Laboratory Study of Steel Slag Used for Stabilizing Expansive Soil

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Abstract: This paper presents an experimental study in stabilization of expansive soil using Steel Slag (SS). Experimental program was conducted to evaluate the influence of Steel Slag on improving the engineering properties of expansive clay. A series of tests to measure consistency limits, free swell index, compaction parameters and unconfined compressive strength of natural and stabilized soils. The effectiveness of adding 0, 5, 10, 15, 20, and 30 percentages of SS to the soil was studied. Comparing the results obtained for the natural and stabilized soils, revealed that SS has significant effect on strength parameters and considerable improvement in plasticity and swelling properties. Addition of SS to the soil increased the dry density and decreased the optimum moisture content as well as increased the unconfined compressive strength. It is concluded that the use of steel slag to enhance properties of expansive soil is successful and beneficial.

Keywords: *Expansive soil; improving; steel slag; strength; swelling.*

1. INTRODUCTION

Expansive soil exhibits significant volume change due to change in moisture content. The clay in this soil is rich of montmorillonite minerals which has great ability to absorb water. The swell-shrinkage behavior of this soil causes damages to infrastructures such as light buildings and road pavements constructed on it. Many stabilization techniques are widely used for improving expansive soil properties.

Chemical additives such as lime, cement, fly ash, inorganic salts and other chemical compounds are commonly used for soil stabilization. In Sudan, cement stabilization is not preferred, because of the increasing cost of Portland cement and environmental hazard due to its application. Hydrated lime is not available and even not suitable for soils containing sulphates [1]. With this regard, the demand of finding other alternative materials is necessary. This study focused on the use of industrial waste materials like steel slag to stabilize expansive soil.

Steel slag is a waste produced during manufacturing of iron and steel. Due to rapid growth in steel and iron manufacturing throughout the world, huge amount of waste materials are generated. In Sudan, many factories produce significant quantities of steel slag as the major waste during the manufacture of iron and steel. The estimated daily production of steel slag is 15–20 tons [2]. The disposal of steel slag in landfills may cause environmental hazards. Therefore, utilization of steel slag waste material as an additive to expansive soil can be a proper solution and will help in reducing the environmental pollution. Additionally, this waste material may be introduced in the soil to modify the soil or reduce its swelling potential.

Therefore, it is imperative to carry out a comprehensive study, based on local materials and conditions, to investigate the possibility of utilizing the steel slag in soil stabilization.

Metal Slag is a waste or by-product material produced during manufacturing process of steel and iron metals. It is divided into two main groups, slag derived from metal production processes consists of ferrous slag and non-ferrous slag; and slag derived from waste heat-treatment and melting. Non-ferrous slag can be further subdivided into Ferronickel slag and copper slag. Ferrous slag can also be further subdivided into Blast Furnace slag and Steel slag. Blast furnace slag may be either granulated slag, air-cooled slag, which has been cooled in the atmosphere, and expanded slag [3].

Steel slag is produced from various processes that include Open Hearth (OH), Basic Oxygen Furnace (BOF) and Electric Arc Furnace (EAF) [4]. Hot iron (BOF) and/or scrap metal (EAF) are the primary metals to make steel in each process. Lime is injected to act as a fluxing agent.

Steel slag consists essentially of calcium silicates and ferrites combined with fused oxides of iron, aluminum, manganese, calcium and magnesium that are developed simultaneously with steel [6]. Because it is generated at temperatures of 1200 °C and greater, steel slag contains no organic matter whatsoever [3]. Steel slag usually contains four major oxides, namely lime; magnesia; silica and alumina. Minor elements

include sulfur; iron; manganese; alkalis and trace amount of several others [2].

The physical properties of steel slag according to National Slag Association [5] are angular shape, generally well-graded material, has a high degree of internal friction angle and high shear strength. Steel slag has high bulk specific gravity and usually less than 3% water absorption as well as dry unit weight $1600 – 1920$ kg/m^3 [5]. According to Proctor et al [7], the slag particle size is generally larger than silt or clay, which has an upper size 0.075 mm, and smaller than gravel which has a lower limit of 2 to 5 mm. The mechanical properties of steel slag include good abrasion resistance, good soundness characteristics, and high bearing strength [2]. Due to these mechanical properties steel slag can be used as aggregates in construction projects.

Numerous studies have been conducted by various researchers for the use of steel slag to improve the engineering properties of weak soils [1-3][8-15].

The use of steel slag has been established in a number of applications in the construction industry. Slag can be applied as a material in cement, as road base course material due to large bearing capacity and excellent in wear resistance [8], as aggregate material for the asphalt concrete mixture [9], as fine and coarse aggregates in cement concrete mixture [10], and as improvement weak soil due to high angle of internal friction and high particle density.

Osinubi et al [11] studied the effect of using Blast Furnace Slag (BFS) to stabilize a lateritic soil to be used as hydraulic barrier. It was observed that inclusion of BFS increased the CBR value to 10% of the soil treated with 9% BFS and it became suitable for the use as hydraulic barrier.

Oormila and Preethi [12] examined the properties of black cotton soil stabilized using fly ash (FA) and Ground Granulated Blast Furnace Slag (GGBFS). Different percentages of FA and GGBFS were added. They found that the stabilizers have significantly improved the index properties of the soil and to achieve the maximum CBR value, the soil was blended with 20% GGBFS.

Golakiya H.D., and Savani [13] investigated the effect of Electric Arc Furnace Dust (EAFD) and Dolime fine addition on black cotton soil to improve geotechnical properties. Electric arc furnace dust generated during steel production and considered as hazardous waste. Dolomite stone is a type of lime stone and additive for slag formation. During the crushing process of Dolomite stone, fine particle is generated known as Dolime fine and regarded as industrial waste. They found that addition of 30% EAF dust and 12% Dolime to the black cotton soil had shown a good result.

Akinwumi [14] studied soil improvement using electric arc furnace (EAF) steel slag. Various percentages of pulverized steel slag were applied to the soil. It was observed that pulverized steel slag improved the plasticity, uncured strength and drainage characteristics of the soil at the optimum percent of slag 6%.

Biradar et al [15] investigated the effect of using Fly ash and Steel slag to stabilize clay soils. Fly ash and Steel slag were mixed at different percentages 0%, 10%, 20%, 30%, 40% and 50% by weight of the soil to obtain the optimum percentage of admixture required. The study results showed that addition of steel slag and fly ash decreased the consistency limits and increased the CBR value of the soil.

2. MATERIALS AND METHODS

To achieve the current study objective, laboratory testing program was undertaken. Laboratory experiments were conducted on expansive soil to investigate the influence of adding steel slag on its engineering properties.

2.1 Materials Used

The expansive soil used in this study was obtained from Buri in Khartoum. The soil is dark grey stiff silty clay. The basic engineering properties of the soil were determined and presented in Table 1. For this study, the steel slag was collected from Giad factory in Khartoum. The steel slag was crushed into finer particles and graded to the desired size, then added in varying proportions by weight to the dry soil sample. The finer particle of steel slag was found non-plastic material. The chemical compositions of steel slag are given in Table 2 below.

Table 1: Engineering properties of the soil used

Property		Value
Specific gravity (G_s)		2.70
Particle size	Sand, %	1
	Silt, %	17
	Clay, %	82
Atterberg's limits	Liquid limit, %	66
	Plastic limit, %	30
	Plasticity index, %	36
Compaction parameters	Max. Dry Density, kN/m^3	14.0
	Optimum Water Content, %	27.5
Free swell index, %		144
Unconfined compressive strength, kN/m^2		222
Soil classification		CH

Table 2: Chemical composition of steel slag, [3]

Constituent	Value
Calcium oxide (CaO)	25.8
Silicon dioxide (SiO$_3$)	16.4
Iron (FeO or Fe$_2$O$_3$)	26.0
Magnesium oxide (MgO)	10.0
Manganese oxide (MnO)	11.2
Aluminium oxide (Al$_2$O$_3$)	2.4
Titanium oxide (TiO$_2$)	0.8
Free lime (free CaO)	2.1

2.2 Sampling and Testing

The soil was initially air dried and pulverized. The soil samples were prepared by sieving through sieve number 4 (4.75mm) and then oven dried at 105-110 °C for 24 hours. The steel slag was subjected to crushing and sieving through sieve number 4 (4.75mm). The soil mixed with steel slag at six different contents (0%, 5%, 10%, 15%, 20% and 30%). The dry soil mixed with each percent of steel slag then subjected to testing.

Laboratory tests were conducted to determine the properties of the natural and stabilized soils. The tests carried out include consistency limits, compaction proctor, free swell and unconfined. All tests were performed in accordance to BS [16].

The consistency tests conducted include the liquid limit and plastic limit tests. The soil was mixed with the fine of steel slag at different percentages then water added for mixing. The prepared sample of stabilized soil was then placed in plastic bags to remain for 24 hours. The liquid limit tests were determined by Cassagrande apparatus and the plastic limit tests were performed according to BS [16].

The free swell was measured for the natural and stabilized soils in a standard graduated glass cylinder. 50 grams of dry soil mixed with each percentage of steel slag were poured into the glass cylinder of 100 ml capacity filled with water. The swollen volume of the stabilized soil was observed after 24 hours. The free swell index is determined as a percentage increase in the volume to the original volume of the stabilized soil.

Compaction test is usually conducted to determine the compaction characteristics. Proctor compaction tests were performed on natural and stabilized soil with steel slag at different percentages.

Unconfined compression tests were carried out on compacted soils at maximum dry density and optimum moisture content. The sample prepared and placed in the compression test machine on the lower plate. The machine adjusted carefully and the deformation indicator set to zero. The load applied and the axial strain deformation values were recorded. The test continued until failure or 20% axial strain reached. The unconfined compressive strength was determined at failure.

3. RESULTS AND DISCUSSION

The tests results are presented and discussed in this section. **Table 3** presents the summary of the tests performed to evaluate the effect of steel slag on the engineering properties of the soil. The relationships between each of the properties with the steel slag content are graphically shown in **Fig. 1 to 5.**

3.1 Consistency Limits

The variation in liquid limit (LL) and plastic limits (PL) of the expansive soil stabilized with steel slag is shown in Figure 1. From this figure, it can be seen that increase in steel slag percentage decreases liquid limit and increases plastic limit. Addition of 30% steel slag to the soil is causing about 33% reduction in the liquid limit value of natural soil. Also from the plastic limit results, it is noticed that as the percent of steel slag increases from 0 to 30%, there is little increase in the plastic limit values for the soil. As a result, plasticity index decreases as steel slag content increase. At 30% steel slag, the reduction in plasticity index is about 75 %.

3.2 Free Swell Index

In expansive soil the free swell is the important parameter to understand the severity of problem posed by expansive soil. The variation of Free Swell Index (FSI) with percentages of Steel Slag of the soil is presented in Figure 2. From this figure, it can be observed that as the percentage of Steel Slag increased from 0 to 30%, there is a considerable reduction in FSI. The reduction in FSI value is about 55% with addition of 30% Steel Slag.

3.3 Compaction Characteristics

The variation of the compaction parameters namely maximum dry density (MDD) and optimum moisture content (OMC) values with different percentages of steel slag added to the expansive soil is presented in **Figs 3 and 4**. Significant change in MDD and OMC are observed with addition of steel slag to the expansive soil. From Figure 3, it is notice that the MDD increases up to about 10% of steel slag and thereafter decreases with addition of steel slag to the soil. The reason is due to the high water absorption with addition of steel slag above 10%, this will reduce the soil density

Table 3: Summary of tests results

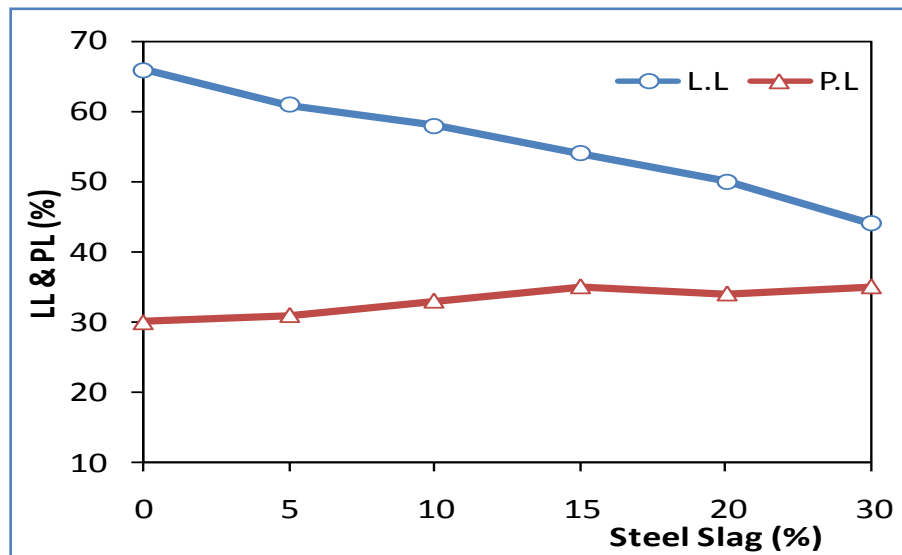| Property	Steel Slag Content (%)					
	0	5	10	15	20	30
Liquid limit, %	66	61	58	54	50	44
Plastic limit, %	30	31	33	35	34	35
Plasticity index, %	36	30	25	19	16	9
Free swell index, %	144	135	126	110	95	65
Max. dry density, kN/m^3	14.0	14.5	15.3	14.8	--	--
Optimum moisture content, %	27.5	23.5	22.4	20.6	--	--
Unconfined comp. strength, kN/m^2	222	343	522	403	--	--

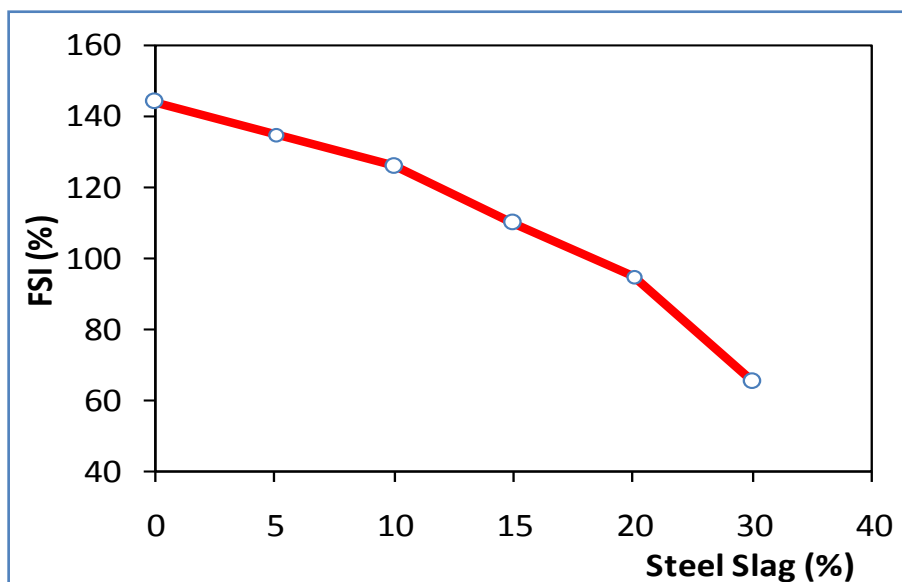**Fig. 1**: Influence of steel slag on liquid and plastic limits of the soil.

Fig. 2: Variation of Free Swell Index (FSI) with Steel Slag content

3.4 Compaction Characteristics

The variation of the compaction parameters namely maximum dry density (MDD) and optimum moisture content (OMC) values with different percentages of steel slag added to the expansive soil is presented in **Figs 3 and 4**. Significant change in MDD and OMC are observed with addition of steel slag to the expansive soil. From Figure 3, it is notice that the MDD increases up to about 10% of steel slag and thereafter decreases with addition of steel slag to the soil. The reason is due to the high water absorption with addition of steel slag above 10%, this will reduce the soil density. The influence of steel slag with varying percentages on OMC is clearly shown in Figure 4. From this figure, it was seen that there is considerable decrease in OMC with increase the percentage of the steel slag. The reduction in OMC with 15% steel slag additive is almost 25% of the initial value of natural soil. The improvement in the compaction parameters with added steel slag may be attributed to the cation exchange between mineral layers.

3.5 Unconfined Compressive Strength

The variation of unconfined compressive strength (UCS) of the soil stabilized with Steel Slag is presented in Figure 5. From this figure, it is observed that the UCS values increases with increase in Steel Slag. The UCS values are increased with higher rate up to 10 % steel slag and then decreased with slower rate. The justification of this result may be due to the reduction in density with addition of steel slag beyond 10%. at The UCS value at 10% steel slag showed almost 1.5 times improvement as compared to untreated soil. Overall from the results, it is understand that the strength of the expansive soil stabilized with steel slag are increasing significantly up to the optimum content of steel slag and then decreases with addition steel slag. Therefore, steel slag can be used to improve the strength characteristics of expansive soil.
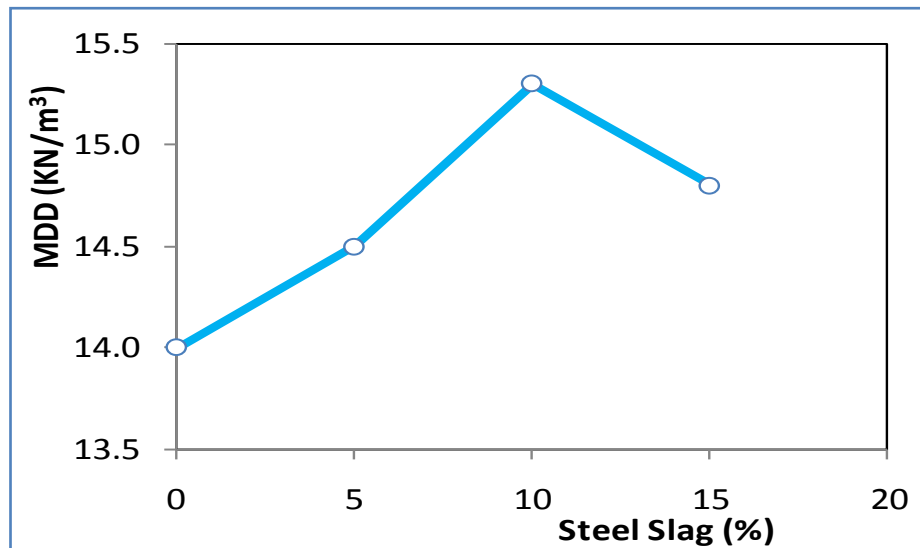
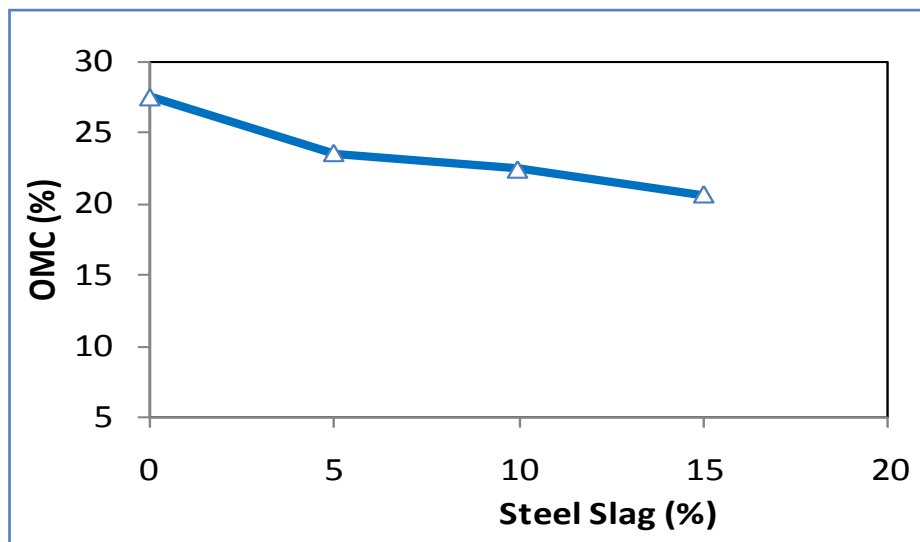**Fig. 3**: Effect of Steel Slag on Maximum Dry Density (MDD)

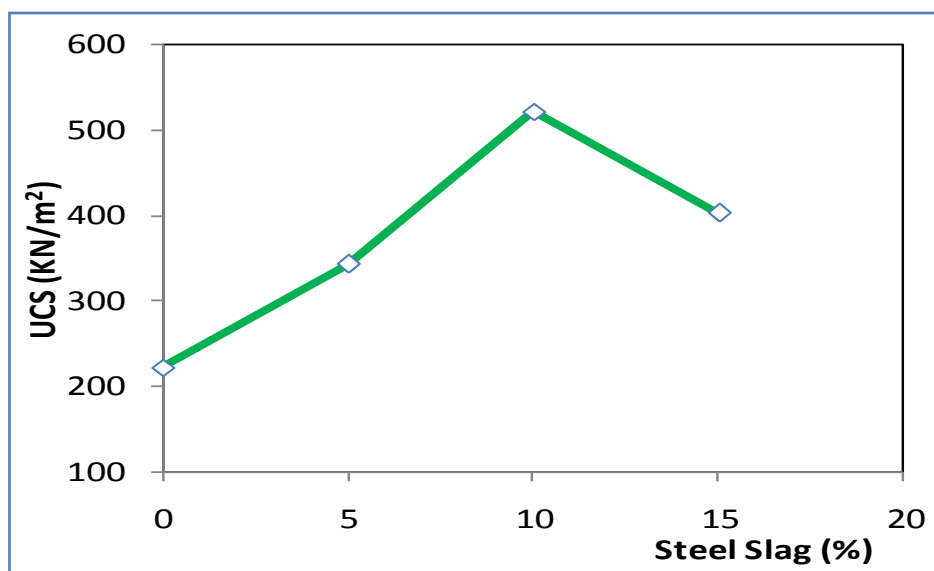**Fig. 4**: Variation of Optimum Moisture Content (OMC) with Steel Slag content

Fig. 5: Unconfined compressive strength relationship with steel slag content

4. CONCLUSIONS

This study has concentrated on the effect of Steel Slag stabilizer on engineering properties in particular the swelling and strength properties of a highly expansive soil. Based on the study findings, the following conclusions are drawn:

− The basic properties of the soil studied were determined, clay content 82%; liquid limit 66%; plasticity index 36%; free swell index 144%; unconfined compressive strength 222 kPa. The soil is classified as high expansive clay. For this specific soil, the properties improvements by adding steel slag are mentioned below.

− The liquid limit decreases with an increase in Steel Slag content. Addition of Steel Slag to the expansive soil is causing about 33% reduction in the liquid limit value at 30% of Steel Slag. For plastic limit, as Steel Slag increases from 0 to 30%, there is a little increase in the plastic limit values of the stabilized soil. Moreover, plasticity index reduces by 75% with the addition of 30% Steel Slag.

− Free swell index is significantly decreased as Steel Slag increases. At 30% Steel Slag, the free swell index of the soil is decreased and the reduction observed is almost 55%.

− Addition of Steel Slag has major effect on compaction characteristics of the stabilized soil. An increase in Steel Slag content leads to a significant increase in maximum dry density up to 10% Steel Slag and beyond this percentage. Further addition of Steel Slag is causing gradual decrease in MDD, while a considerable decrease in OMC is observed with increasing percentage of Steel Slag. Therefore, an optimum value of Steel Slag may be taken as 10% with respect to compaction parameters.

− The strength of expansive soil can be effectively improved by addition of Steel Slag. The Unconfined Compressive Strength (UCS) values increases with increase in Steel Slag. The UCS values of the soil are increased with higher rate up to 10 % Steel Slag and then decrease with slower rate. The UCS value at 10% Steel Slag showed almost significant improvement as compared to untreated soils.

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