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Effect of Thermal Stabilization of Soil, Bentonite, Calcium Carbonate and Fibers on Behavior Properties of Clay Soil

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ABSTRACT

Various factors, including the thermal stabilization and the presence of chemicals such as bentonite for the protection of nuclear waste lead to the exposure of clay soil to the heat. Besides, the presence of large amounts of carbonate as one of the main components of clay soils, especially in the arid and semi-arid regions, and its effect on the soil engineering properties emphasize the necessity to study the combined effect of heat and carbonate on the engineering behavior of clay soils. Accordingly, the present paper studies the interaction of clay-bentonite, clay-lime, and clay-fiber at high temperatures and its effect on the properties of clay soils. In this regard, a series of macro-structural experiments are conducted. The different thermal levels considered in the present study, according to the previous research, are 0 to 900. The soil behavior is investigated using numerical and laboratory methods. The experiments conducted in this area include the weight changes and the unconfined compressive strength of the soil. The effect of using the bentonite and fiber on the strength indicates that at a given temperature, increasing the percentage of bentonite leads to increased strength. In addition, the rate of increase is different at different temperatures, so that the highest increase occurs for the addition of 30% bentonite to the soil, reaching the unconfined compressive strength to 1.88 times the control sample. However, adding 0.5% fiber and 4% lime shows the maximum strength.

Keywords: Thermal stabilization, Clay soil, Bentonite, Behavior properties, calcium carbonate.

1. INTRODUCTION

Soil stabilization is considered part of the road construction process, which is usually performed by two physical and chemical methods. In the chemical stabilization, the chemicals are added to the soil. The successful implementation of the soil chemical stabilization requires finding the appropriate chemical with the optimal dosage, studying the proper mixing method, proper treatment, and studying the chemical conditions of the soil [1]. However, the thermal methods (heating, cooling) used for the absorption of soil contaminants including industrial materials such as nuclear waste, oil and industrial materials have long been studied to improve the soil strength properties [2]. The presence of industrial materials in the nature as the environmental pollutants and the added nuclear waste poses a serious threat to human health, and removing such materials from the environment has been studied in different research [3]. O'Brien (2018) studied the restoration behavior and the physical properties of soil using the thermal stabilization. It was noted in this research that the environmental pollutants can be reduced by the soil thermal stabilization to help improve the soil strength [4]. Tzovolou (2011) suggested cleaning the contaminated environment in Nepal using the chemical injection method, which reduced the environmental pollution. It was noted that the application of steam injection method in the low-permeability saturated soils has been rarely investigated, and it was used for the contaminated soils in Nepal. This research also mentioned the chemical and physical properties of the soil after the stabilization [5]. The use of two methods, namely thermal heating and steam injection, as the main methods for the thermal soil stabilization has been mentioned in previous studies [6]. O'Brien (2017) used thermal soil stabilization on a large scale and indicated that the thermal stabilization can be effective in improving the soil physical and chemical properties [7]. The thermal stabilization with and without adding the chemicals has been used in various studies [8]. For example, Abu-Zreig (2001) examined three soil samples from the northern Jordan region, which were heated at 100 to 400 °C. Some physical properties of the soil such as Atterberg limits, particle size distribution, optimum water content, maximum dry density, swelling potential, and unconfined compressive strength after the soil thermal stabilization were investigated in this study [9]. Blázquez (2017) studied the changes in the thermal properties of the soil due to the thermal stabilization in the Avila region of Spain [10]. In this study, it was noted that the thermal soil improvement is not feasible in all regions of Spain and to use this method, the map of thermal conductivity distribution should be proposed in different regions. Cruz (2012) explored the low-temperature thermal stabilization in the Superfund wood-treating site and used two chemicals, pentachlorophenol (PCP) and environmentally persistent free radical (EPFR), to stabilize the soil [11]. Živica (2016) studied the behavior of clay soils with aluminosilicate materials (bentonite, kaolin and zeolite) for the thermal improvement of clay soils. This research discussed the soil pore size obtained at 0 to 650 °C and the SEM images were used for the soil structural analysis [12]. Mohammed et al. (2016) optimized the Algerian clay, which is composed of clay, calcite, dolomite, and illite/muscovite. The thermal cycles were applied to the soil in different quantities of these materials and different time periods, and the optimum temperature was obtained to analyze the optimal soil behavior during the optimal time period [13]. Tironi (2012) explored the thermal properties of kaolin soils and found the duration of the thermal cycle and the optimum temperature in the clay soils. The results of this study showed that the soils have the best performance when heated to 800 °C for 30 minutes [14]. Firoozi (2012) investigated the clay soils combined with silica sand and studied the physical and behavioral properties of the soil using the thermal improvement method. In this research, the unconfined compressive strength, Atterberg limits, liquid limit, and density of the soil were analyzed [15]. The increased strength and reduced permeability for improving the thermal properties of clay soils were evaluated by Wong (2013) in the peat soils. The composite cement, calcium chloride and silica sand were used for the addition of peat in the thermal stabilization [16]. The objective of the present paper was to investigate three widely-used materials, namely polypropylene (PP), lime and bentonite, for the thermal stabilization of clay. The effect of using these three materials on a clay soil sample was investigated.

2. MATERIALS AND METHODS

2.1. GEOGRAPHIC AREA OF SOIL SUPPLIED FOR TESTS

For conducting the tests, a suitable soil was selected from the borrow pits in East Kerman province. During the geological and geotechnical studies and the numerous experiments performed by the consultants and laboratories in this area, the clay soils of this region were found susceptible to liquefaction according to the local observations and also the results of laboratory tests. The grading test performed on the soil of this region is shown in Fig. 1.

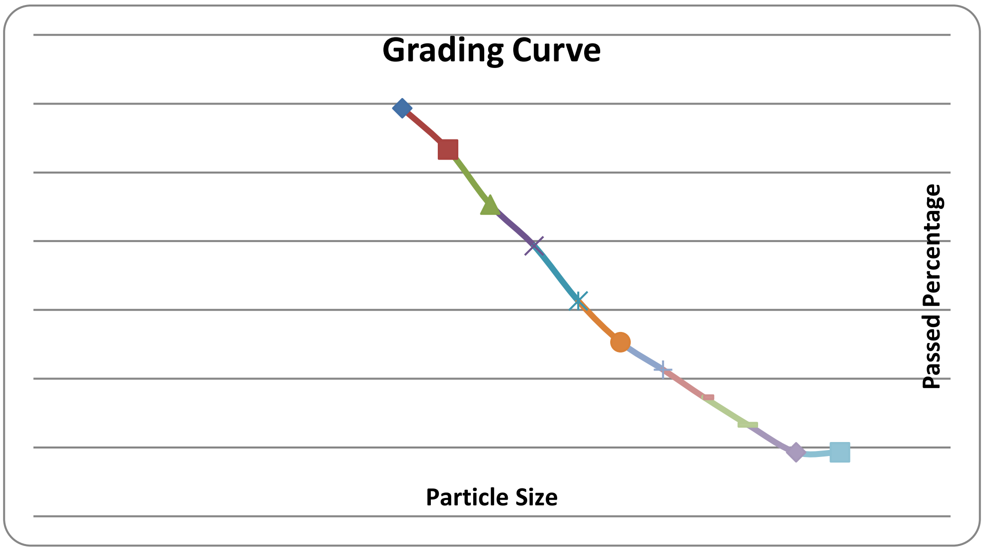

Figure 1. Grading diagram by hydrometric method

Table 1. Properties of study soil

Lime Specifications		Bentonite Specifications		Fiber Specifications		Soil Specifications	
Color	white	Absorption	>600	Color	white	Liquid Limit	45
Ca		Yield	6.25%	Length	6	Plastic Limit	22
Chemical Formula **Ca(CO3)**		Chemical Formula (Na, CaO) (Al, Mg) (Si4O10)3 (OH)6 nH2O		Diameter	22	Plasticity Index	21
				Density	1.19	Shrinkage Limit	13
		Water Absorption	250	Tensile Strength	29.4-49	Natural Moisture	20
Appearance	Granular	Appearance	Granular	Specific Volume	0.84	Dry Unit Weight	2015

Lime, polypropylene (pp), bentonite, and kaolinite were used to stabilize the soil. After the initial tests, each of the additives was used with the specific proportion for the soil stabilization. For the lime, 1, 2, 4, 7 and 9% by weight of soil were used as the stabilizing additive. Fig. 2 shows the materials used in the research. The lime used in this study is the slaked lime obtained from the Kerman plant. The bentonite known as the Iran plateau bentonite was prepared from the Pars Shimi Co. in Tehran. The polypropylene fibers were prepared from the Mayson Sazeh Alyaf Co. to reinforce the concrete and soil with the requirement to comply with all international standards. In the present study, the samples were subjected to the temperature range from 0 to 900 °C, and then, the unconfined compressive strength test, percentage of weight changes and soil shrinkage changes, and diagram of soil elasticity modulus changes were studied in these samples. The proposed lime percentage in the present study consistent with previous research was considered 1, 2, 4, 7 and 9% [17-19]. The use of polypropylene fibers has also been seen in previous studies to stabilize the clay soil, and various researchers have examined the soil behavior in different percentages. According to previous research, the amount of polypropylene fiber (PPF) added to the clay was 0, 0.5 and 1% [20-22]. The amount of bentonite and kaolinite was also selected using the previous studies as 5, 10 and 15% [23-24].

a) b) C)

Figure 2. Materials used in this study (a) fibers, b) lime, c) bentonite

2.2. PREPARATION

homogeneous. Each sample was then quickly poured into the plastic bags and again, in this case, the plastic bags were shaken by hand for two minutes. Finally, by removing the air inside the plastic, the plastic bags were kept at room temperature for 24 hours. To perform the thermal test, the samples were placed in an oven made by the Kureh Sanat Amin Co. for the Sofal Company. To ensure the uniform heating of the samples inside the oven, the oven was initially set at 0°C to 900 °C required for the study for 2 hours and reached the set temperature with a given rate (about 4 minutes). After cooling, the samples were removed from the oven and the considered experiments were performed. Fig. 3 shows the samples prepared in the laboratory.

To prepare the clay samples, water was added to the clay and the lime or bentonite additive until the plastic limit, and a uniform mixture was gradually obtained by adding the fibers to the sample. For the moisture to be uniform, the samples were placed in a nylon bag for 72 hours. Then, to ensure the uniformity of the samples, the soil was passed through the sieve No. 10 and compacted in the mold in three stages. It was then placed the open air for 12 days to be dried. Finally, the samples were dried in the oven for 24 hours. To prepare the samples by lime or bentonite, the dry soil was completely combined with the preset amount of lime or bentonite, and the water was added again to the soil for each sample. The samples were manually combined for two minutes to become

a b c d

Figure 3. Stabilization of soil with a) bentonite, b) lime, c) polypropylene; d) prepared samples

2.3. EXPERIMENTS

2.3.1. Uniaxial compressive strength

By definition, the uniaxial compressive strength is the axial load applied to the unit area of the cylindrical or prismatic soil sample Fig 4. The uniaxial compressive strength test is the maximum force applied to the surface when the sample fails or the force applied to the surface for the 20% strain (ASTM D2166). The moisture content has an indirect effect on the ultimate soil strength. In the unsaturated soils, if the soil density does not change, the strength is decreased with the increase in the moisture content. The Mohr-Coulomb model can be plotted using the results of the unconfined strength test. The Mohr-Coulomb model can be directly used in the situations where the materials are subjected to the uniaxial loading.

Figure 4. Uniaxial device

2.3.2. Linear shrinkage and weight variations

After placing the sample in the oven, the length of the sample was measured, and the length variations were divided by the initial length of the sample and the result was reported. Also, to evaluate the sample weight variations, the weight of prepared samples was obtained after being placed in the oven at each temperature and divided by the weight of initial sample, and the results were reported.

3. RESULTS AND DISCUSSION

The results show that the fiber composition increases the unconfined compressive strength (UCS) to certain fiber content, and then, the unconfined compressive strength is decreased. The incorporation of fibers significantly reduces the soil hardness, improves flexibility and increases the post-peak strength of the soil. The samples reinforced with 0.5% polypropylene fiber (PPF) have the highest resistance to cracking. Figs. 5-7 show the variations in the unconfined compressive strength of the soil by changing the temperature. Fig. 5 shows the variations in the weight of clay samples combined with polypropylene fibers as 0, 0.5 and 1%. The results indicate that the use of fibers causes that the changes in the weight of soil samples to be less than the typical ones due to the insulation of the fibers. The higher the percentage of used fiber, the later the soil particles will be degraded than the clay minerals and reach the dihydroxylation temperature. The sudden weight loss of the clay occurs at 600-700 °C, with the soil weight reaching 9% of its initial weight. For the samples containing the fiber, the maximum reduction in the soil weight occurs at 600 °C and then, the soil weight variations remain constant.

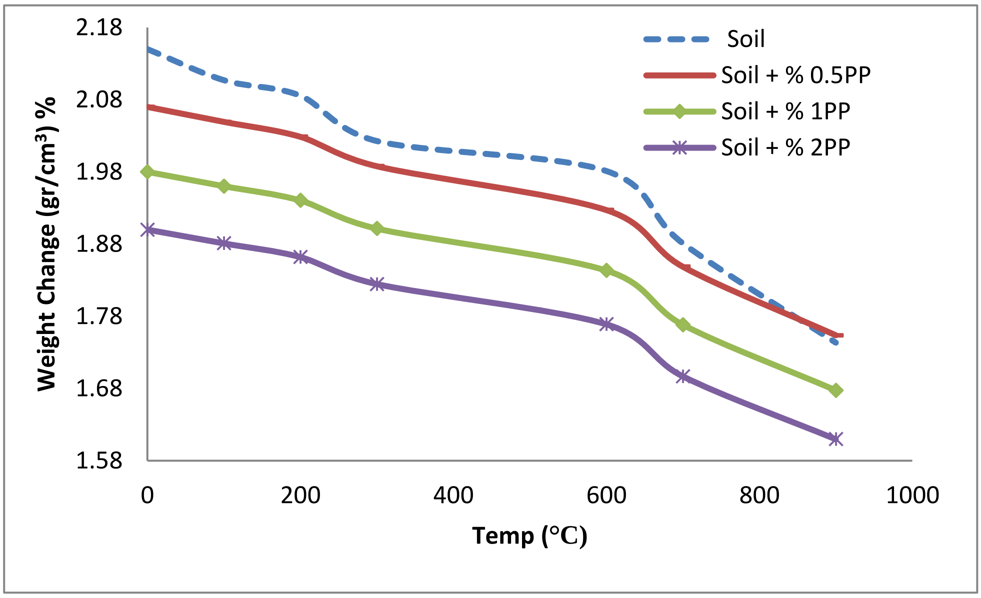

Figure 5. Weight changes of soil samples subjected to heat in PP fibers

The ovens are filled with limestone, and then, the fuel is added, and the limestone is heated for four consecutive days to be cured and the quick-setting lime to be obtained. From the chemical point of view, limestone, namely calcium carbonate, is converted into calcium oxide by the heat. Calcium oxide is mostly used in the cement production. It is an inexpensive material and both chemical and mineral types have widespread uses. At high temperatures, carbon dioxide is removed from the lime and the lime is decomposed. These changes lead to the reduction in the weight variations of the samples at high temperatures, so that the soil samples stabilized with lime at temperatures between 700 and 900 °C would not have significant weight changes, and by increasing the lime content, the weight changes of the samples are decreased. The addition of lime to the soil samples in the initial mix design leads to the decrease in the volume of soil samples, because the void space in the soil is filled with the lighter lime particles. However, the moisture existing in the soil is absorbed by the lime and the moisture content of the samples is increased to its maximum level by adding 7% lime.

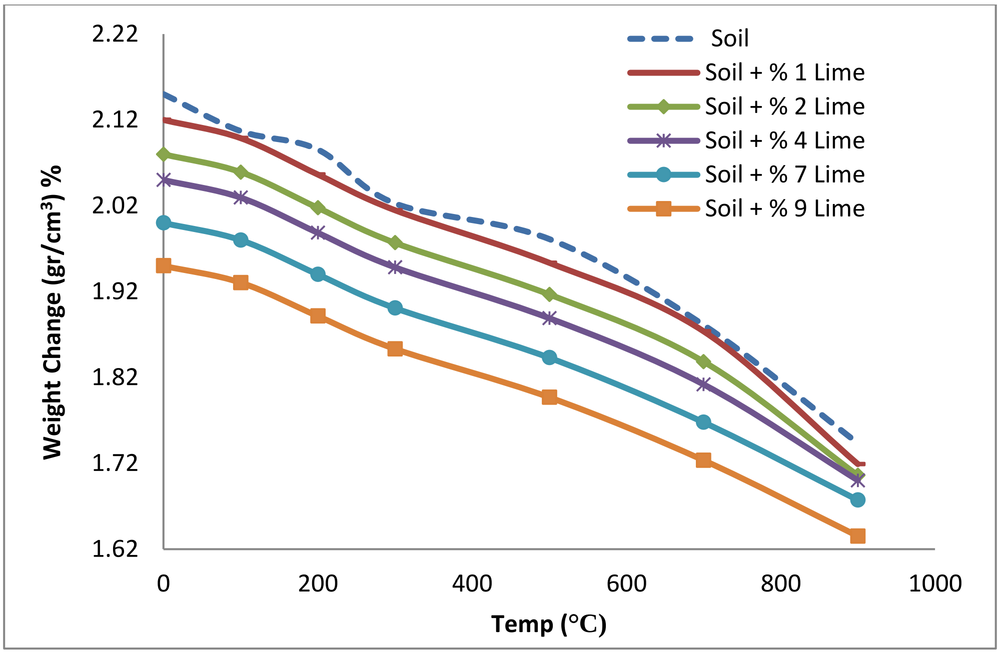

Figure 6. Weight changes of soil samples subjected to heat for samples containing lime

In the following, the weight changes in soil samples containing bentonite are plotted in Fig. 7. The use of bentonite begins the degradation of clay minerals, and the sudden weight loss is observed at 600 °C. In addition, the weight of the samples is reduced up to 15% by adding 30% bentonite at the temperature of 900 °C, which is 10% for adding 18% bentonite. Therefore, it can be stated that the use of bentonite reduces the soil weight at higher temperatures less than the initial sample.

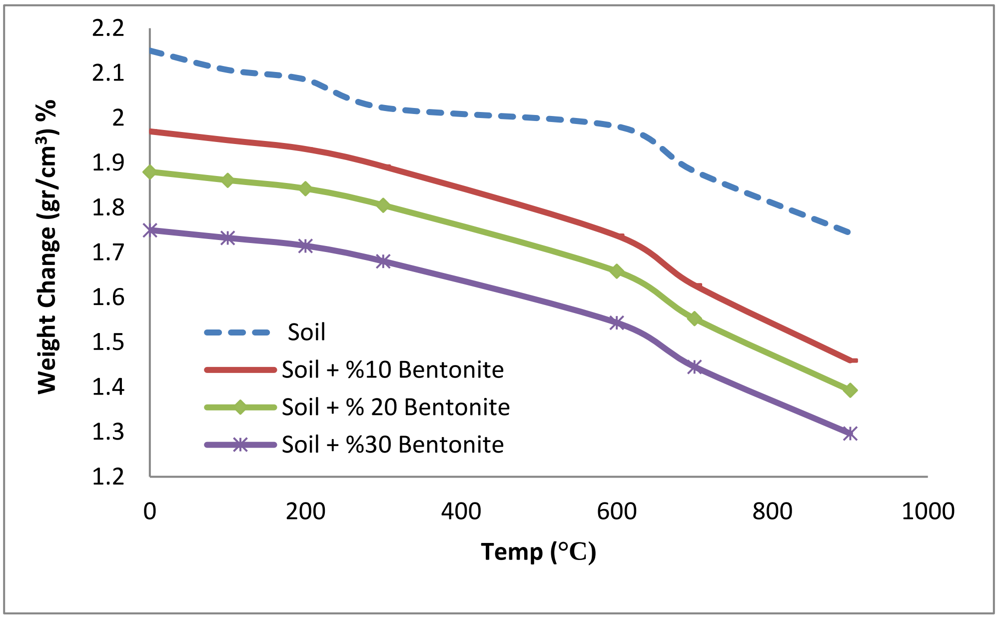

Figure 7. Weight changes of soil samples subjected to heat for samples containing bentonite

Figs. 8-10 show the unconfined compressive strength of the soil at different temperatures by adding lime, fibers and bentonite. The use of lime and bentonite for the stabilization of clay soils leads to a significant increase in the unconfined compressive strength at high temperatures. The application of lime for the stabilization of clay soil to increase the unconfined compressive strength has long been studies in previous research. In the present study, the results show that the use of 0.5% PP fibers caused the unconfined compressive strength of the soil to reach its maximum level. Also, the use of 30% carbonate leads to an increase in the unconfined compressive strength of the soil by 2.2 times the control sample and for bentonite to 1.65 times the control sample, while adding the fibers at the optimal percentage increases the strength by 1.23 times the control sample in the present study. It can be stated that the use of PP fibers added to the soil can increase the unconfined compressive strength of the soil less than bentonite and lime. The soil thermal stabilization increases the unconfined compressive strength of the soil two times the control sample.

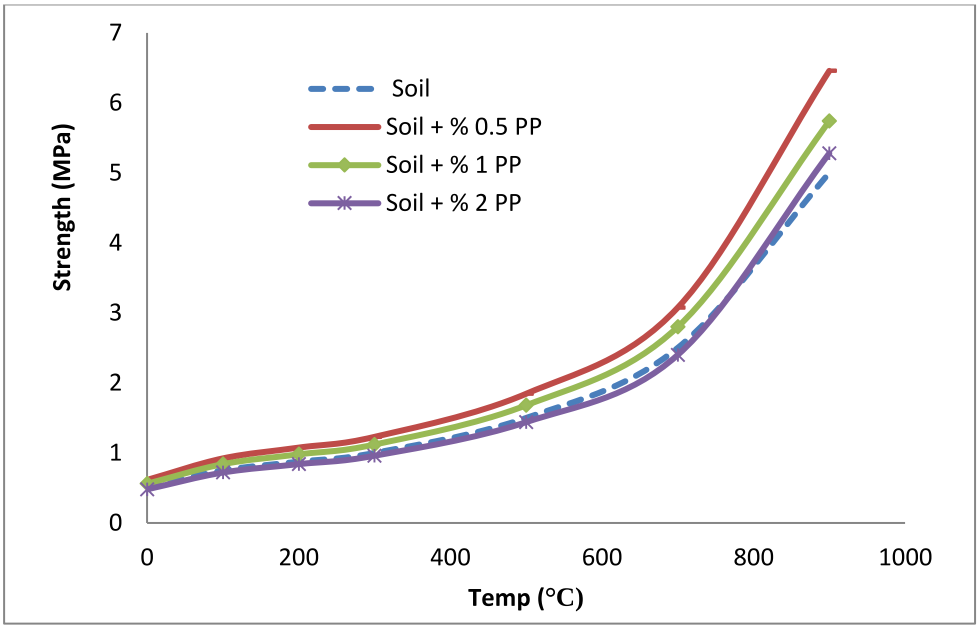

Figure 8. Effect of heat on soil unconfined compressive strength with PP

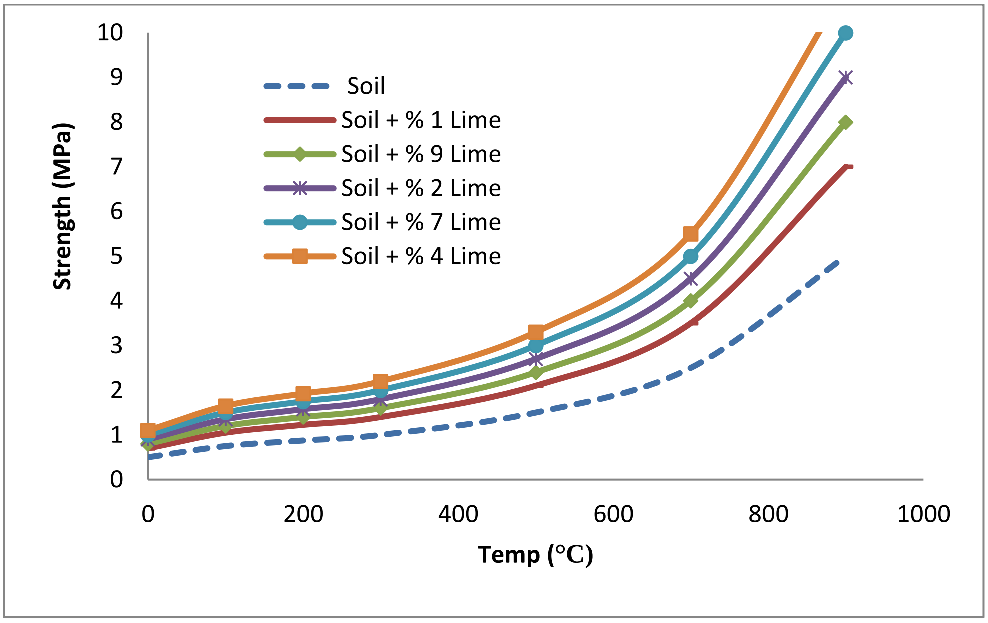

Figure 9. Effect of heat on soil unconfined compressive strength with lime

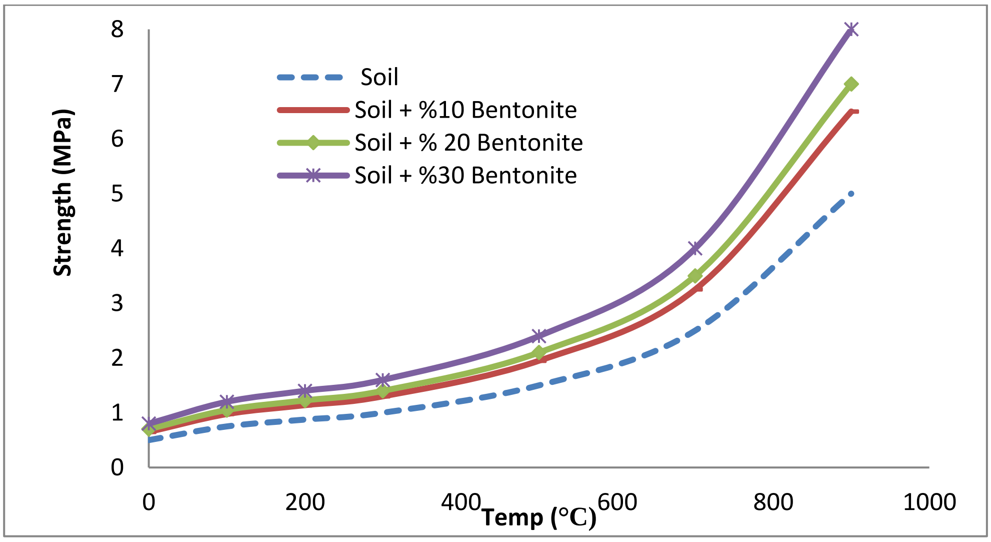

Figure 10. Effect of heat on soil unconfined compressive strength with bentonite

The estimation of the correlation coefficient between the laboratory results is one of the problems found in the numerical research [25-28]. The present study investigates the numerical correlation between the experimental results of the soil unconfined compressive strength and temperature. Fig. 11 shows that the temperature increase has a significant relationship with the increased unconfined compressive strength of the soil, because the correlation coefficient is greater than 0.9 for all the results of the research.

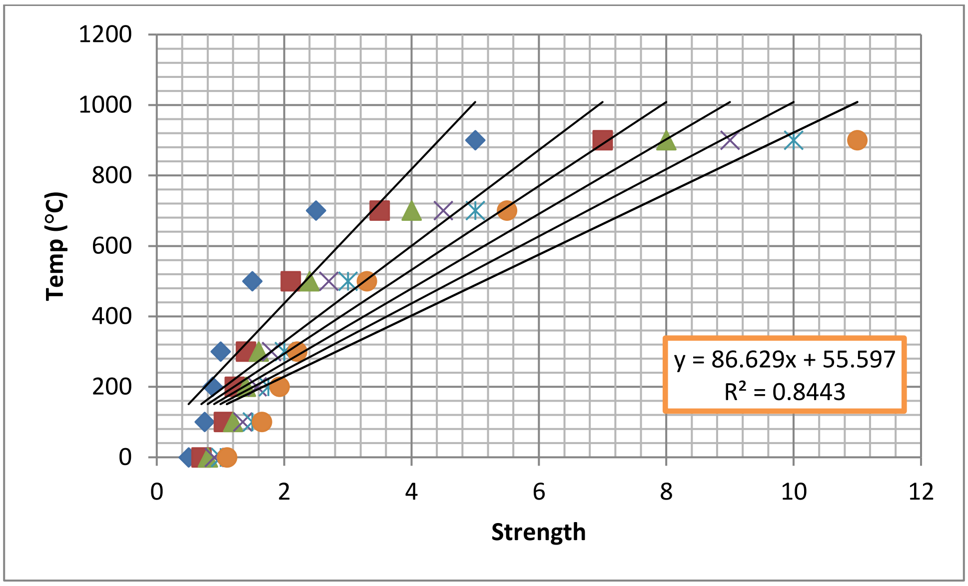

Figure 11. Relationship between unconfined compressive strength and heat

4. CONCLUSION

In the present study, three additives, bentonite, lime and fibers, were used for the thermal stabilization of the soil in the Kerman region. The results of the research show that the thermal stabilization of the soil with these three types of additives at high temperatures can lead to the increase in the unconfined compressive strength of the soil. The following results are derived from this research.

• By increasing the lime percentage by 5%, the unconfined compressive strength of the soil is significantly increased and the maximum strength reaches 2.2 times the control sample, and then, the soil strength is decreased.

• By increasing the bentonite percentage by 20%, the unconfined compressive strength of the soil is increased and the maximum strength reaches 1.65 times the control sample, and then, the soil strength is decreased.

• By increasing the fiber percentage by 0.5%, the unconfined compressive strength of the soil is increased and the maximum strength reaches 1.23 times the control sample, and then, the soil strength is decreased.

• The thermal stabilization of the soil results in the increase in the unconfined compressive strength of the soil, so that in the bentonite samples, by increasing the temperature to 900 °C, the unconfined compressive strength of the soil reaches 10 times the initial state. If the polypropylene fibers and soil heat stabilization are used, the unconfined compressive strength of the soil reaches 10.5 times the control sample. Finally, it can be stated that the use of lime causes the unconfined compressive strength of the soil to reach 9.09 times the control sample. It can be argued that the fibers increase the unconfined compressive strength at higher temperatures by insulating the soil sample.

• Due to the light weight and high volume, the use of polypropylene fibers reduces the dry density of the soil for the fiber samples. However, because of the lower density of lime and bentonite, the density of the samples is reduced if these two additives are added to the soil.

• In general, it can be stated that polypropylene fibers, lime, bentonite and thermal stabilization

Used for the production of the sample result in a significant increase in the unconfined compressive strength of the soil, and the effect of the thermal stabilization will be higher than the above-mentioned additives.

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AUTHORS CONTRIBUTION
This work was carried out in collaboration among all authors.

CONFLICT OF INTEREST
The author (s) declared no potential conflicts of interests with respect to the authorship and/or publication of this paper.

5. REFERENCES

[1] Patel A. Geotechnical Investigations and Improvement of Ground Conditions.1st ed. New York: Woodhead Publishing; 2019. [View at Google Scholar] ; [View at Publisher].

[2] Piña J, Merino J, Errazu AF, Bucalá V. Thermal treatment of soils contaminated with gas oil: influence of soil composition and treatment temperature. Journal of hazardous materials. 2002 Oct ;94(3):273-90.[View at Google Scholar] ; [View at Publisher].

[3] Heron G, Carroll S, Nielsen SG. Full-scale removal of DNAPL constituents using steam-enhanced extraction and electrical resistance heating. Groundwater Monitoring & Remediation. 2005 Nov;25(4):92-107. [View at Google Scholar] ; [View at Publisher].

[4] O'Brien PL, DeSutter TM, Casey FX, Khan E, Wick AF. Thermal remediation alters soil properties–a review. Journal of environmental management. 2018 Jan;206:826-35. [View at Google Scholar] ; [View at Publisher].

[5] Tzovolou DN, Aggelopoulos CA, Theodoropoulou MA, Tsakiroglou CD. Remediation of the unsaturated zone of NAPL-polluted low permeability soils with steam injection: an experimental study. Journal of soils and sediments. 2011 Jan;11(1):72-81.[View at Google Scholar] ; [View at Publisher].

[6] FRTR. Remediation Technologies Screening Matrix and Reference Guide [Internet], Remediation Technologies Screening Matrix and Reference Guide, Version 4.0. https://frtr.gov/matrix2/section1/toc.html. [Accessed 28 June 2017]. [View at Publisher].

[7] O'Brien PL, DeSutter TM, Ritter SS, Casey FX, Wick AF, Khan E, Matthees HL. A large-scale soil-mixing process for reclamation of heavily disturbed soils. Ecological engineering. 2017 Dec 1;109:84-91.[View at Google Scholar] ; [View at Publisher].

[8] Ikeagwuani CC, Nwonu DC. Emerging trends in expansive soil stabilisation: A review. Journal of Rock Mechanics and Geotechnical Engineering. 2019 Apr ;11(2):423-40. [View at Google Scholar] ; [View at Publisher].

[9] Abu-Zreig MM, Al-Akhras NM, Attom MF. Influence of heat treatment on the behavior of clayey soils. Applied Clay Science. 2001 Nov 1;20(3):129-35. [View at Google Scholar] ; [View at Publisher].

[10] Blázquez CS, Martín AF, Nieto IM, García PC, Pérez LS, Aguilera DG. Thermal conductivity map of the Avila region (Spain) based on thermal conductivity measurements of different rock and soil samples. Geothermics. 2017 Jan 1;65:60-71.. [View at Google Scholar] ; [View at Publisher].

[11] Cruz AL, Cook RL, Lomnicki SM, Dellinger B. Effect of low temperature thermal treatment on soils contaminated with pentachlorophenol and environmentally persistent free radicals. Environmental science & technology. 2012 Jun 5;46(11):5971-8. [View at Google Scholar] ; [View at Publisher].

[12] Živica V, Palou M. Influence of heat treatment on the pore structure of some clays-precursors for geopolymer synthesis. Procedia Engineering. 2016 Jan 1;151:141-8. [View at Google Scholar] ; [View at Publisher].

[13] Mohammed S, Elhem G, Mekki B. Valorization of pozzolanicity of Algerian clay: optimization of the heat treatment and mechanical characteristics of the involved cement mortars. Applied Clay Science. 2016 Nov 1;132:711-21.[View at Google Scholar] ; [View at Publisher].

[14] Tironi A, Trezza MA, Irassar EF, Scian AN. Thermal treatment of kaolin: effect on the pozzolanic activity. Procedia Materials Science. 2012 Jan 1;1:343-50. [View at Google Scholar] ; [View at Publisher].

[15] Firoozi AA, Taha MR, Firoozi AA, Khan TA. Evaluation of Physical Properties of Clays Mixed with Silica Sand (Penilaian Ciri-ciri Fizikal Tanah Liat Dicampur Pasir Silika). Journal Kejuruteraan (Journal of Engineering). 2014 Dec 31;26:77-82.[View at Google Scholar] ; [View at Publisher].

[16] Wong LS, Hashim R, Ali F. Improved strength and reduced permeability of stabilized peat: Focus on application of kaolin as a pozzolanic additive. Construction and Building Materials. 2013 Mar 1;40:783-92.[View at Google Scholar] ; [View at Publisher].

[17] Baldovino JA, Moreira EB, Teixeira W, Izzo RL, Rose JL. Effects of lime addition on geotechnical properties of sedimentary soil in Curitiba, Brazil. Journal of rock mechanics and geotechnical engineering. 2018 Feb 1;10(1):188-94.[View at Google Scholar] ; [View at Publisher].

[18] Kawasaki S, Akiyama M. Enhancement of unconfined compressive strength of sand test pieces cemented with calcium phosphate compound by addition of various powders. Soils and foundations. 2013 Dec 1;53(6):966-76.[View at Google Scholar] ; [View at Publisher].

[19] Al-Swaidani A, Hammoud I, Meziab A. Effect of adding natural pozzolana on geotechnical properties of lime-stabilized clayey soil. Journal of Rock Mechanics and Geotechnical Engineering. 2016 Oct 1;8(5):714-25.[View at Google Scholar] ; [View at Publisher].

[20] Ayeldeen M, Kitazume M. Using fiber and liquid polymer to improve the behaviour of cement-stabilized soft clay. Geotextiles and Geomembranes. 2017 Dec 1;45(6):592-602. [View at Google Scholar] ; [View at Publisher].

[21] Bekhiti M, Trouzine H, Rabehi M. Influence of waste tire rubber fibers on swelling behavior, unconfined compressive

strength and ductility of cement stabilized bentonite clay soil. Construction and Building Materials. 2019 May 30;208:304-13. [View at Google Scholar] ; [View at Publisher].

[22] Ghazavi M, Roustaie M. The influence of freeze–thaw cycles on the unconfined compressive strength of fiber-reinforced clay. Cold regions science and technology. 2010 May 1;61(2-3):125-31. [View at Google Scholar] ; [View at Publisher].

[23] Iravanian A, Bilsel H. Tensile Strength Properties of Sand-bentonite Mixtures Enhanced with Cement. Procedia engineering. 2016 Jan 1;143:111-8. [View at Google Scholar] ; [View at Publisher].

[24] Elmashad ME. Improving the geotechnical behavior of sand through cohesive admixtures. Water Science. 2018 Apr 1;32(1):67-78. [View at Google Scholar] ; [View at Publisher].

[25] Khotbehsara MM, Miyandehi BM, Naseri F, Ozbakkaloglu T, Jafari F, Mohseni E. Effect of SnO2, ZrO2, and CaCO3 nanoparticles on water transport and durability properties of self-compacting mortar containing fly ash: Experimental observations and ANFIS predictions. Construction and Building Materials. 2018 Jan 15;158:823-34. [View at Google Scholar] ; [View at Publisher].

[26] Ghanei A, Jafari F, Khotbehsara MM, Mohseni E, Tang W, Cui H. Effect of nano-CuO on engineering and microstructure properties of fibre-reinforced mortars incorporating metakaolin: Experimental and numerical studies. Materials. 2017;10(10):1215-20. [View at Google Scholar] ; [View at Publisher].

[27] Badarloo B, Jafari F. A Numerical Study on the Effect of Position and Number of Openings on the Performance of Composite Steel Shear Walls. Buildings. 2018 Sep;8(9):121. [View at Google Scholar] ; [View at Publisher].

[28] Naseri F, Jafari F, Mohseni E, Tang W, Feizbakhsh A, Khatibinia M. Experimental observations and SVM-based prediction of properties of polypropylene fibres reinforced self-compacting composites incorporating nano-CuO. Construction and Building Materials. 2017 Jul 15;143:589-98. [View at Google Scholar] ; [View at Publisher].