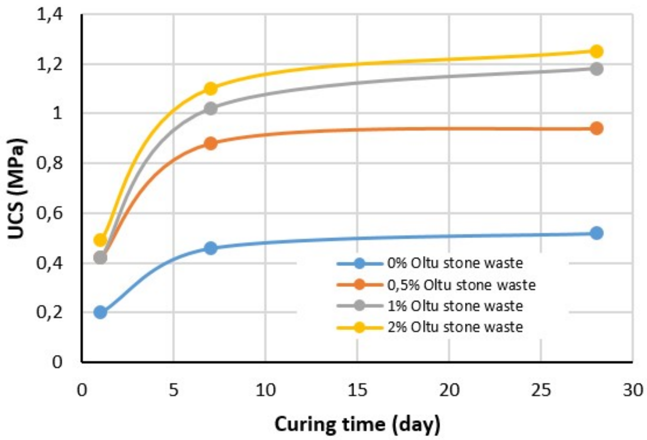

Fig. 3. Effects of Oltu stone waste on UCS of grained soils

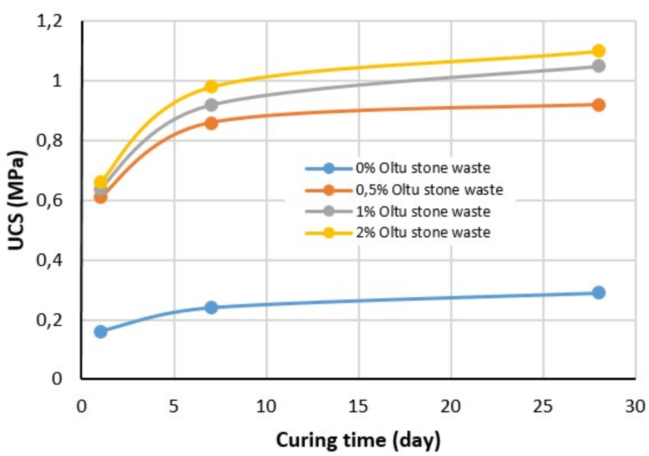

Fig. 4. Effects of Oltu stone waste on UCS of grained soils exposed freeze and thaw

After the freeze and thaw procedure, the UCS values of stabilized samples with 0,5%, 1% and 2% Oltu stone waste increase compared to the unstabilized grained soil samples. The increases due to these rates are 38.84%, 63.11% and 34.96%, respectively (Fig. 4). All three samples have the highest UCS values after the freeze and thaw cycles in 28 days of curing time. This three results compared with the untouched sample of grained soil. Comparison showed that the stabilized samples containing 0,5% Oltu stone waste has 38.84% of strength increase according to untouched sample. This ratio occurred 63.11% for the stabilized samples containing 1% Oltu stone waste and 17.47% for the stabilized samples containing 2% Oltu stone waste. With these results it can be said that the stabilized samples containing 1% Oltu stone waste has the highest value of 63.11%.

4.2. XRD patterns

The XRD pattern of grained soil and Oltu stone waste samples have been shown in the Fig. 5. As seen from the pattern, the sample of Oltu stone waste (blue color) shows a wide peak at 25^o. The sample of grained soil shows (red color) 3 huge and tight peaks close to 28^o and 30^o. These figures indicate that Oltu stone waste and grained soil samples are totally different.

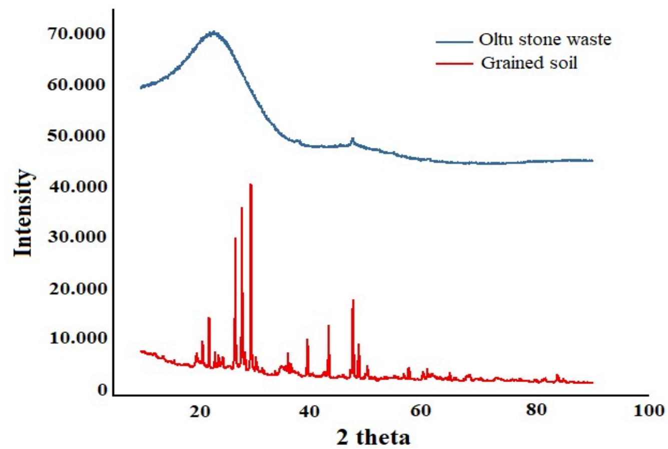

Fig. 5.The XRD pattern of grained soil and Oltu stone waste samples

Fig. 6 shows the XRD pattern of samples of stabilized grained soil with Oltu stone before and after the freeze and thaw cycles. As seen from pattern, carbon metal for 30^o and oxygen element for 28^o have been found. It is considered that, carbon element helps to increase strength in samples of stabilized grained soil with Oltu stone. There have been no differences observed between before and after the freeze and thaw cycles in XRD graphs, but there was a slight change to downwards of amplitudes. This can be explained with the environmental change in other words with the humidity and temperature differences.

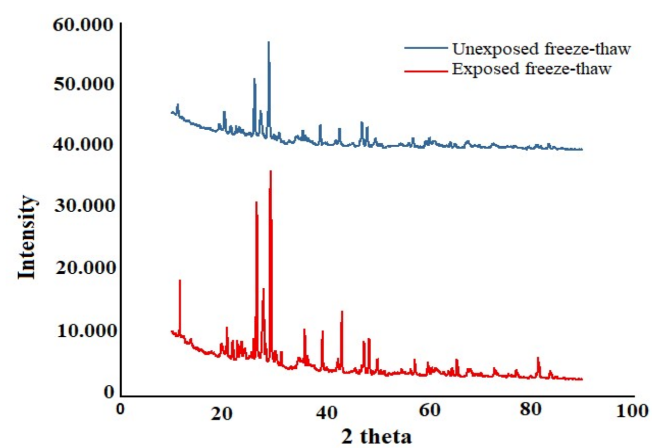

Fig. 6.The XRD pattern of stabilized samples unexposed and exposed freeze-thaw

4.3. SEM images

The SEM images of stabilized grained soil samples with the Oltu stone waste unexposed and exposed the freeze and thaw cycles were shown in the Figs. 7 and 8. It is clear that adding the Oltu stone waste to grained soil made some changes in structure before the freeze and thaw procedure. Oltu stone waste increasing the UCS, also connects the grained materials in soils. After the mixing process, samples become more stiff and have more massive appearance. When morphological appearance examined, it can be seen that the structural characteristics are not changed much but the integrity has increased and granular appearance is mostly disappeared. The cracks in the structure are also an evidence for freeze and thaw process.

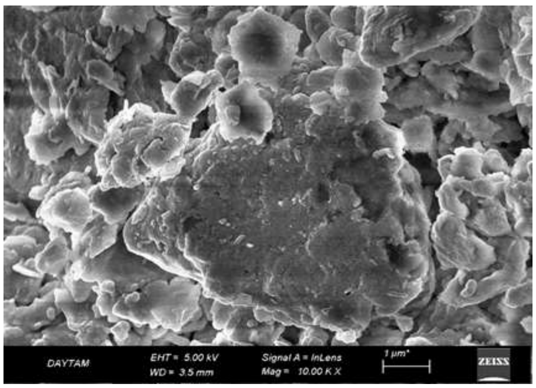

Fig. 7.The SEM image of stabilized samples unexposed to the freeze-thaw

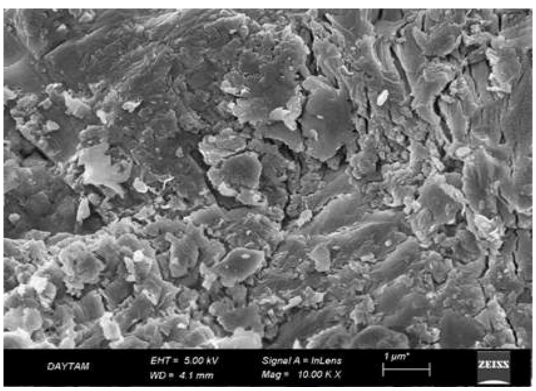

Fig. 8.The SEM image of stabilized samples exposed to the freeze-thaw

V. CONCLUSIONS

In this study, the UCS values of the stabilized samples prepared by the addition of various amounts of Oltu stone waste were investigated by unconfined compressive tests. Some conclusions were drawn from findings of this study. The addition of Oltu stone waste increased the UCS values of stabilized samples. The highest UCS results that got from the 28 days of waiting stabilized samples with Oltu stone waste was compared to untouched sample of natural granular soils. After the freeze and thaw procedure, the UCS values of stabilized samples with Oltu stone waste increase compared to the unstabilized grained soil samples. All samples have the highest UCS values after the freeze and thaw cycles in 28 days of curing time. The XRD pattern indicate that Oltu stone waste and grained soil samples are totally different. It is clear from SEM images that adding the Oltu stone waste to grained soil made some changes in structure before the freeze and thaw procedure.

REFERENCES

[1] Abuel-Naga, H.M., Bergado, D.T., Chaiprakaikeow, S., 2006. Innovative thermal technique for enhancing the performance of prefabricated vertical drain during the preloading process. Geotextiles and Geomembranes 24 (6), 359-370.
[2] Akbulut, S., Arasan, S., Kalkan, E., 2007. Modification of clayey soils using scrap tire rubber and synthetic fibers. Applied Clay Science 38, 23-32.
[3] 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.
[4] 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.
[5] Bilgin, Ö., Kalkan, E., Dilmaç, M.K. 2011. Equipments used for production and processing of Oltu stone. The proccedings of 3rd Mining Machinery Symosium. May 05-06.2011, Izmir. Turkey (in Turkish).
[6] Buchberger, W., Falk, H., Katzmayr, M.U., Richter, A.E., 1997. On the chemistry of baltic amber inclusion droplets. MonatsheftefürChemie-Chemical Monthly 128, 177-181.
[7] Cetin, H., Fener, M., Gunaydin, O., 2006. Geotechnical properties of tire-cohesive clayey soil mixtures as a fill material. Engineering Geology 88, 110-120.
[8] Chu, J., Bo, M.W., Choa, V., 2006. Improvement of ultra-soft soil using prefabricated verticaldrains. Geotextiles and Geomembranes 24 (6), 339-348.
[9] Ciftci, E., Coskun, S., Yalcinalp, B., 2002. Oltustone-mineralogical and physical properties. 55th Geological Congress of Turkey. March 11-15. 2002. Ankara. Turkey.
[10] Ciftci, E., Yalcin, M.G., Yalcinalp, B., Kolaylı, H., 2004. Mineralogical and physical characterization of the Oltustone. a gemstone occurring around Oltu (Erzurum-Eastern Turkey). International Congress on Applied Mineralogy (ICAM 2004). September 19-22. 2004, Brazil.
[11] Donmez, M., Isık, I., 1999. Stratigraphy and Mineralogy of Oltu (Erzurum) Stone beds. Sciences J. Dumlupınar University, 1: 281-295.
[12] Elagok, C., 2002. Oltu Taşı Madenciliği. Osmangazi University Geology Dept., (BSc. Thesis, 34 pp.) 2002. Eskisehir, Turkey.
[13] Hatipoğlu, M., David,A., Kibici, Y., Daniele, P., 2012. Natural carbon black (Oltu-stone) from Turkey: a micro-Raman study. NeuesJahrbuchfürMineralogie - Abhandlungen. 189(1): 97-101.
[14] Firoozi, A.A., Olgun, C.G., Firoozi, A.A., Baghini, M.S., 2017. Fundamentals of soil stabilization. International Journal of Geo-Engineering 8:26, 1-16.
[15] Gillot, J.E., 1968. Clay in Engineering Geology. Elsevier, New York.
[16] 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.
[17] Hamzah, H.N., Abdullah, M.M.A., Yong, H.C., Zainol, M.R.R.A., Hussin, K., 2015. Review of Soil Stabilization Techniques: Geopolymerization Method One of the New Technique. Key Engineering Materials 660, 298-304.
[18] Hassan, H.F., Taha, R., Al Rawas, A., Al-Shandoudi, B., Al-Gheithi, K., Al-Barani, A.M., 2005. Potential uses of petroleum-contaminated soil in highway construction. Construction and Building Materials 19, 646-652.
[19] Kalkan, E., 2009. Influence of silica fume on the desiccation cracks of compacted clayey soils. Applied Clay Science 43, 296-302.

[20] 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.
[21] Kalkan, E., 2012. Effects of waste material-lime additive mixtures on mechanical properties ofgranular soils. Bulletin of Engineering Geology and the Environment 71 (1), 99-103.
[22] Kalkan, E., Akbulut, S., 2004. The positive effects of silica fume on the permeability, swellingpressure and compressive strength of natural clay liners. Engineering Geology 73, 145-156.
[23] Kalkan, E., Bilici, Ö., Kolaylı, H., 2012. Evaluation of Turkish black amber: A case study of Oltu (Erzurum). NE Turkey. International Journal of Physical Sciences 7(15), 2387-2397.
[24] Kaminskas, R., Barauskas, I., 2014. Influence of pozzolana on sulfate attack of cement stone affected by chloride ions. Materials and Structures 47(11), 1901-1910.
[25] Karayigit, A.I., 2007. Origin and properties of Oltu Gemstone coal. Energy Sources. Part A. 29: 1279-1284.
[26] 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.
[27] Makusa, G.P., 2012. Soil stabilization methods and materials. Department of Civil, Environmental and Natural Resources Engineering Division of Mining and Geotechnical Engineering, Luleå University of Technology, Luleå, Sweden.
[28] McDowell, C., 1959. Stabilization of soils with lime, lime-fly ash, and other lime reactive materials. Highway Res Board Bull 231:60-66.
[29] 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.
[30] 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.
[31] Neville, A.M., Aitcin, P.C., 1998. High-performance concrete-an overview. Materials and Structures 31, 111–117.
[32] Ogundare, D.A., Familusi, A.O., Osunkunle, A.B., Olusami, J.O., 2018. Utilization of Geotextile for Soil Stabilization. American Journal of Engineering Research 7 (8), 224-231.
[33] Okagbue, C.O., Onyeobi, T.U.S., 1999. Potential marble dust to stabilize red tropical soils for road construction. Engineering Geology 53, 371-380.
[34] Ola, S.A., 1978. Geotechnical properties and behavior of some stabilized Nigerian lateritic soils. Quarterly Journal of Engineering Geology 11, 145-160.
[35] Parlak, T., 2001. Oltu Stone and Jevelry Art in the Erzurum. Published by Development of Oltu Stone Art, Protection of Artisans and Improvement Association Cheirmanship, Oltu-Erzurum, Turkey, pp. 103 (in Turkish).
[36] 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.
[37] Puppala, A.J., Musenda, C., 2002. Effects of fiber reinforcement on strength and volume change in expansive soils Paper No: 00-0716 Transportation Research Record 134-140.
[38] Puppala, A.J., Hanchanloet, S., Jadeja, M., Burkart, B., 1999. Sulfate induced heave distress: acase study. In: Proceedings, transportation research board annual meeting, Washington DC, USA.
[39] Saussaye, L., Boutouil, M., Baraud, F., Leleyter, L., 2015. Influence of sulfate and chloride ions on the geotechnical and microstructural properties of soils treated with hydraulic binders: individual and coupling effects. Engineering Geology 189:98-103.
[40] Senol, A., Edil, T.B., Bin-Shafique, M., 2006. Soft subgrades' stabilization by using various fly ashes. Resources, Conservation and Recycling 46, 365-376.
[41] 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.
[42] Tang, C.S., Shi, B., Gao, W., Chen, F., Cai, Y., 2007. Strength and mechanical behavior of short polypropylene fiber reinforced and cement stabilized clayey soil. Geotextiles and Geomembranes 25, 194-202.
[43] Thompson, M.R., 1968. Lime treated soils for pavement construction. ASCE J. Highway Division 94 HW-2 59-67.
[44] Yarbaşı, N., Kalkan, E., 2019.Stabilization of Grained Soils by Using Wastes of Oltu Stone. Proceedings of the 3. Çukurova Internatıonal Conference on Innovative Scientific Researches, October 3-6, 2019 Adana, Turkey.
[45] Yarbasi, N., Kalkan, E., Akbulut, S., 2007. Modification of the geotechnical properties, as influenced by freeze-thaw, of granular soils with waste additives. Cold Regions Science & Technology 48, 45-54.