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**Using Steel Slag for Stabilizing Clayey Soil in Sulaimani City-Iraq**

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**ABSTRACT**

The clayey soils have the capability to swell and shrink with the variation in moisture content. Soil stabilization is a well-known technique, which is implemented to improve the geotechnical properties of soils. The massive quantities of waste materials are resulting from modern industry methods create disposal hazards in addition to environmental problems. The steel industry has a waste that can be used with low strength and weak engineering properties soils. This study is carried out to evaluate the effect of steel slag (SS) as a by-product of the geotechnical properties of clayey soil. A series of laboratory tests were conducted on natural and stabilized soils. SS was added by 0, 2.5, 5, 10, 15, and 20% to the soil. The conducted tests are consistency limits, specific gravity, hydrometer analysis, modified Proctor compaction, swelling pressure, swelling percent, unconfined compressive strength, and California Bearing Ratio (Soaked CBR). The results showed that the values of liquid limit, plasticity index, optimum moisture content, swelling pressure, and swelling percent were decreased when stabilized the soil. However, the values of maximum dry density, unconfined compressive strength, and California bearing ratio were increased with the addition of steel slag with various percentages to the clayey soil samples. The steel slag was found to be successfully improving the geotechnical properties of clayey soils.

**Keywords:** Clayey soil, Soil Stabilization, Steel Slag, Geotechnical Properties.

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## تحسين الخصائص الجيوتقنية للتربة الطينية باستخدام خبث الفولاذ في مدينة السليمانية – العراق

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### الخلاصة

التربة الطينية ، والتي تعرف بالتربة المتورمة، أو التربة المنكمشة، هي التربة التي تميل إلى الانتفاخ والانكماش مع التباين في محتوى الرطوبة. ان تثبيت التربة هي تقنية معروفة، يتم تنفيذها لتحسين الخواص الجيوتقنية للتربة. ان الكميات الهائلة من النفايات الناتجة عن اساليب الصناعة الحديثة تخلق مخاطر عند التخلص منها بالإضافة إلى المشاكل البيئية. نظرًا لأن النفايات التي تفرزها صناعة الصلب تحمل بعض الخصائص الهندسية الجيدة، لذلك يمكن استخدامها مع التربة ذات القوة المنخفضة وذات خصائص هندسية ضعيفة. تمت هذه الدراسة لتقييم آثار خبث الفولاذ (SS) على الخصائص الجيوتقنية للتربة الطينية. وأجريت سلسلة من الاختبارات المختبرية على التربة الطبيعية والمثبتة. و تمت إضافة خبث الفولاذ بنسبة 0، 2.5، 5، 10، 15 و 20% إلى التربة الانتفاخية المستخدمة. ان الاختبارات التي أجريت تتضمن: حدود القوام، الوزن النوعي، تحليل الهيدروميتر، رص بروكتور المعدل، ضغط الانتفاخ، نسبة الانتفاخ، ونسبة تحمل كاليفورنيا ( CBR المشبعة). ان النتائج أظهرت أن كلا من حد السيولة ومؤشر اللدونة ومحتوى الرطوبة الأمثل وضغط الانتفاخ ونسبة الانتفاخ للتربة المثبتة قد انخفض مع اضافة خبث الفولاذ. وبالرغم من ذلك، ازدادت كثافة الجفاف القصوى ونسبة تحمل كاليفورنيا. و من خلال هذه الدراسة تم التوصل الى ان خبث الفولاذ ساهم بنجاح في تحسين الخصائص الجيوتقنية للتربة الطينية.

**الكلمات الرئيسية:** للتربة الطينية ، تثبيت التربة، خبث الفولاذ، الخصائص الجيوتقنية.

### 1. INTRODUCTION

Clayey soils are subjected to massive volume changes that severely affect highways and construction projects. Montmorillonite clay is one of the expansive soil minerals. It has a high capability of absorbing water that later causes the swelling of the soil. This swelling exerts a leading force that seriously affects the foundation of the engineering projects, basement floors, sidewalks, pipelines. The indirect consequence of the swelling has coasted enormous damages, including repair and rehabilitation of many foundations (Nelson and Miller, 1992; Fattah et al., 2015; Ahmed and Hamza, 2015). Several methods have utilized to decrease the impact of swelling, including, but not limited to, dewatering, earth reinforcement, and soil stabilization. Perhaps using admixtures to maximize soli stability is more practical and advantageous. The perfect places for expansive soils are tropical and temperature zones, which coincide with low rainfall and weak drainage system (Nelson and Miller, 1992). Soil stabilization is the process of soil alteration to enhance the physical, mechanical, and chemical aspects of the soil. It raises some of the essential qualities of the soil like shear strength, volume changes, and bearing capacity. Alternatively, it is a process of mixing soil with a designated amount of additives (Hossain, 2011; Ahmed & Adkel, 2017). One of the secondary products of the steel industry is steel slag. It is formed from the isolation of the molten steel from the impurities. Steel slag is formed like a liquid, floating on the molten steel as a distinct layer. It is a mix of silicates and oxides that become dense and solid upon cooling. It consists of silica, alumina, calcium oxide, and iron oxide. Civil engineers have employed steel slag for many purposes such as (Chen, et al., 2007), mortar road base material (Shen, et al., 2009), cement manufacturing (Huang and Lin, 2010), heavy metals immobilization (Grubb, et al., 2011), and soil improvement (Liang, et al., 2013). Steel slag is mixed with expansive soil; the friction of the soil increases due to the granular nature of the steel slag (James, et al., 2018). In the Kurdistan Region of Iraq, especially in Sulaimani City, there are steel factories that produce a large quantity of steel slag, and this type of waste material causes several damages to the environment. To eliminate this problem, steel slag can be used as a soil stabilizer to improve the geotechnical engineering of expansive soils.



Many researchers have studied the stabilization of soils. **James and Pandian (2013)** studied the effect of eggshell powder on the geotechnical properties of soil. The laboratory test included the determination of the Atterberg limits, swelling, compaction, UCS, and CBR. It was found that the addition of eggshell powder to the soil led to a decrease in plasticity properties, improved soil strength, and reduced swelling. **Rashmi, et al. (2016)** investigated the effect of groundnut shell ash on the geotechnical properties of soil. The experimental program included: Atterberg limits, standard proctor compaction test. Based on the test result, the values of the plasticity index and optimum moisture content were decreased, and the value of maximum dry density was increased with the addition of groundnut shell ash to the expansive soil samples. **AL-Soudany, (2017)** studied the effects of silica fume on the engineering properties of expansion soil. The test program included the effect of bentonite on natural soil then study the effect of silica fume (SF) on prepared soil by adding different percentage of silica fume (3, 5, and 7 by weight) to the prepared soils. The results show that both liquid limit and plasticity index decreased with the addition of silica fume. As well as, a decrease in the maximum dry unit weight with an increase in the optimum water contents have been obtained with increasing the percentage of addition of the silica fume. It is also observed an improvement in the free swell, swelling pressure by using silica fume. It can be concluded that the silica fume stabilization may be used as a successful way for the treatment of expansive clay. **Goud, et al. (2018)** studied the stabilization of soils used coir pith and lime with various percentages of coir pith (1, 2, and 3%) and lime (2, 3, and 4%). Unconfined compressive strength (UCS) of natural and stabilized soils was investigated. The optimum percentage of coir pith and lime are determined based on the UCS of the soil. California bearing ratio of soil determined based on optimum percentages of coir pith and lime. **Alzaidy, (2019)** investigated an experimental study for stabilizing a clayey soil with eggshell powder (2%, 5%, and 8% ) as a replacement of commercial lime and plastic wastes strips (0.25%, 0.5%, and 1%). Laboratory tests were done by conducting compaction, unconfined compression, swelling potential, direct shear, and California bearing ratio tests. The results showed that the unconfined compression strength, California bearing ratio values, and shear strength parameters had increased with an increase in eggshell powder content up to specific limit, after that it will slightly decrease, while an increase in eggshell powder led to a reduction of swelling potential. **Hussein and Ali (2019)** studied the effect of polypropylene fiber (PPF) on the behavior of expansive soil. Multiple laboratory tests have been carried are unconfined compression test, one-dimensional consolidation test, swelling test, sieve analysis, and cycle swell shrink test. The results showed that the increase in the percentage of (PPF) led to decrease the swelling and to increase the unconfined compression strength. **Ibrahim, et al. (2019)** studied the effects of waste glasses on the engineering properties of high plasticity clay. Waste glasses are collected then crushed and sieved via sieve number 200 (0.075 mm), and the glass powder is mixed with the expansive soil in different percentages: 6%, 12%, 18%, 27%, and 36% of the dry weight of soil. Atterberg limits, standard compaction, unconfined compressive strength, consolidation, and swelling tests are conducted for the soil samples with and without glass powder. According to the test results, the Atterberg limits, maximum dry density, optimum moisture content, unconfined compressive strength, consolidation, and swelling characteristics are improved by adding glass powder as a stabilizer. The main objective of this study is to improve the geotechnical engineering properties of clayey soil using the by-product of steel slag with various percentages.

## 2. MATERIALS AND EXPERIMENTAL METHODS

### 2.1 Materials

#### 2.1.1 Clayey Soil

The used clayey soil in this study was collected from Raparin site in Sulaimani city locates in the



north part of Iraq with Latitude 35°35'13" and Longitude 45°19'17". The soil sample was taken at a depth of 1.0 meter from the natural ground surface and sealed in plastic bags to keep their field moisture content. Then, the soil sample was tested in the soil laboratory of the College of Engineering at the University of Sulaimani, Iraq. The soil sample was dried, pulverized, and sieved through sieve No.4 (4.75 mm) to eliminate gravel fraction, if any. This dried and sieved soil is stored in airtight containers ready for stabilization purposes. The soil sample classified as clayey soil with low plasticity clay (CL) based on Casagrande's plasticity chart according to the unified soil classification system (USCS) (ASTM D2487–11). The chemical compositions of the soil sample were determined using X-ray fluorescence (XRF) test conducted, as presented in **Table 1**. The geotechnical properties for the soil sample are presented in **Table 2**.

**Table 1.** The chemical compositions for the soil sample.

Compound	Values (%)
MgO	2.89
Al <sub>2</sub> O <sub>3</sub>	16.2
SiO <sub>2</sub>	65.82
K <sub>2</sub> O	2.34
CaO	4.15
TiO <sub>2</sub>	2.13
Cr <sub>2</sub> O <sub>3</sub>	0.21
MnO	0.18
Fe <sub>2</sub> O <sub>3</sub>	2.98
Na <sub>2</sub> O	3.1

**Table 2.** The geotechnical properties for the soil sample.

No.	Properties	Values	
1	Particle Size Distribution	Gravel (%)	0
2		Sand (%)	21
3		Silt (%)	45
4		Clay (%)	34
5	Atterberg Limit Test	Liquid Limit (LL) (%)	45.2
6		Plastic Limit (PL) (%)	25.37
7		Plasticity Index (PI) (%)	19.83
8		Linear Shrinkage (LS) (%)	10.93
9	Activity of Clay (%)		0.583
10	Classification according to USCS		CL
11	Specific Gravity (Gs)		2.72
12	Compaction Characteristics	OMC (%)	15
13		MDD (kN/m <sup>3</sup> )	18.34
14	Swelling Percent (%)		5.96
15	Swelling Pressure (kPa)		141.5
16	Unconfined Compressive Strength (UCS) (kPa)		649
17	Soaked CBR (%)		4.5

### 2.1.2 Steel Slag (SS)

Steel slag is a by-product of the steel manufacturing process. It is producing during the separation of molten steel from impurities in steel-making furnaces. For this study, steel slag was collected from the Suli-Steel factory in Sulaimani city, Iraq. Steel slag samples were crushed into finer particles and passed through sieve No.40 (0.425 mm), as shown in **Fig. 1**, then stored in a plastic bag. Steel slag mixed with soil in various percentages of 0, 2.5, 5, 10, 15, and 20% added by the weight of dry soil samples. The specific gravity of the steel slag sample was computed as 3.31. The chemical compositions of the steel slag were determined using X-ray fluorescence (XRF) test conducted, as presented in **Table 3**.



**Figure 1.** The used steel slag in the laboratory tests, A- Large particle size, B- Crushed and powdered.

**Table 3.** The chemical composition of the steel slag.

Compound	Values (%)
MgO	5.49
Al <sub>2</sub> O <sub>3</sub>	12.28
SiO <sub>2</sub>	13.63
K <sub>2</sub> O	0.11
CaO	45.27
TiO <sub>2</sub>	1.62
Cr <sub>2</sub> O <sub>3</sub>	1.18
MnO	4.34
Fe <sub>2</sub> O <sub>3</sub>	11.38
P <sub>2</sub> O <sub>5</sub>	0.73
FeO	2.34
SiO <sub>3</sub>	0.85
Na <sub>2</sub> O	0.78

### 2.2 Experimental Works

The laboratory tests have been carried according to ASTM standards. The tests were carried out on both natural and stabilized soil samples with steel slag, as follows:

- Atterberg limits (ASTM D 4318-10).
- Hydrometer analysis (ASTM D422).
- Specific gravity (ASTM D 854-14).
- Modified Proctor Compaction (ASTM D1557-12).
- Swelling Pressure and Swelling Percent (ASTM D 4546-14).
- Unconfined Compressive Strength (UCS) (ASTM D2166-16).
- California Bearing Ratio (CBR) (ASTM D1883-16).



### 3. RESULTS AND DISCUSSION

#### 3.1 Effect of Steel Slag on Atterberg limits.

Atterberg limits of soils are the essential determiner of the water content of fine-grained soils. Atterberg limits such as liquid limit, plastic limit, and linear shrinkage limit were considered in this study. For consistency characteristics purpose, it is clear that within the addition of steel slag from 0% to 20% causes decrease in the capability of water absorption, which can be seen with the deduction of liquid limit, plastic limit, plasticity index, and linear shrinkage limit, as shown in **Fig. 2** and **Fig. 3**. With the addition of steel slag from 0% to 20% to the expansive soil sample, the value of liquid limit reduced by 26%, and the value of the plasticity index decreased from 19.83% to 12.64% and the value of linear shrinkage reduced by 53.6%. Based on the results, the replacement technique for expansive soil stabilization successfully achieved. Also, using of non-expansive stabilizer minimized the percent of absorbed water and hence reduction in Atterberg limits obtained.

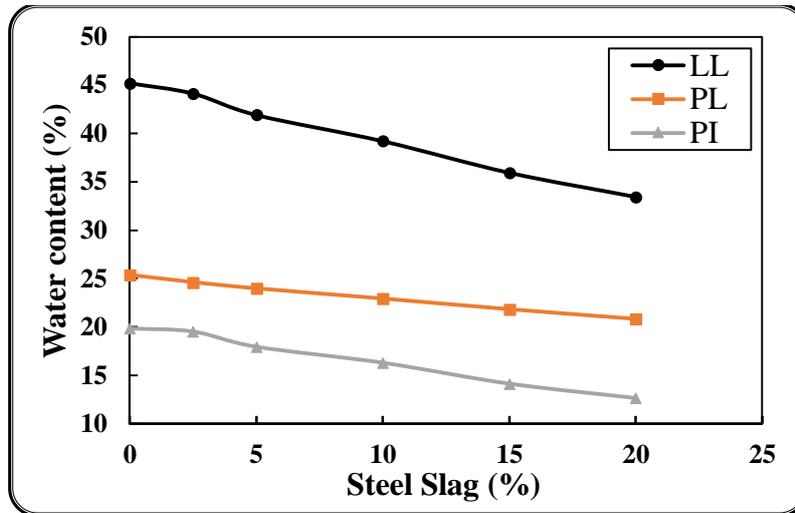


Figure 2. Variation of liquid limit, plastic limit, and plasticity index with various percentages of steel slag.

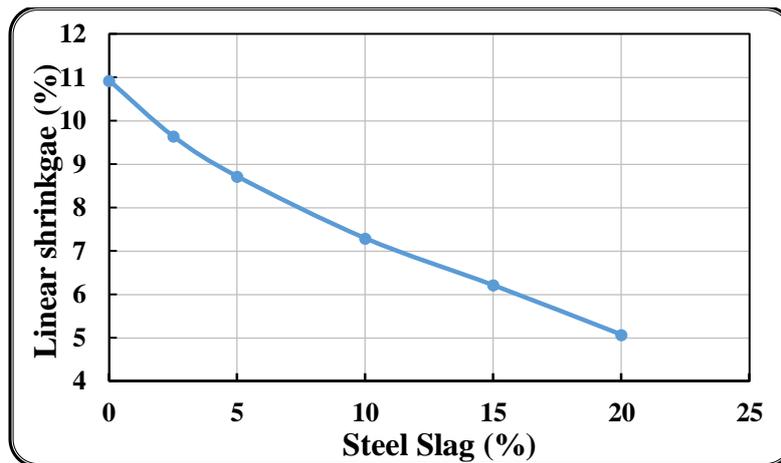
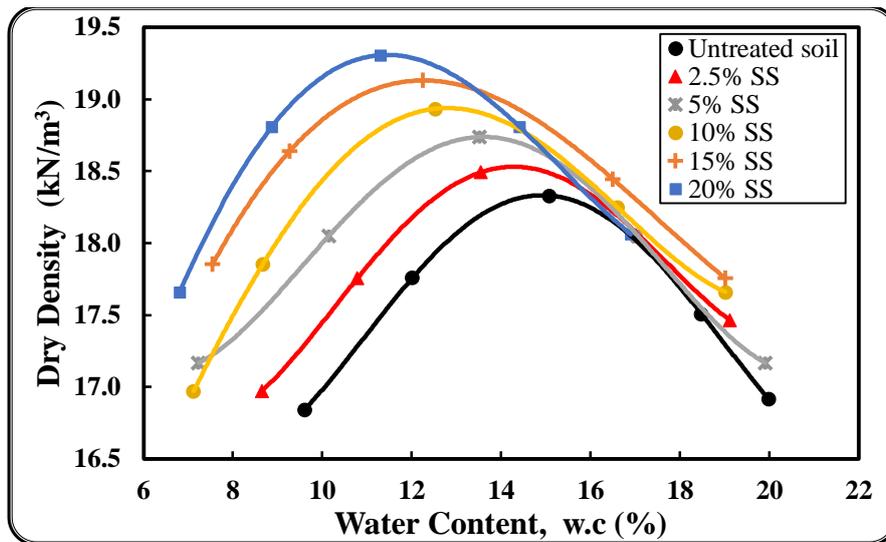


Figure 3. Variation of the linear shrinkage with various percentages of steel slag.

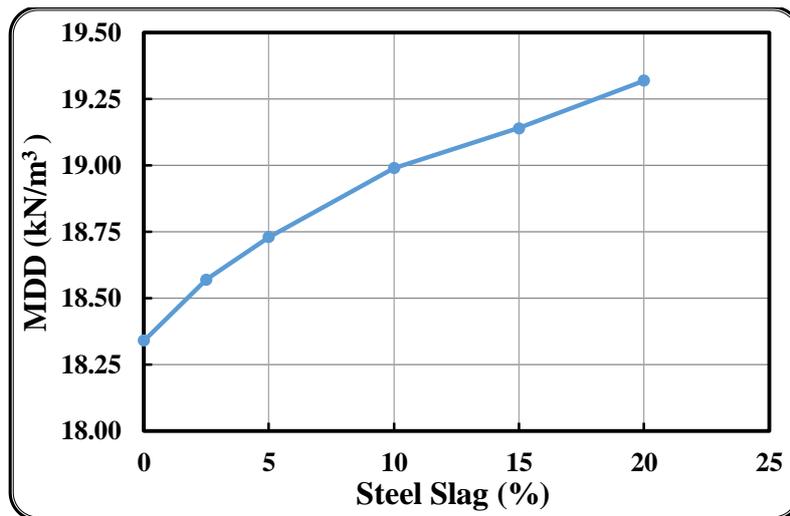


### 3.2 Effect of Steel Slag on Compaction Parameters.

The modified Proctor compaction tests were carried out for the natural and stabilized soil sample with various percentages of steel slag (0, 2.5, 5, 10, 15, and 20%) by the weight of the dry soil. The variations of dry density and water content with various percentages of steel slag are shown in **Fig. 4**. The values of OMC and MDD of natural soil were found to be 15% and 18.34 kN/m<sup>3</sup>, respectively. It can be noticed from **Fig. 4** that, with the addition of steel slag to the expansive soil sample, the values of maximum dry density (MDD) were increased, and the values of optimum moisture content (OMC) were reduced. **Fig. 5** presents the variation in MDD with the percentage of steel slag. According to the results, the value of MDD increased from 18.34 kN/m<sup>3</sup> to 19.32 kN/m<sup>3</sup>, with the addition of steel slag from 0% to 20% added to the soil sample. However, the value of OMC decreased from 15 % to 11.28 %, with the addition of steel slag from 0% to 20% added to the soil sample, as shown in **Fig. 6**.



**Figure 4.** Compaction characteristics curves of natural and stabilized soil sample With various percentages of steel slag (SS).



**Figure 5.** Variation of MDD with various percentages of steel slag (SS).

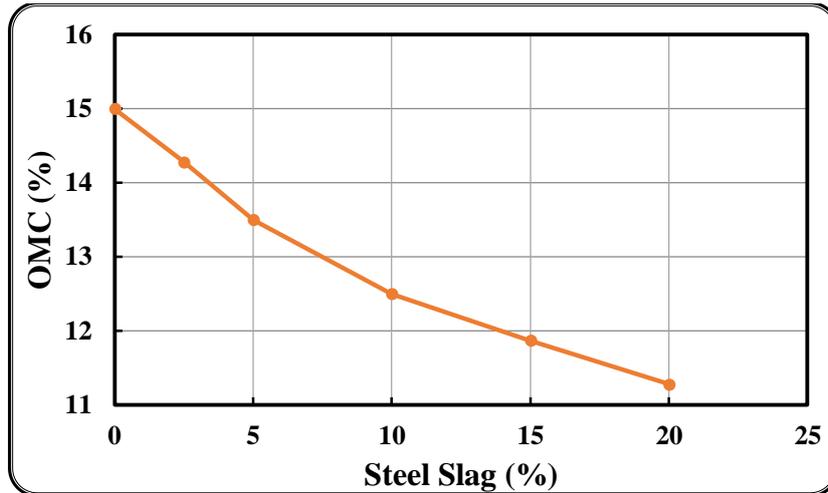


Figure 6. Variation of OMC with various percentages of steel slag (SS).

### 3.3 Effect of Steel Slag on Swelling Characteristics

Swelling pressure and swelling percent tests were conducted on both untreated and treated soil samples. Various percentages of 0, 2.5, 5, 10, 15, and 20% of steel slag were added to the expansive soil samples. The values of swelling pressure decreases with the increase in the steel slag percent added to the expansive soil sample. With the addition of steel slag from 0% to 20%, the values of swelling pressure were decreased from 141.5 kPa to 74.2 kPa, as shown in Fig. 7. Also, the values of swelling percent decrease with the increase in steel slag percent added to the expansive soil sample. With the addition of steel slag from 0% to 20%, the values of swelling percent were decreased from 5.96% to 2.62%, as shown in Fig. 8. The added steel slag achieved the highest hardening points among soil particles, which generated new capable bonds among the soil particles. Newly created bonds tighten the soil particles firmly together, which can face the happen swelling strongly due to the reduction in water absorption capability of the soil samples and resulted in very low swelling pressure and percent. Furthermore, the decrease in the values of swelling pressure and swelling percent can be because of the swelling of an expansive soil is influenced by many factors, such as clay mineral composition, amount of non-clay material present, density, void ratio, and cementation. In other words, the presence of steel slag (non-clay materials) reduces the clay-mineral content per unit mass of the mixture, which means that the total surface area of expansive clay particles decreases and can cause a decrease in the values of swelling pressure and swelling percent.

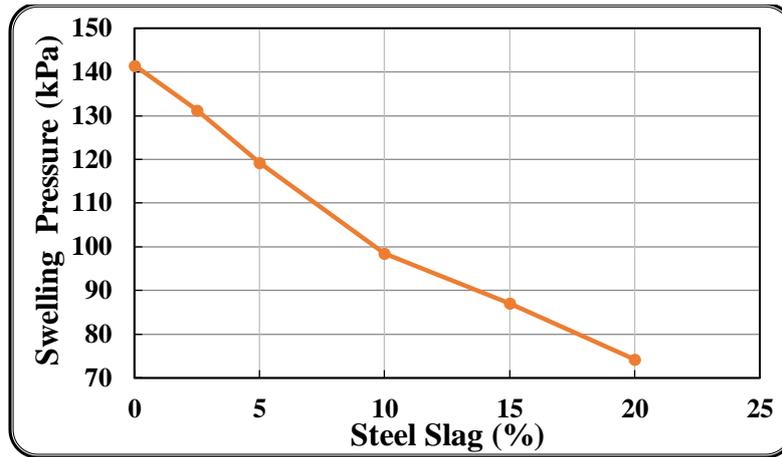


Figure 7. Variation of swelling pressure with various percentages of steel slag.

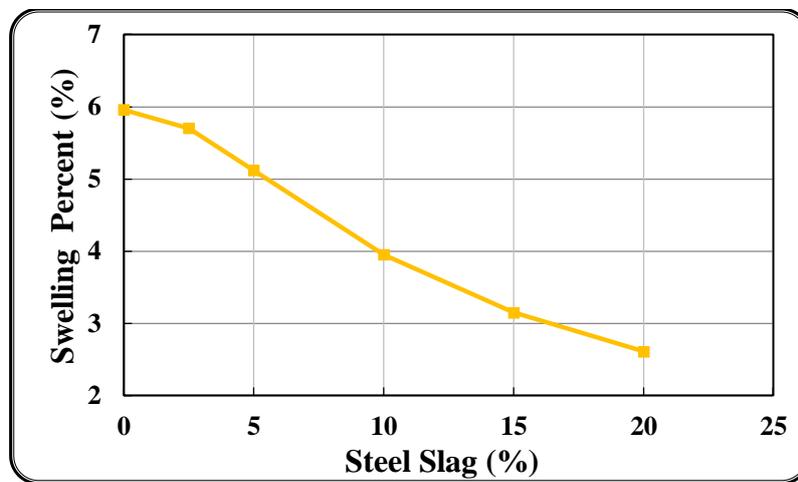


Figure 8. Variation of swelling percent with various percentages of steel slag.

### 3.4 Effect of Steel Slag on Unconfined Compressive Strength Test (UCS)

The unconfined compressive strength (UCS) test was carried out for both natural and treated soil samples with various percentages of 0, 2.5, 5, 10, 15, and 20% steel slag. The samples were prepared and compacted in the cylindrical mold at the optimum moisture content (OMC) and maximum dry density (MDD), which were obtained from the modified Proctor compaction test. Fig. 9 shows the variations of axial strain with axial stress with various percentages of steel slag for selected soil sample. The values of UCS increase with the increase of steel slag contents. The values of UCS for untreated and treated expansive soil samples with various percentages of steel slag are presented in Table 4. With the increase in steel slag from 0% to 20%, the value of UCS increased from 649 kPa to 864 kPa. The increase in the value of UCS is because of adding non-expansive material to the expansive soil samples and then reduced the amount of clay minerals and decreases the void spaces among the clay particles. Also, the specific gravity of the SS is higher than the specific gravity of the expansive soil samples, which makes the modified sample with SS more capable against compression, and hence higher UCS values were recorded.

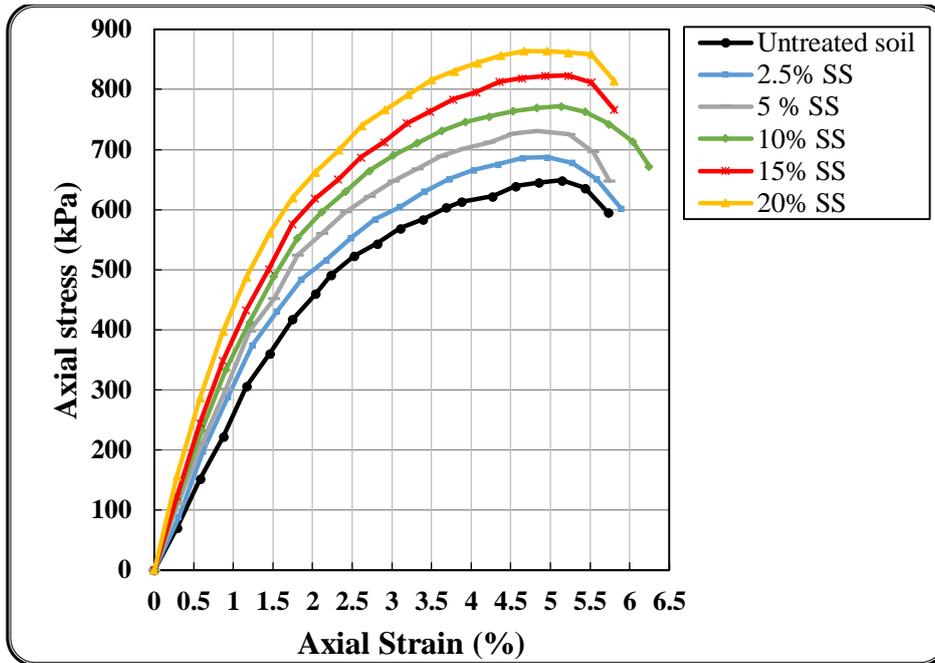


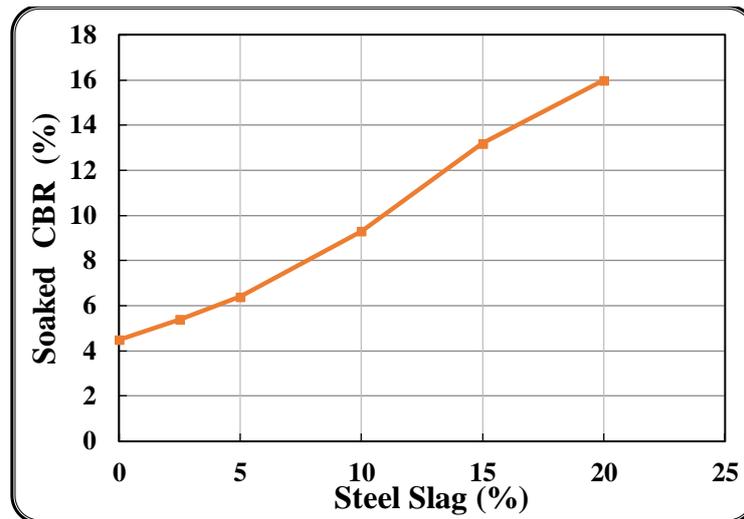
Figure 9. Effect of different SS contents on the stress-strain behaviors for selected soil sample.

Table 4. The values of UCS for untreated and treated expansive soil sample with various percentages of steel slag.

Soil samples conditions	UCS (kPa)
Untreated soil	649
97.5% soil + 2.5% SS	687
95% soil + 5% SS	731
90% soil + 10% SS	773
85% soil + 15% SS	824
80% soil + 20% SS	864

### 3.5 Effect of Steel Slag on California Bearing Ratio (CBR).

California Bearing Ratio (CBR) test is a penetration test for a comprehensive evaluation of the mechanical strength of road subgrades and base courses. To investigate the CBR value, the samples were prepared at the optimum moisture content, which obtained from the modified Proctor compaction test, and the samples were soaked for seven days. Fig. 10 shows the variations of soaked CBR values with percentages of steel slag. It can be noticed in Fig. 10 that, the value of CBR increases with the increase in the percentages of steel slag. The value of CBR increased from 4.5 % to 16 %, with the addition of steel slag from 0% to 20% added to the soil sample. The increase in CBR value is may be due to the role of the iron material in the steel slag. Hence, the steel slag played a significant role in either add new capable particles in terms of friction and new capable particles in terms of cohesion. Newly created bonds tighten the soil particles strongly together, which increases the strength and then CBR value.



**Figure 10.** Variation of CBR values with various percentages of steel slag.

#### 4. CONCLUSION

This study has concentrated on the effect of steel slag as stabilizers on the engineering properties of clayey soil. Based on the results of the conducted tests, the following conclusions are drawn:

- The values of liquid limit and plasticity index were decreased by 25.4% and 36.3%, respectively, with an increase in the percentages of steel slag from 0% to 20% added to the soil sample.
- The values of the linear shrinkage limit were decreased by 53.6%, with the addition of steel slag 0% to 20% to the soil sample.
- The values of MDD were increased from 18.34 kN/m<sup>3</sup> to 19.32 kN/m<sup>3</sup>, and the values of OMC were decreased from 15% to 11.28% with the addition of steel slag from 0% to 20% to the soil sample.
- The values of swelling percent and pressure were decreased from 5.96% to 2.61% and from 141.5 kPa to 74.2 kPa respectively, with the addition of steel slag 0% to 20% to the soil sample.
- CBR values were increased from 4.5% to 16%, with the addition of steel slag from 0% to 20% to the soil sample.

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