EFFECTS OF GROUND GRANULATED BLAST-FURNACE SLAG ON THE INDEX AND COMPACTION PARAMETERS OF CLAYEY SOILS

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Abstract

The use of industrial wastes in soil stabilization not only provides for the re-use of waste materials, which may cause environmental pollution, but also leads to cost benefits. In this context, the use of industrial wastes in the stabilization of fine-grained soils has become a research topic in recent years. The aim of this study is to evaluate the potential use of granulated blast-furnace slag (GBFS) in clayey soil stabilization. In this study, the GBFS obtained from the Iskenderun iron-steel plant as an industrial waste was ground into two different fineness levels, and the effects of their incorporation into low-plasticity Kolsuz clay and high-plasticity bentonite clay in various rates (5%, 10%, 20%, 30%, and 50%) on the particle weight of unit volume, the consistency limits, and the compaction parameters are investigated. Based on the experimental results, it is clear that the GBFS has a positive effect on the stabilization of both clayey soils. It was also concluded that the improvement in bentonite clay is greater than that in Kolsuz clay. Thus, GBFS seems to be a promising material for the stabilization of clayey soils.

keywords

clayey soils, index properties, granulated blast-furnace slag, stabilization

1 INTRODUCTION

One of the main environmental problems in this century is the storage of solid waste materials such as municipal waste, industrial waste, hazardous waste and low-level radioactive waste [1]. While countries are being industrialized, enormous amounts of solid waste are being generated. These waste materials are generally placed in landfills. As a result of the extensive recovery and usage of natural resources there exists a shortage of high-quality natural materials all over the world. In addition, the disposal of industrial waste or by-products has become a more difficult and expensive process as a result of the increasing strictness of environmental regulations and a shortage of suitable disposal sites.

Waste utilization is an attractive alternative to disposal in that disposal costs and potential pollution problems are reduced or even eliminated along with the goal of resource conservation. Nevertheless, the utilization strategy must be coupled with environmental and energy considerations to use the available materials most efficiently. The increasing global awareness of environmental pollution as well as increasing waste-material disposal legislation provides the impetus for material upgrading by the stabilization of in-situ soil as an alternative to its export to land-fill and replacement by imported granular fill [2, 3].

In this context, significant quantities of slag are being generated as a solid waste material or as a by-product of the iron-steel industry every day. Furthermore, from an energy-conservation point of view, slag can be considered as an environment-friendly material in terms of resource saving, and CO_2 reduction in the 21st century. However, these products pose a great threat to the environment unless they are stored or exploited for use in various sectors [4].

Iron and steel slag is broadly divided into blast-furnace slag (BFS) and steel slag. BFS may be either granulated blast-furnace slag (GBFS), a glass form that is quenched, or air-cooled slag, which is cooled in the atmosphere. During the production of iron, GBFS and steel slag are formed as by-products. BFS is a non-metallic by-product during the manufacture of pig iron in a blast furnace. BFS consists primarily of silicates, alumina-silicates, and calcium-alumina-silicates. The color of GBFS is whitish. Slag has some unique puzzolanic properties that are difficult to obtain from natural materials. GBFS is used as a cement additive, a concrete admixture, an earthwork material such as in backfilling, covering, embankments and sub-grade improvement, a fine aggregate for concrete, an aggregate for asphalt mixtures and a fertilizer, etc. Air-cooled blast-furnace slag (ACBFS) is primarily used as a road-building material. Most of the steel slag is used in such civil-engineering works as weak ground improvement [4, 5, 6, 7].

Based on typical ratios of slag to crude iron and steel output, it is estimated that the annual amount of world iron furnace slag was about 200 to 250 million tons, and steel slag was about 110 to 160 million tons, [8]. A total of 50 million tons of steel slag is produced per year as a residue throughout the world. In Europe, nearly 12 million tons of steel slag is produced each year [9, 10]. GGBS has been widely used in Europe, and its usage is expanding in the United States and Asia because of its superiority [8, 5, 11]. It is estimated that approximately 15.5 million tons of BFS is produced annually in the United States [12]. Just a single plant in Turkey has 4 million tons of granulated blast-furnace slag (GBFS) and 3 million tons of steel slag storage in 2006 [13]. According to the Nippon slag Association, in Japan the cumulative field sales of ferrous slag products from 1978 to 2004 amounts to 790 million tons, of which 610 million tons are blast-furnace slag and 180 million tons are steel slag products. While the consumption of ACBFS was about 6 million tons (27 %), that of GBFS was about 19 million tons, with 1 % used in-house, 59 % in the cement industry, and, of the remainder, 9 % as concrete aggregate and 4 % for civil-engineering purposes [4]. Research shows that the production of GBFS reached approximately 20 million tons, where 4 % was used as soil-improvement material in Japan in 2010 [14].

In the literature, studies have been performed on the possible utilization of ground granulated blast-furnace slag (GGBFS) as a binder in the stabilization of clayey soils and its effect on the volume change of expansive soils [3, 6, 7, 15]. The authors noticed that there is limited work on the usage of GBFS in comparison with other industrial by-products, such as fly ash and silica fume on the stabilization of soils. The published literature has given little attention to the use of GGBFS for the stabilization of soils. The aim of the current research work is to investigate the possibility of the use of GBFS obtained from the Iskenderun Iron Steel Factory, Turkey, as an active material for the stabilization of fine-grained soils.

2 MATERIALS AND METHOD

In this study, the variations in the particle unit weights, consistency and compaction parameters of the clay samples of low and very high plasticity that are mixed with different ratios of GGBFS are examined. A series of laboratory experiments on a variety of samples by blending GGBFS have been conducted in the soil mechanics laboratory of the Civil Engineering Department, Niğde University, Turkey.

All the soil tests were conducted in accordance with ASTM standards. The unit weight of the particle (γ_s) value was obtained in accordance with [16]. The liquid limit (w_L), plastic limit (w_P) and plasticity index (I_P) of the natural and stabilized clayey soil samples were determined by Atterberg tests in accordance with [17]. The plasticity index was calculated as the difference in the liquid limit and plastic limit values. The compaction parameters (optimum water content w_{opt} and maximum dry unit weight γ_{dmax}) were obtained using the Standard Proctor (SP) test in accordance with [18].

2.1 FINE-GRAINED SOILS

Two types of clayey soils were used in this study. The clayey soil with low plasticity was collected from clay deposits of the Kolsuz area in Niğde, Central Anatolia, Turkey. The Kolsuz deposit is characterized by successions of red siliciclastic deposits that are more than 60 m thick and contain massive amounts of conglomerate, sandstone, and silt-mudstone. The bulk mineralogy is characterized by small amounts and variable proportions of clay minerals, quartz, feldspar, and calcite. Most clayey sediments are made up of relatively homogeneous clay assemblages with dominant detrital chlorite, illite and smectite in terms of clay mineralogy [19]. The other clay type of bentonite with a very high plasticity was supplied by Bensan Ltd. Co., Turkey, for this study. It is produced from raw bentonite in Edirne, Turkey. The material is used in drilling mud, and includes large amounts of montmorillonite.

The clayey soils are classified in accordance with the Unified Soil Classification System (USCS) [20]. The Kolsuz clay can be described as an inorganic clay of low plasticity (CL) and Bensan Bentonite clay can be classified as inorganic clay of high plasticity (CH), (Fig. 1). The sieve analysis and hydrometer tests [20, 21, 22] were performed to determine the grain size distributions, which are given in Fig. 2. Furthermore, their chemical, index and compaction properties are summarized in Table 1 and Table 2, respectively.

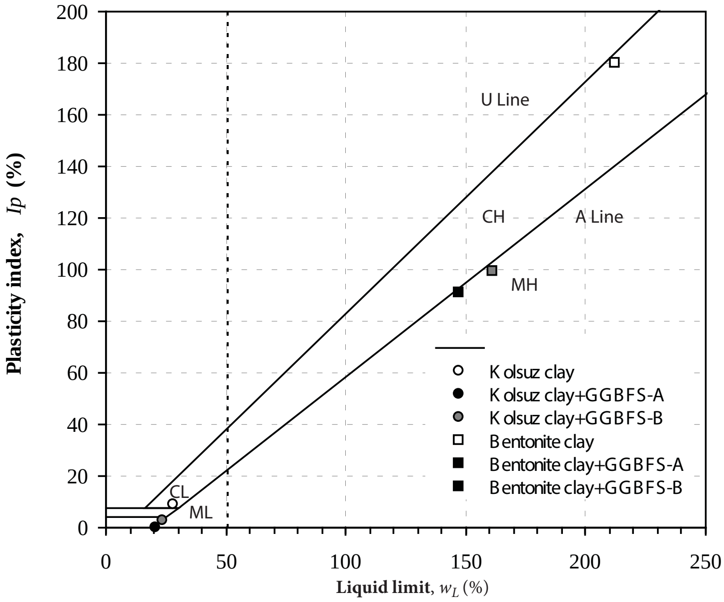

Figure 1. The plasticity chart for clays and stabilized clay samples with 50% GGBFS.

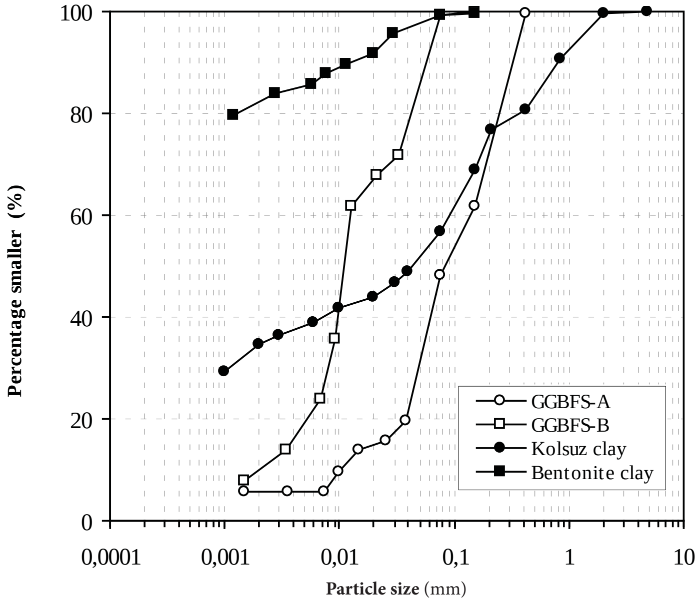

Figure 2. The grain size distributions of the clays and GGBFS used in the tests.

Table 1. Chemical composition of clayey soils and GGBFS.

Property	Kolsuz clay	Bentonite clay	GGBFS
SiO_2 (%)	49.12 -48.57	64.0	37.60
Al_2O_3 (%)	9.46-13.97	21.0	14.21
Fe_2O_3 (%)	4.24-8.10	3.5	0.98
MgO (%)	2.90-5.09	2.3	10.12
CaO (%)	15.04-6.94	0.5	32.61
Na_2O (%)	1.72-1.10	2.6	0.42
K_2O (%)	1.65-2.64	0.4	0.76
SO_3 (%)	-	-	0.99

Table 2. Engineering properties of clayey soils and GGBFS.

Property	Kolsuz clay	Bentonite clay	GGBFS-A	GGBFS-B
γ_s (gr/cm^3)	2.55	2.62	2.81	2.79
Grain size				
Gravel (%)	0	0	0	0
Sand (%)	43	0.8	52	1
Silt %	22	7.2	42	88
Clay (%)	35	92	6	11
Atterberg limits				
w_L (%)	28	212		
w_P (%)	19	32		
I_P (%)	9	180		
Compaction parameters				
SP w_{opt} (%)	14.20	16.97		
γ_{dmax} (kN/m^3)	17.61	15.65		
Soil classification				
USCS	CL	CH		

Figure 3. Samples of GBFS and GGBFS.

2.2 BLAST-FURNACE SLAG

The granulated blast-furnace slag (GBFS) samples were collected from the Iskenderun Iron-Steel Factory as an industrial by-product in Hatay, Turkey. In this study, the GBFS was ground into two different fineness levels (GGBFS-A and GGBFS-B) and used in the tests (Fig. 3). The particle unit weight of the ground granulated blast-furnace slag (GGBFS) was on average 2.80 g/cm^3. The grain size distributions of the ground granulated blast-furnace slags are shown in Fig. 2. The chemical and index properties are summarized in Table 1 and 2, respectively.

2.3 PREPARATION OF SAMPLES FOR THE TESTS

The clayey soil was first dried in an oven at approximately 105°C before being used in the mixture. The required amounts of clayey soil and GGBFS were weighed and mixed together in their dry state. The dry clayey soil and GGBFS were then mixed with the required amount of water for the preparation of test samples. All the mixing procedures were performed manually, and great care was taken to prepare homogeneous mixtures at each stage of the mixing. The stabilized clayey soil samples were obtained at various GGBFS contents (5%, 10%, 15%, 20%, 30% and 50% of dry weight of soil).

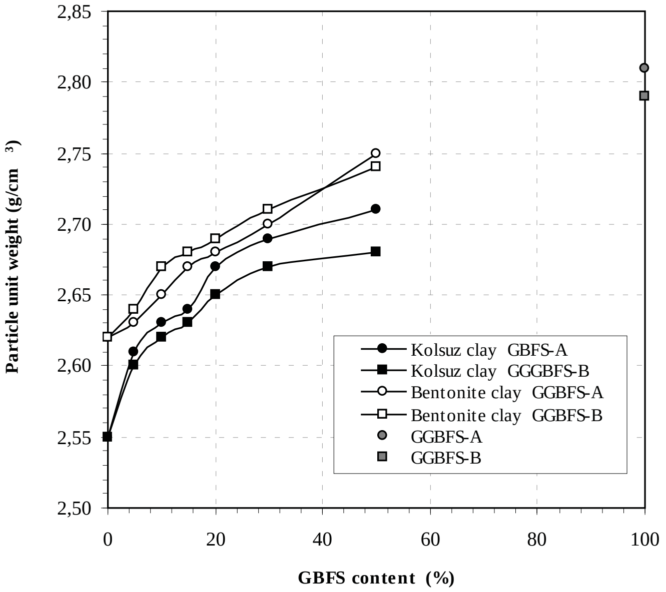

Figure 4. Effect of GGBFS on the unit weight of a particle of the clayey soils.

3 RESULTS AND DISCUSSION

3.1 EFFECT OF BLAST-FURNACE SLAG ON THE UNIT WEIGHT OF A PARTICLE

The unit weights of a particle (γ_s) for the destabilized (raw) and stabilized clayey soil samples prepared at a desired percentage of GGBFS were determined and the results are plotted for the low and high plastic clays in Fig. 4. It is clear from Fig. 4 that the unit weights of a particle for the stabilized clayey soil sample increases with an increase of the content of GGBFS. This indicates that the stabilized clayey soil sample is heavier than that of its natural conditions.

3.2 EFFECT OF BLAST-FURNACE SLAG ON THE CONSISTENCY LIMITS

The effects of GGBFS on the consistency limits are presented for low-plasticity Kolsuz clay (CL) and high-plasticity Bentonite clay (CH) in Figs. 5 and 6, respectively. The liquid limit and plasticity index values decrease and the plastic limit values increase with increasing GGBFS content up to 50% for all the stabilized samples of both the low-plasticity and high-plasticity clays (Figs. 5 and 6). These may be due to the soil type, the associated exchangeable cations and the relative amount of silicate clay mineral in the samples.

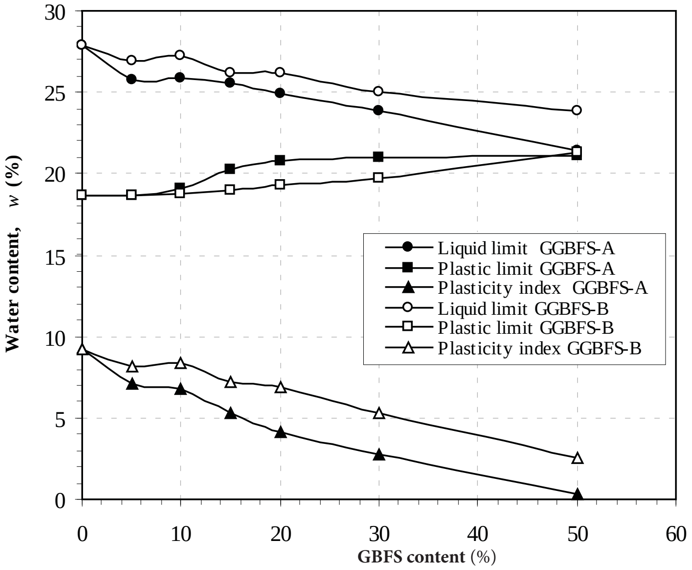

Figure 5. Effect of GGBFS on the consistency parameters of the Kolsuz clay.

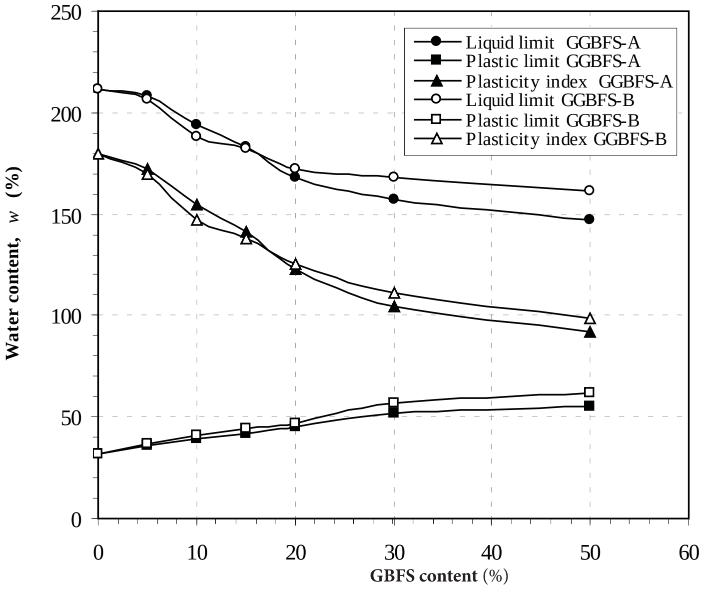

Figure 6. Effect of GGBFS on the consistency parameters of Bentonite clay.

In the Kolsuz clay of low plasticity, the plastic limit of the stabilized clay samples slightly increased from 19% to 21% for both GGBFS-A and GGBFS-B. However, the liquid limit of the stabilized clay samples decreased from approximately 28% to 21% and from 28% to 24% for the GGBFS-A and GGBFS-B, respectively. The plasticity index of the stabilized clay samples decreased from approximately 9% to 0% and from 9% to 3% for GGBFS-A and GGBFS-B, respectively. Thus, the stabilization at 50% GGBFS content for the low-plasticity Kolsuz clay converted it almost into a non-plastic soil, irrespective of the GGBFS level (Fig. 5).

In the Bentonite clay with high plasticity, the plastic limit of the stabilized clay samples increased slightly from 32% to 55% and from 32% to 62% for the GGBFS-A and GGBFS-B, respectively. The increase in the plastic limit is approximately 100%. However, the liquid limit of the stabilized clay samples decreased approximately from 212% to 147% and from 212% to 161% for the GGBFS-A and GGBFS-B, respectively. Therefore, the plasticity index of the stabilized clay samples decreased from approximately 180% to 92% and from 180% to 99%, respectively (Fig. 6).

In addition, it is clear from Fig. 5 and Fig. 6 that there is no major influence of the fineness of the GGBFS (grain size distribution) on the stabilization in both the low and highly plasticity clays.

3.3 EFFECT OF BLAST-FURNACE SLAG ON THE COMPACTION PARAMETERS

The Standard Proctor test was performed on both the clayey and stabilized clayey soil samples to determine their compaction curves. The compaction curves for the Kolsuz clay stabilized with GGBFS-A and GGBFS-B are presented in Figs. 7 and 8, respectively. Fig. 9 also shows the variation of the water content and the dry unit weight values of the Bentonite clay samples stabilized with GGBFS-A.

The optimum water content and maximum dry unit are determined from these compaction curves, shown in Figs. 7, 8 and 9. The optimum water contents of the stabilized soil samples belonging to the Kolsuz clay range from 14.2% to 14.9% and from 14.2% to 14.7% for GGBFS-A and GGBFS-B, respectively. In addition, the maximum dry unit weights of the stabilized soil samples belonging to the Kolsuz clay range from 17.6 to 18.2 kN/m^3 and from 17.6 to 18.1 kN/m^3 for GGBFS-A and GGBFS-B, respectively. The grain size distribution effect (GGBFS-A, GGBFS-B) was not observed to any significant extent on the stabilized soil samples. In the same way, the optimum water contents of the stabilized soil samples belonging to the Bentonite clay range from 16.8% to 17.5% for GGBFS-A, and the maximum dry unit weights of the stabilized soil samples belonging to the Bentonite clay range from 15.65 to 16.41 kN/m^3 for GGBFS-A.

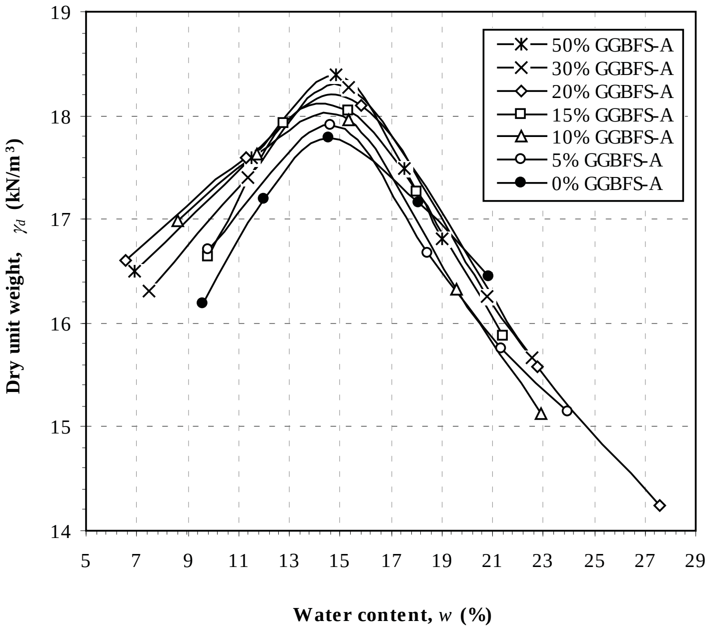

Figure 7. Effect of GGBFS-A on the compaction curves of the Kolsuz clay.

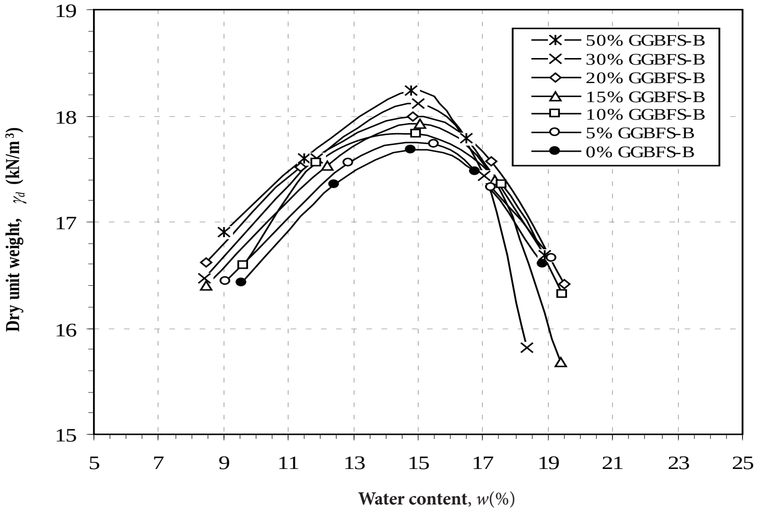

Figure 8. Effect of GGBFS-B on the compaction curves of the Kolsuz clay.

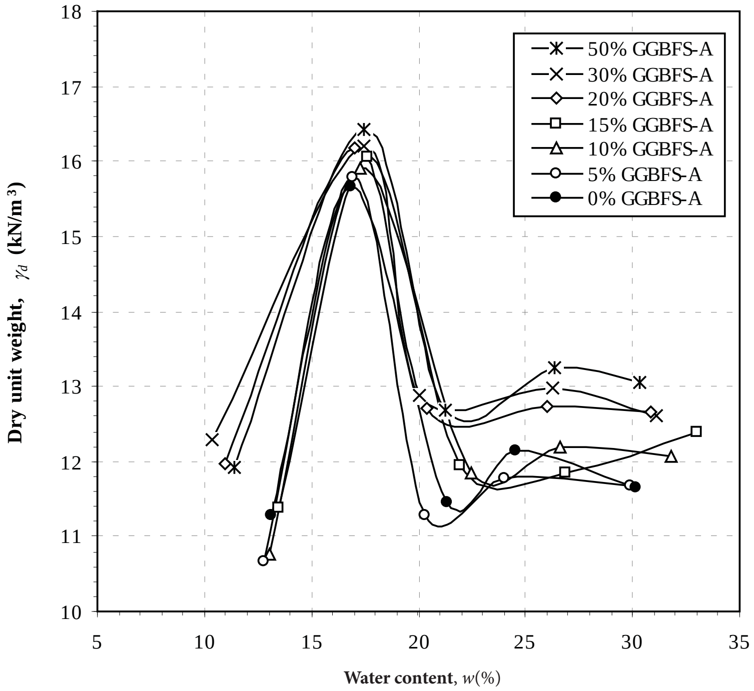

Figure 9. Effect of GGBFS-A on the compaction curves of the Bentonite clay.

The low optimum water contents and dry unit weights occur in the destabilized soil (raw) samples, while the high optimum water contents and dry unit weights occur in the 50% GGBFS - clay stabilized soil samples. There is an increase in the optimum water content and the maximum dry unit weight due to the addition of GGBFS to the clay samples for the same compaction effort (Figs. 10 and 11). The cause of the increase in the water content is due to the change in surface area of the stabilized soil samples. In the same way, the cause of the increase in the maximum dry unit weight is thought to be due to the addition of higher GGBFS with high density, which fills the voids in the stabilized soil samples. The amount of increase in the optimum water content and the maximum dry unit weight for the Bentonite clay is higher than for the Kolsuz clay in a manner that is proportional to their plasticity.

4 CONCLUSIONS

In this study, the effect of ground granulated blast-furnace slag (GGBFS) on the index and compaction parameters of two clayey soils with different plasticities has been examined and the following conclusions have been derived:

- The unit weights of a particle of the stabilized clayey soils increase with increasing GGBFS in the clays of low and high plasticity.
- The GGBFS decreases the liquid limits and plasticity index and increases the plastic limits in all the stabilized clay samples. Thus, the soil types of the stabilized clay samples with 50% GGBFS changed from low plasticity clay (CL) to low plasticity silt (ML) and from high plasticity clay (CH) to high plasticity silt (MH) for Kolsuz and Bentonite clays, respectively.
- The GGBFS changes the compaction parameters. The addition of GGBFS increases both the optimum water content and maximum dry unit weight.

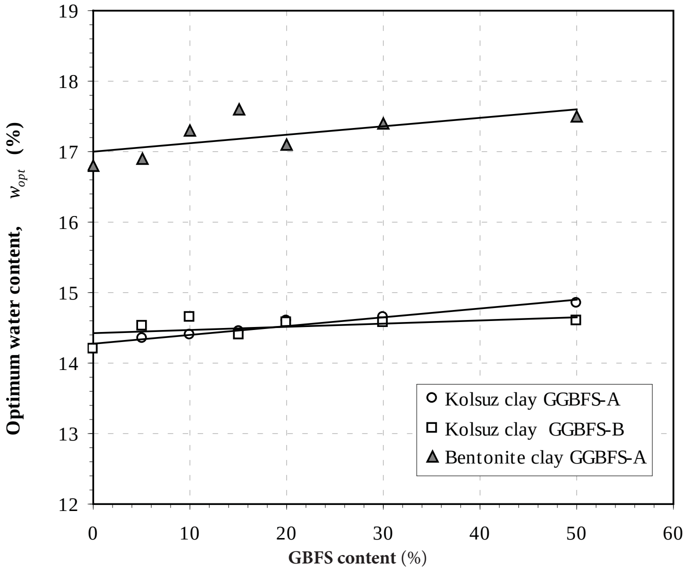

Figure 10. Effect of GGBFS on the water content of clayey soils.

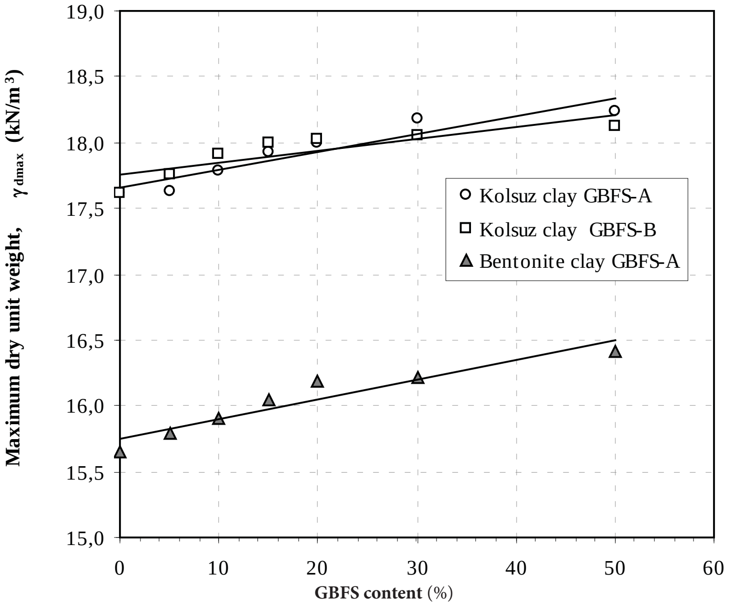

Figure 11. Effect of GGBFS on the maximum dry unit weight of clayey soils.

- The stabilization performance of the high plastic clay is higher than that of the low plastic clay for each of the GGBFS contents. However, the grain size distribution of the GGBFS on the stabilization performance was not observed to any great extent.
- This study has revealed that the use of GGBFS waste material has the potential to modify the properties of clays in order to decrease their swelling potential, and therefore positively affect the stabilized soil samples.

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