MAUN Fen Bil. Dergi., 12:1, 1-6 Araştırma Makalesi/ Research Article
MAUN J. of Sci., 12: 1, 1-6 DOI: 10.18586/msufbd.1365598

Strength Values of Soil Stabilized with Fly Ash, Lime, and Seawater

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Received (Geliş): 24.09.2023 Revision (Düzeltme):14.10.2023 Accepted (Kabul): 09.01.2024

ABSTRACT

This study investigates the strength values of soil that was treated with fly ash (FA) and lime additives. Besides the effects of additives on the mechanical behavior of soil, feasibility of using seawater as kneading water was examined. For these purposes, a number of geotechnical tests were carried out on the samples, including sieve analysis, California bearing ratio (CBR), consistency limits, proctor, and unconfined compressive strength (UCS) tests. Fourier transform infrared (FT-IR) and scanning electron microscope (SEM) analyses were also conducted to describe the structural properties of FA. Test results showed that the UCS and CBR values of the soil were 134 kPa and 3.1 %, respectively. In the mixture where all additives were used together, the UCS and CBR values increased up to 846 kPa and 16.3 % after 28 days of the curing period.

Keywords: Fly ash, Lime, Seawater, Soil stabilization

Uçucu Kül, Kireç ve Deniz Suyu ile Stabilize Edilen Bir Zeminin Dayanım Değerleri

ÖZ

Sunulan bu çalışmada, uçucu kül (FA) ve kireç katkıları uygulanan bir zeminin dayanım değerleri, deneysel olarak incelenmiştir. Çalışmada katkıların etkilerinin yanında, yoğurma suyu olarak deniz suyu kullanılmasının etkisi de irdelenmiştir. Deneysel çalışmalarda, numuneler üzerinde elek analizi, kıvam limitleri, Proctor deneyi, serbest basınç (UCS) ve Kaliforniya taşıma oranı (CBR) deneyleri uygulanmıştır. Ayrıca FA'nın yapısal özelliklerini tanımlamak için Fourier dönüşümü kızılötesi (FT-IR) analizinin yanında taramalı elektron mikroskobu (SEM) görüntülerinden de faydalanılmıştır. Deney sonuçları, zeminin UCS ve CBR değerlerinin sırası ile 134 kPa ve % 3,1 olduğunu, 28 günlük kür sonucunda tüm katkıların birlikte kullanıldığı karışımda bu değerlerin sırası ile 846 kPa ve % 16,3 değerine yükseldiğini göstermiştir.

Anahtar Kelimeler: Deniz suyu, Kireç, Uçucu kül, Zemin iyileştirme

INTRODUCTION

During the implementation of additives as a means of soil stabilization, the use of seawater instead of fresh water has attracted significant attention in recent years [1–4]. Using seawater in construction works instead of fresh water will contribute to the sustainable conservation of dwindling clean water resources. It has been officially reported by the World Meteorological Organization (WMO) that the clean water resources in the world are rapidly decreasing [5–7]. In addition, using seawater, especially in construction works near the sea, will contribute to reducing undesirable costs (i.e., transportation, fuel consumption) and environmental effects such as exhaust emissions (i.e., from vehicles) since clean water will not be needed for transportation [8-9].

In addition to the decrease in clean water resources, the increase in waste volume and the damage they cause to the environment are also prominent issues [10–14].

Fly ash (FA), which is a waste generated as a result of coal combustion, is based on silicate and aluminate as the chemical composition [15,16]. FA has been researched on its use in different application areas such as ceramic industries and road construction applications. It is also interpreted as a potential raw material for the synthesis of materials such as porous silica. Moreover, FA has a pozzolanic effect depending on its fineness and the amount of free lime it contains, and therefore it is a waste material to be used in soil stabilization [16,17]. FA is already available in powder form, and the reuse of pulverized waste is handled in different ways in the published literature [10,17,18]. Previous studies have shown that the use of FA together with lime is more effective in improving geotechnical properties [13,19].

The effects of FA and lime on the mechanical properties of the soil are widely studied in the published literature. However, there is a lack of research examining the feasibility of using seawater in the soil stabilization process, and this study aims to fill this gap. In addition, available studies mostly focus on the effects of additives on clayey soils, whereas this study places its main focus on silty sand (SM).

In the present work, the test samples were prepared by blending the additives and soil, namely, silty sand. Seawater was used as kneading water in the application of FA and lime which were used as additives during the soil stabilization process. Eventually, the mechanical and geotechnical properties of treated soil samples were determined to assess the geotechnical suitability of the additives with seawater.

MATERIAL and METHODS

Materials

The FA used as an additive is obtained from the chimneys of Çatalağzı Thermal Power Plant in Zonguldak province. The FA is an F-type fly ash. Lime, the other additive, is hydrated lime purchased from the market. The soil used was obtained from the vicinity of Alapli district, approximately 0.8-1.0 meters below the surface. Seawater was obtained from the shores of the town of Alapli, located on the Black Sea coast.

Methods

In the experimental study, the geotechnical properties of the soil were determined. In addition, Fourier transform infrared (FT-IR) analyses were applied and Scanning Electron Microscopy (SEM) images were utilized to describe the structural properties of FA used as an additive material. XRF analysis was performed with the Rigaku ZX Primus-2 instrument.

Table 1. Granulometric values of the soil and FA

Property	N	F
Gravel (%)	13	0
Sand (%)	47	0
Fine (%)	40	100
D_{10}	0.021	0.003
D_{30}	0.050	0.013
D_{60}	0.166	0.033
Coefficient of uniformity (C_u)	7.89	11.00
Coefficient of curvature (Cc)	0.72	1.71
Classification (USCS)	SM	ML
Classification (AASHTO)	A-2-6	A-4

The soil classification was made in accordance with both the Unified Soil Classification System (USCS) and the American Highways Soil Classification System (AASHTO). Then, mixtures were prepared by using 5 % FA and 5 % lime additives.

Two sets of samples were prepared in the same conditions. The only difference was the type of kneading water used, which was either tap water or seawater.

Specific gravity [20], organic matter determination [21], consistency limits [22], sieve analysis [23], and hydrometer tests [24] were conducted on the prepared samples for soil classification. This was followed by the modified Proctor tests [25], which were performed to identify the water-density relationships. The optimum water (moisture) content (OWC) and maximum dry density (MDD) parameters of mixtures were determined for all mixtures. These values were used in the preparation of the strength test samples.

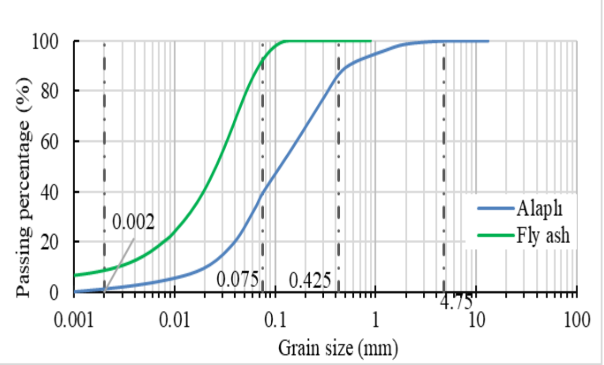

Figure 1. Granulometry curves of the soil and FA

The strength tests were performed on the blends prepared according to the OWC of the relevant mixture. The tests were performed 0-day (in an hour after blending), 7-day, and 28-day curing period. Samples were kept in a desiccator after being wrapped in airtight plastic bags and labeled for the test of 7 days and 28 days. Finally, the Unconfined Compressive Strength (UCS) test [26] and California Bearing Ratio (CBR) test [27] were performed to determine the strength values of the blends.

The materials were symbolized as follows: the soil is "N", FA is "F", lime is "L", tap water is "T" and sea water is "S". Thus, for example, the sample prepared with tap water was coded as "NT", and the sample prepared with seawater and lime was coded as "NLS". The codes and components of all mixtures are shown in Table 4.

Table 2: XRF analysis of FA

Oxide	%	Oxide	%
Al_2O_3	25.6586	Na_2O	1.0116
CaO	5.4701	P_2O_5	1.3392
Fe_2O_3	7.6509	SiO_2	51.9666
K_2O	2.3516	TiO_2	1.1865
MgO	1.7316	SO_3	1.5436
MnO	0.0679	Cl	0.0219

RESULTS and DISCUSSION

The physical properties and the grain distribution curves of the soil used, and FA are presented in Table 1 and Figure 1, respectively. The soil is classified as SM, and FA is classified as low plasticity silt (ML) according to the USCS. The specific gravity (Gs) is 2.65, the Atterberg limits are 29.3 % for liquid limit (LL) and 25 % for plastic limit (PL). The soil has 0.5 % organic matter (OMC). The OWC and MDD were determined as 17.2 % and 15.2 kN/m^3, respectively.

The chemical composition of FA can be seen in Figure 2, Figure 3, and Table 2. The FA were analyzed at the Düzce University Scientific and Technological Research Application and Research Center (DUBIT) using the

SEM Quanta FEG250 FEI. SEM is a device used to image the surface texture of each particle in detail as well as its morphology.

The 1410 cm^{-1} peak belongs to symmetric and asymmetric CH3–deformation vibrations. The absorption peak of the C–H bond, which belongs to the aromatic functional group, is at 777 cm^{-1}, corresponding to the out-of-plane bending vibration, and the Si-O-(Si) bending vibration peak is at 678 cm^{-1}. Therefore, the peak is thought to occur at 999 cm^{-1}. This vibration means stretching vibration consisting of silicon oxide or alumina such as Si-O-Si or Si-O-Al.

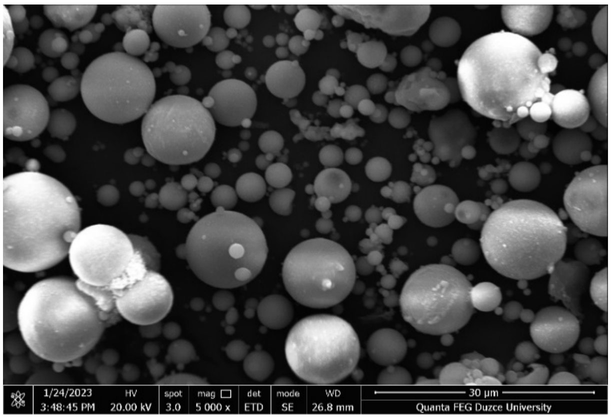

Figure 2. SEM image

While controlling the morphology of FA, combustion temperature and cooling rate were taken into account. SEM image, as seen in Figure 2, shows that fly ash is in spherical lumps.

The range of particle sizes is from less than 1 µm to greater than 8 µm in this study.

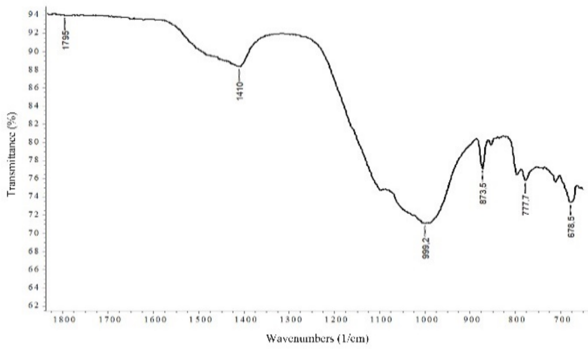

Figure 3. FT-IR spectrum of FA

Silicon oxide and aluminum oxide ratios in fly ash are in the order of 77.6252 % as seen in Table 2. Recordings of infrared spectra were carried out at room temperature and a Perkin-Elmer Spectrum 100 FT-IR Spectrophotometer instrument was used. The instrument features an attenuated total reflection (ATR) accessory containing a zinc selenide (ZnSe) crystal. The wavelength used in the analysis is in the range of 400–4000 cm^{-1} as seen in Figure 3.

The consistency of blends is seen in Table 3. Seawater causes an increase in LL from 29.3 % to 32 %, a decrease in PL from 25 % to 21.7 %, and an increase in PI from 4.3 % to 10.3. FA with tap water increases LL, PL, and PI to 31.5 %, 26.3 %, and 5.2 %, respectively. FA with seawater also increases LL, PL, and PI to 31.5 %, 23.2 %, and 8.3 %, respectively. The lime with tap water increases the LL and PI to 32 % and 9.1 %, while it decreases PL from 25 % to 22.9 %. Likewise, the lime with seawater increases the LL and PI to 30 % and 7 %, whereas it decreases PL from 25 % to 23 %. While all additives used together with tap water do not affect the PI, using them with seawater increases the PI to 7.2 %.

The UCS values of samples are presented in Table 4 and Figure 4. The UCS value (0 days) of the soil used was determined as 134 kPa. With the effect of compaction and aging, the 28-day UCS value reached 162 kPa. In the samples prepared with seawater, these values were determined as 141 kPa and 167 kPa, respectively.

Table 3. Consistency limits of blends

Code	LL (%)	PL (%)	PI (%)
NT	29.3	25	4.3
NS	32	21.7	10.3
NFT	31.5	26.3	5.2
NFS	31.5	23.2	8.3
NLT	32	22.9	9.1
NLS	30	23	7
NLFT	31	27	4
NLFS	31.2	24	7.2

The FA used with tap water at a rate of 5 % as an additive, increased the 28-day UCS value to 214 kPa. This value was determined to be 201 kPa in blending with seawater. When 5 % lime was mixed with tap water, the 28-day UCS value increased to 419 kPa.

In the case of using seawater in the same blend, the UCS value, 28 days cured, increased to 435 kPa. When the lime and FA were blended together with tap water, the UCS value of the samples (28 days cured) was determined as 845 kPa. On the other hand, the UCS value was 856 kPa for the samples blended with seawater.

Load-sink curve and CBR values of the samples, 28 days cured, are presented in Figure 5 and Figure 6. The CBR of the sample which was kneaded with tap water and cured for 28 days, is 3 % while this value is 5 % for the sample prepared with seawater. The CBR value was determined as 6 % in the samples of the fly ash blended with both tap water and seawater.

CBR value, 28 days cured, increases to 8 % in the sample prepared with 5 % lime additive and tap water. In the sample prepared with 5 % lime additive and seawater, the CBR value, cured for 28 days, was determined as 9 %. In the samples prepared by using fly ash and lime together, the CBR values of the samples, cured for 28 days, and prepared with either fountain or seawater were determined as 14 % and 16 %, respectively.

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Table 4. The blending content and geotechnical properties

Code	N (%)	F (%)	L (%)	Water	OWC (%)	MDD (kN/m^3)	UCS (kPa) 0-day	7-day	28-day	CBR (%) 0-day	28-day
NT	100	0	0	T	15.0	17.2	134	150	162	2	3
NS	100	0	0	S	14.5	17.3	141	160	167	2	5
NFT	95	5	0	T	14.8	17.3	154	207	214	4	6
NFS	95	5	0	S	14.4	17.5	151	200	210	2	6
NLT	95	0	5	T	15.5	17.0	153	276	419	6	8
NLS	95	0	5	S	15.3	17.1	151	362	435	5	9
NLFT	90	5	5	T	15.2	17.1	187	679	845	6	14
NLFS	90	5	5	S	15.1	17.2	206	758	856	6	16

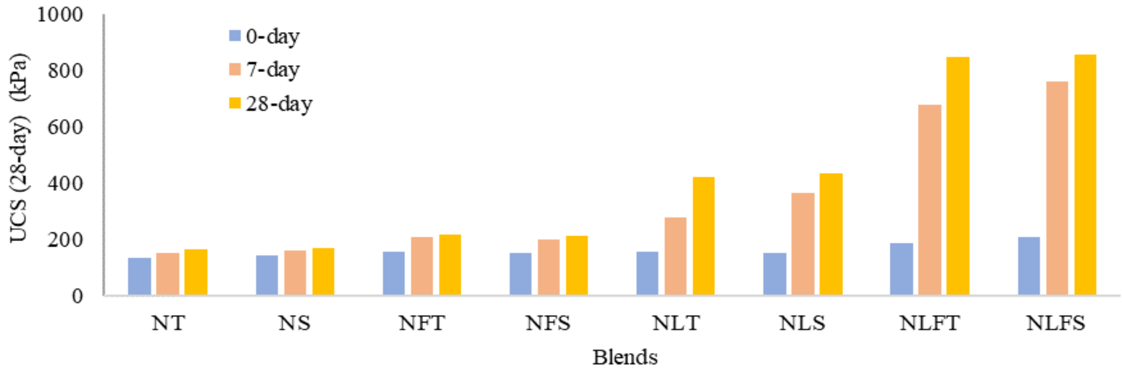

Figure 4. 0, 7, and 28 days UCS values of the blends

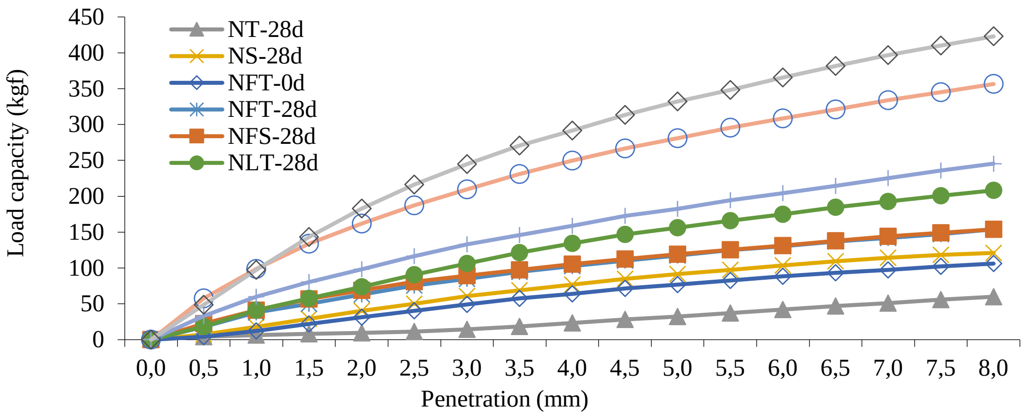

Figure 5. Load-sink curve of blends.

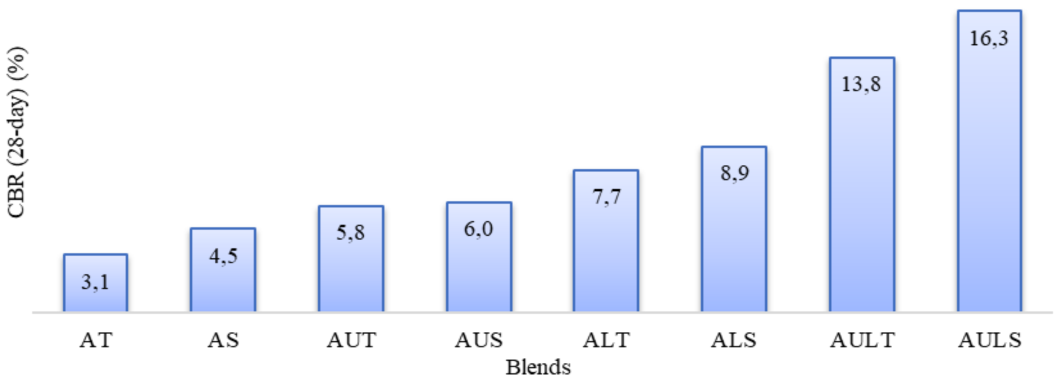

Figure 6. CBR values of blends

CONCLUSION

In the present study, the strength values of soil that was blended with seawater and additives such as FA, and lime, were investigated experimentally. While FA and lime were used as additives, seawater was used as kneading water. Accordingly, the effects of using seawater instead of tap water as the kneading water on treated soil were investigated.

The soil class used in the experimental work is SM (silty sand). Since the main research question in the study was to determine whether there was a difference between the effects of additives when using either seawater or tap water, the additive rates were limited to 5 % FA and 5 %. The detailed investigation of the experimental results showed that FA used at the rate of 5 % improves the strength values of SM-class soils. This improvement is slightly more effective when seawater is used as the kneading water. In addition, the use of FA together with lime ensures higher recovery rates. The mixture that provided the highest improvement in strength values was observed in mixtures where lime and FA were used together, and seawater was used as kneading water.

The test results suggest that the use of additives with seawater provides more desired results than tap water.

THANKS & ACKNOWLEDGEMENT

Geotechnical experiments were carried out in the Zonguldak Bülent Ecevit University Construction laboratory. Also, I would like to express my gratitude.

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