Effect of steel slag used with sea water upon the strength of Uzunciftlik clay

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ABSTRACT: This experimental study was undertaken to determine effect of steel slag with seawater on the strength of Uzunciftlik which is low plastic clay soil. The goals of this research are to improve soil strength properties; the use of sea water directly in the construction sector thus to ensure the protection of clean water resources; and through recycling, the steel slag which is an industrial waste, is to become available. Clay soil samples were reconstituted by adding 3.33% (weight base) of steel slag and seawater at optimum water contents based on standard compaction tests results. The specimens were cured for 1, 7 and 28 days. A series of tests were conducted such as unconfined compression and California Bearing Ratio (CBR) tests. As a result of these experiments, unconfined compression strength (q_u) value of the pure clay, prepared with tap water, after 28 days cured, was 172 kPa. When tap water used in conjunction with steel slag in clay, and cured for 28 days, revealed 2.7 - fold by increasing the q_u value of 670 kPa. Furthermore, using sea water instead of tap water, (sea water used in conjunction with steel slag in clay), revealed 3.3 - fold increase in (q_u) and increased to value of 828 kPa. In addition, Soaked CBR value which prepared with sea water used in conjunction with steel slag in clay, revealed 3-fold increase in soaked CBR value and increased to value of 18% compare to CBR value of stabilized clay samples.

1 INTRODUCTION

Soil stabilization by waste materials for recycling purposes is a subject to be considered critical based on sustainable environment. Likewise, Edil (2011) expressed the importance of the issue the following: “Large quantities of reclaimed materials are disposed in landfills every year. Research has demonstrated that these materials can be recycled into a variety of products. From a sustainability point of view, use of recycled materials in construction avoids energy and emissions associated with mining and processing construction materials. Promotion of the use of recycled materials requires safe and wise use of recycled materials in construction through education, technology transfer, and applied research.”

Soil stabilization is to improve the engineering properties of soil using chemical methods. In recent years, many studies have been conducted on the use of waste material in improving the soil. Some of the materials are studied on the use of additives, lime, cement, fly ash and blast furnace slag. Especially, there are many studies about blast furnace slag, the use as an additive on soil stabilization (Wild et al. 1998; Veith 2000; Al-Rawas et al. 2002; Bilgen 2004; Larsson 2009; Capar et al. 2009;

Saride et al. 2010). Although Blast furnace slag and steel slag are by-products occurring during production of steel, there are very few research projects about steel slag used in soil stabilization (Aiban 2006; Chaurand et al. 2006)..

In addition, 97.5% of all water on Earth is salt water and it is just 2.5% water that can be used as fresh water. The population is also growing fast, putting more burdens on fresh-water supplies and concrete numbers are pointed out that the amount of sea water is increasing rapidly due to global warming (Nordell 2003). Scientists have worked to obtain fresh water from sea water (Elarbash 1991; Khawaji et al. 2008). Alternatively, they have also turned to the study of fields as possible to use of sea water instead of tap water. For example, Bilgen et al., (2010) studied at effect of sea water on the geotechnical properties of clayey soil. Arasan et al. (2008) investigated the effect of clayey soil's consistency limits of inorganic salts. When salt proportion increases in the low plasticity clayey soil, the liquid limit increases, more different behaviors were observed in high plasticity clayey soil.

In this study, when used in conjunction with steel slag, sea water, were investigated on the strength of low plasticity clays. Studies on the subject, serve the two different purposes. One of them is to improve soil strength properties. The other is the use of sea water directly in the construction sector and ensures the protection of clean water resources.

2 MATERIALS AND METHODS

Low plasticity clay was selected as research material in this research. It was provided from the Uzunçiftlik town located between Kocaeli and Adapazari, Turkey. Steel slag and sea water were used as additives. The sample prepared with sea water and steel slag was subjected to various experiments. For the purposes of comparison, pure clay samples were subjected to the same experiments. For classification of Uzunçiftlik clay, sieve analysis, hydrometer, organic matter determination, consistency limits, and specific gravity were also determined.

Steel slag (BOS) was obtained from Eregli Iron and Steel Works Co. (Erdemir, Turkey) and used as an additive. The natural size of BOS is like size of course grained soil particles i.e. 19-40 mm. Before using this material it was ground to pass through the bottom sieve No. 100 for use as an additive in clay. For the grinding process, machine built by Erdemir, was operated as seen in Fig. 1.

Figure 1. BOS Grinding machine.

The percentage of BOS used for stabilizing clay samples was selected based on previous researches on using blast furnace slag in soil stabilization (Bilgen 2004; Çapar at al. 2009; Kavak at al. 2009; Kavak at al. 2011; Bilgen 2011). In these studies, the amount of blast furnace slag was used as 3.33% on weight base in order to re-construct soil samples having the desired engineering properties. For these reasons, the same amount of BOS used as additive in this study was chosen as 3.33%.

Owing to the fact that there are several additives in the soil mixture, the sample names are encoded as follows: UT (tap water, Uzunçiftlik clay); BOSUT (3.33% steel slag, tap water and Uzunçiftlik clay); US (sea water, Uzunçiftlik clay) and BOSUS (3.33% steel slag, sea water and Uzunçiftlik clay). The prepared samples were reconstituted via the standard Proctor test and then, the samples were cured in humid environment for 0, 1, 7 and 28 days. Because when additives are added to a reactive soil to generate long-term strength gain through pozzolanic reactions, soil stabilization occurs. The slag chemistry is such that the finer portions of BOS display the properties of cement. If the ratio($CaO+MgO+Al_2O_3$)/(SiO_3) is higher than unity it means this material has enough reactivity (Emery et al. 1976). In this case, the ratio of BOS was calculated as 4.27. The cured samples were subjected to unconfined compression test (UC) to measure their strengths. In addition, the cured samples were kept in water for 96 hours and then CBR (California Bearing Ratio) values of the samples were determined.

2.1 Uzunçiftlik Clay

The clay used in this study, has been excavated at 2 meters below the soil surface from the town of Uzunçiftlik. It is light-yellow colored, organic matter content is 2%, the specific gravity is 2.56, proportion of the fine material with particle size smaller than 0.075 μm (#200 sieve) was approximately 89%. According to Unified Soil Classification System (USCS), the soil is classified as CL in the low plasticity clay group. The soil can also be defined as A-7-6(12) according to the American Highways Classification System (AASHTO). All necessary data related to Uzunçiftlik clay are given in Table 1.

Table 1. Index properties of clay Uzunciftlik.

Property	Uzunciftlik
Soil Classification	
Classification - USCS	CL
Classification - AASHTO (GI)	A-7-6 (12)
Atterberg limits	
LL (%) (Tap water)	48
PL (%) (Tap water)	20
PI (%) (Tap water)	28
Sieve Analysis - USCS	
Boulder (%) (>76.2 mm)	0
Gravel (%) (76.2 mm - 4.76 mm)	2
Sand (%) (4.76mm-0,074)	9
Silt (%) (0.02 < 0.074)	62
Clay (%) (< 0.02)	27
Specific weight (Mg/m^3)	2.56
Organic material (%)	2

2.2 Steel Slag (BOS)

Steel slag is the co-product of the steel making process in the basic oxygen system (BOS). In the iron and steel process, at first, liquid raw iron is obtained from the blast furnace. Before transmit to steel making plant, some procedures are applied to liquid raw iron. Procedures applied to raw iron are, desulphurization, removal of sulphate, phosphorus, silicon, etc. In steel making plant, for removal of carbon content in raw iron, pure oxygen is blown to it. In the meantime, "Steel Slag" is described as a waste material consisting of different oxides, is released. Characteristic properties and chemical analysis of steel slag used in this study is given in Table 2 and Table 3.

Table 2. Characteristic properties of BOS (Erdemir, 2005).

Properties	(BOS)
Bulk Density (gr/cm^3)	3.71 (25-19mm) 3.69 (40-25mm)
Specific Gravity(gr/cm^3)	3.12 (+4 mm) 3.08 (-4+0,075mm.) 2.95 (-0,0075 mm)
Porosity (%)	2.01 (25-19mm) 1.50 (40-25mm)
Water Absorption(%)	0.95 (+4 mm) 0.83 (-4+0,075mm.)
Peeling Resistance (%)	75-85
Flakiness Index (%)	20
Freezing Loss (%)	8.56 (+5 mm)
Abrasion Loss (%)	15.5

Steel slag; during the steel production, as a result of oxidation of the impurities in steel, oxides and silicates formed, with a complex chemical structure, non-metallic, defined as by-products. Physically, the steel slags are dark gray, cube-shaped, have a rough surface appearance. When compared with blast furnace slag, steel slag is, more hard and stricter, and as a density, greater than 20-25%. Erdemir iron and steel works is producer steel with Basic Oxygen Furnace technology so in this study, steel slag is encoded as follows BOS. When 1 ton of steel production, approximately 125 kg. BOS occurs. Approximately 300 to 350 thousand tons per year steel slag is released in Erdemir (Erdemir 2005).

Table 3. Chemical analysis of BOS.

Element	Fe	SiO_2	MnO	Al_2O_3	CaO	MgO	P_2O_5	S	Na_2O	K_2O	TiO_2
%	20.49	13.30	2.70	5.02	46.57	5.25	0.02	0.32	0.14	0.17	0.47

3 RESULTS OF EXPERIMENTAL STUDIES

The prepared samples were reconstituted by applying the standard Proctor test and were cured 0, 1, 7 and 28 days. Then, UC test and soaked CBR test, were applied on each sample groups. Firstly, pure Uzunçiftlik clay samples were prepared with tap water (UT) at the standard proctor optimum water content of 19% and consequently the biggest dry unit weight is 16.6 kN/m^3. When tap water used in conjunction with 3.33% steel slag in clay mixtures (BOSUT), optimum water content is 16.5% and maximum dry unit weight is 16.3 kN/m^3. Another soil mixture samples were prepared with only sea water at optimum water content and maximum dry unit weight which are 17.4% and 16.8 kN/m^3 respectively. Last group, sea water used in conjunction with 3.33% steel slag in clay (BOSUS), optimum water content is 17.1% and maximum dry unit weight is 16.2 kN/m^3. Mixtures prepared with sea water and steel slag, gives similar results with tap water, and difference is contained in less than 3% on optimum moisture content and maximum dry unit weight. The experimental results of samples are summarized in Table 4.

The experimental results of the q_u values for the samples are shown in Figure 2. While the value of q_u for UT sample is 164 kPa at 0 curing day, the value increases up to 407 kPa for US sample. It can be seen similar result when making comparison q_u values between BOSUT and BOSUS samples. They proved that sea-water can be used as stabilizer to impressively alter the physical strength of the soil. When BOS material is added in the mixture it also stabilizes the engineering properties of the samples as well. For example, q_u value of BOSUT cured for 0 day was measured at 491 kPa which means q_u value increases from 164 (UT) to 491 (BOSUT) kPa.

Table 4. The experimental results of samples.

		UT	BOSUT	US	BOSUS
Optimum moist. cont. (%)		19	16.5	17.4	17.1
Dry unit weight (kN/m^3)		16.6	16.3	16.8	16.2
CBR Value (%)		6	21	32	18
Unconfined compression test results (q_u) (kPa)	0 Day	164	491	407	565
	1 Days	169	484	408	646
	7 Days	167	589	459	712
	28 Days	172	670	536	828

As seen in Table 4 and Figure 2, curing time effects on the strength of the all samples. It can be explained with two possible reasons. The first reason is aging. Aging allows the clay particles to compress, and it gives clay soils more strength and increases elasticity therefore the clay sample becomes stiffer. The other reason is that additives are added to a reactive soil to generate long-term strength gain through pozzolanic reactions.

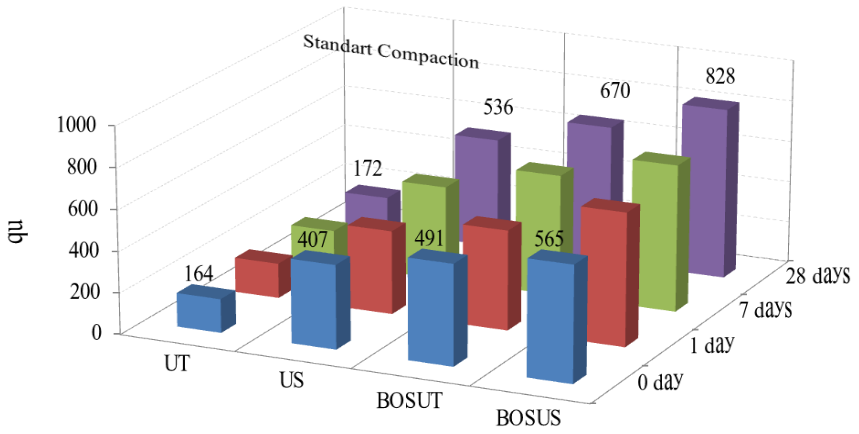

Figure 2. Variation of q_u values of the samples at 0, 1, 7 and 28 days curing periods.

All samples were prepared separately prepared for each mixture, cured for 0, 1, 7 or 28 days, and then subjected to unconfined compressive tests. The results of the unconfined compression test based on stress-strain relations are illustrated in Figure 3 and 4. In order to point out the stabilization effects on clay soils only the test results of 0-day-cured and 28-day-cured samples were plotted.

Figure 3 is the stress–strain responses of Uzunciftlik clay mixtures cured for 0-day periods with allowance for only couple hours reaction. Strain determined at the time of yield for UT sample is almost 6% and unconfined compression strength (q_u) is 164 kPa. It is clear that after steel-slag and sea-water addition in the soil mixture, the specimen developed an almost four fold increase in unconfined compression strength to 565 kPa and failure strain decreases to the level of 3%.

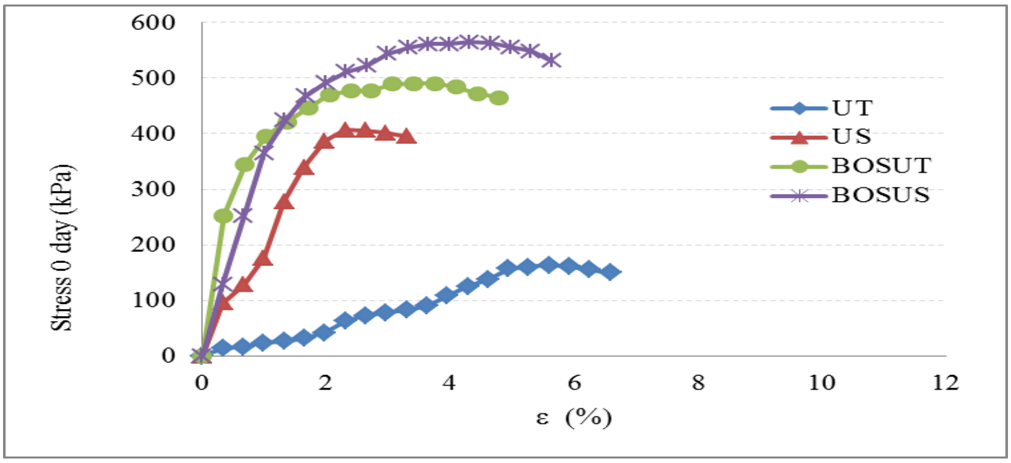

Figure 3. Typical stress – strain behavior of the samples at 0-day curing periods in UC tests.

Figure 4 displays the failure response based on unconfined compression strength of the samples at 28 days curing period. These results prove that all soil samples stood to gain significant strength from reaction with BOS and sea-water even strain determined at the time of yield for all samples have almost not changed. When Uzunciftlik clay was stabilized with only sea water, value of q_u reaches 536 kPa. 3.33 % BOS and sea water mixed with Uzunciflik clay, value of q_u reaches 828 kPa.

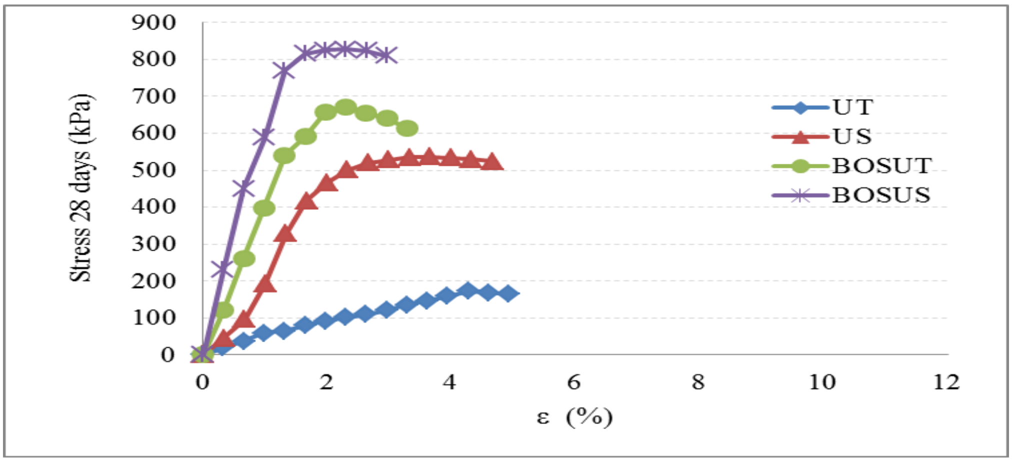

Figure 4. Typical stress–strain behavior of the samples at 28-day curing periods in UC tests.

UT, US, BOSUT and BOSUS samples after 28-day curing periods, After 96 hours soaking time CBR values of them were obtained. This test method is used to determine the CBR of soil mixtures compacted in a mold. CBR test has been performed on the mixtures compacted based on a specific water content and density given in Table 4. As Shown in Figure 5, the soaked CBR value of UT sample was calculated as 6%. Uzunçiftlik prepared with sea water (US) at the end of the 28 curing days, the soaked CBR value increases by 32 %. 3.33 % steel slag and Uzunçiftlik prepared with tap water, (BOSUT) at the end of the 28 days, the soaked CBR value is 21 % and Uzunçiftlik clay prepared with 3.33 % steel slag and sea water (BOSUS) at the end of the 28 days, the wet CBR value is 18%. In addition, Soaked CBR value which prepared with sea water used in conjunction with steel slag in clay, revealed 3-fold increase in soaked CBR value and increased to value of 18% compare to CBR value of stabilized clay samples as shown in Figure 5.

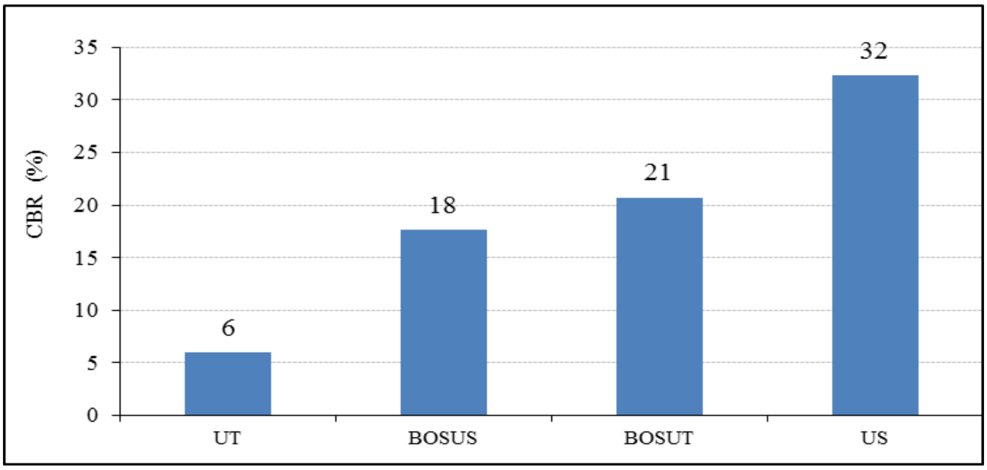

Figure 5. CBR values of samples.

4 CONCLUSIONS

The following conclusions were made on the basis of this experimental study.

Strength tests clearly show that, BOS provide to improve geotechnical properties of clays. Global warming and environmental pollution has become a bigger problem every day in this century, so the BOS is an industrial waste, become available to use as good stabilizers for soil stabilization.

The results of the study of clay samples demonstrate that using seawater instead of tap water will improve the soil's engineering properties. In a period when the availability of freshwater sources is diminishing considerably, the use of seawater can help not only to preserve natural resources, but also provide an easy solution to highway engineering problems in areas with problematic clay soils.

Examination of different aspects of the interaction of the sea water with steel slag, if necessary, but using different additives and/or compression energies is thought to be appropriate to consider increases in re-providing.

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