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An Experimental Study on Swelling Properties of Expansive Soil Treated with Iron Furnace Slag

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A B S T R A C T

Using industrial waste materials in the treatment of problematic soils is an environmentally friendly and cost-effective technique. It helps in decreasing disposal issues induced by various industrial wastes. Also, it is crucial to understand the behaviour of these waste products before use. This paper presents experimental research in the treatment of expansive soil by the utilization of iron furnace slag. Laboratory program was performed to examine the effect of iron furnace slag on enhancing the engineering properties of expansive soil. Several tests included liquid limits, plastic limits, free swell percentage, swelling pressure, and unconfined compressive strength were conducted on untreated and treated soils. The efficiency of adding 0, 2, 4, and 6 percentages of iron slag to the soil was investigated. The results of the natural and iron slag stabilized soils showed that iron slag has a notable effect on strength parameters and considerable improvement in plasticity and swelling properties. The addition of iron slag to the soil increased the unconfined compressive strength while reduced the swelling potential of soil. It is concluded that the utilization of iron slag to improve the properties of expansive soil is successful and useful

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دراسة تجريبية على خواص الانتفاخ للتربة الانتفاخية المعالجة بخبث أفران الحديد

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جودت كاظم عباس/ قسم الهندسة المدنية/ كلية الهندسة/ جامعة تكريت/ العراق

الخلاصة

يعد استخدام مواد النفايات الصناعية في معالجة التربة ذات المشكلات طريقة صديقة للبيئة وفعالة من حيث التكلفة. يساعد هذا الاستخدام للمواد في تقليل مشاكل التخلص من النفايات الصناعية المختلفة. أيضا ، من الأهمية بمكان أن نفهم سلوك هذه المواد قبل الاستخدام. تعرض هذه الورقة البحثية دراسة عملية في معالجة التربة الانتفاخية باستخدام خبث فرن الحديد.

تم إجراء برنامج مختبري لفحص تأثير خبث الحديد على تحسين الخواص الهندسية للتربة الانتفاخية. شملت الدراسة عدة اختبارات منها حدود اتربيرك ، نسبة الانتفاخ الحر ، ضغط الانتفاخ ، وقوة الضغط غير المقيدة على التربة الغير المعالجة والمعالجة باستخدام خبث الحديد. تم فحص كفاءة إضافة 0 و 2 و 4 و 6 في المائة من خبث الحديد إلى التربة. أظهرت النتائج للتربة الطبيعية والتربة المثبتة باستخدام خبث الحديد أن الخبث له تأثير ملحوظ على خواص القوة والتحسن الكبير في خصائص اللدونة والانتفاخ. أدت إضافة خبث الحديد إلى زيادة قوة الضغط غير المقيدة مع تقليل احتمال انتفاخ التربة. وخلصت الدراسة إلى أن استخدام خبث الحديد لتحسين خصائص التربة الانتفاخية أمر ناجح ومفيد.

الكلمات الدالة: تربة انتفاخية, انتفاخ حر, خبث فرن الحديد, ضغط الانتفاخ.

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1. INTRODUCTION

Expansive soil can be defined as the soil that exhibits a change in its volume due to variation in water content [1-4]. The ability of expansive soils to volume change depends on many factors such as moisture content, initial density, soil structure, type and amount of clayey minerals, and vertical stress. Expansive soils contain clayey minerals such as montmorillonite, which increase in volume and swell with an increase in moisture content (wetting), and decrease in volume and shrink with reducing in moisture content (drying) [5]. Expansive soils are widespread in large areas around the world, mainly in the arid and semi-arid regions [6]. In Iraq, the Northern part is considered one of the areas that have this type of soil, especially in Mosul and Duhok. Change in volume of expansive soils can apply extra stress on a building, basement, sidewalks, and foundations which cause damage. Recent studies indicate that damage caused by the problem of swelling is twice as much as damage due to the problem of earthquakes, hurricanes, and floods. Al-Rawas, et.al. [7] added that expansive soil could act as an inherent risk causing severe damage if not treated well. There have been several studies in the literature reporting that the swelling potential of expansive soil is significantly reduced when soil mixed with some additives such as cement, lime, fly ash, and other materials. These studies focused on improving the soil engineering properties, reducing environmental risks, and as well be very cost-effective.

Moreover, most previous studies have focused on using traditional additives, either cement or lime. However, the effect of other materials on the swelling behavior of clay soils need more attention. In recent days, there is rising in levels of production of waste materials which encourage researchers to use them in different engineering applications. Reusing waste materials has environmental advantages, such as the reduction of greenhouse gases. Lambe and Whitman [8] added that mixing clay soil with cement may reduce the liquid limit, plasticity index, and potential volume change and increase the shrinkage limit and shear strength. Murthy [9] stated that the cement stabilization for clayey soils is active when fine fractions (passing No.200 sieve) are less than about 40%, the plasticity index is less than about 25 and the liquid limit is less than 45 to 50. Lime is one of the chemical additives that has also been used effectively in the stabilization of expansive soils by reducing swelling characteristics and plasticity of the soil. Ismaiel [10] suggested a range of 3-5% lime content for efficient stabilization. In addition, Khalil, et.al [11] showed that unconfined compression strength and swelling potential of expansive soil significantly reduced when soil mixed with 4% lime. Seco, et.al. [12] Stated that the combination of lime and cement might produce good results, respecting the decline of the swelling potential of natural soils. Tiza and Iorver [13], Sabat and Pati [14] and Ashango and Patra [15] have confirmed that using other materials such as agricultural solid wastes (groundnut shell ash, olive cake residue, and wheat husk ash), waste tire, eggshell powder, and marble dust may also improve the mechanical properties of expansive soils. Slag is one of the industrial waste materials used in different engineering applications. Slag is the by-product of the steel making process and is classified into two main groups called nonferrous slag and steel slags. Slag and Portland cement are almost similar in chemical components, and it reacts with water but at a slow rate. Ouf [16] investigated the effect of ground granulated blast furnace slag (GGBS) and Lime on the behavior of expansive clay, the results showed that the optimum moisture content slightly increased, and maximum dry density slightly decreased when soil mixed with slag. Furthermore, unconfined compressive strength (UCS) values increased with increasing slag content. The research of Veith [17] showed that the swelling potential of soil reduced from 28% down to only 4% when soil mixed with slag. [17] argued that the effect of slag in reduction of the swelling potential is related to the creation of cementitious gels when the slag is activated with a slight amount of lime. In addition, Yadu and Tripathi [18] stated that the swelling pressure reduced from about 42 kPa for untreated soil to about 34 kPa for the 9% GBFS. Chandra and Lavanya [19] stated that adding granulated blast furnace slag GBFS to the expansive soil reduced the cohesion and increased the internal friction angle. The present study aims to examine the effect of adding three percentages of slag (2, 4, and 6%) on swelling pressure, free swelling percentage, and unconfined compression strength of expansive soil.

2. MATERIALS USED

2.1. Soil

The soil used for the experiments was collected from the Al-Hadbaa district, Mosul city. The soil was 8% sand fraction, 41% silt fraction, and 51% clay fraction and classified as CH according to the Unified Soil Classification System (USCS), while the classification of soil was A-7-5 based on AASHTO. Table.1 presents the properties of natural soil used in this study.

Table 1

Properties of natural soil

Properties	Magnitude
Specific gravity (G_s)	2.75
Liquid limit L. L	85%
Plastic limit P. L	35%
Plasticity index PI	50 %
Maximum unit weight	16.28 kN/m^3
Optimum moisture content	22.3 %

2.1. Iron slag

The Slag was brought from Bazian Steel Factory in Sulaymaniyah city (North of Iraq) in the form of course aggregate, as shown in Fig.1 (a). Then it was crushed to powder form using an electrical crusher Fig.1 (b). Chemical tests on slag were carried out in the Laboratory of the Department of Chemical Engineering at Tikrit University. The results of these tests showed that slag contained calcium oxide (CaO), Silica, Aluminum oxide (Al_2O_3), Magnesium oxide (MgO) as shown in Table 2. It was a coarse light green granular solid, odorless, alkaline, and insoluble in water. Many researchers have argued that slag has a solid specific gravity of 2.8-3.1, bulk density at loose state of 1-1.1 ton/m^3, relative density of 2.85-2.95%, and a surface area of 400-600 m^2/kg [20]. Furthermore, these studies stated that slag has angular particles of different sizes.

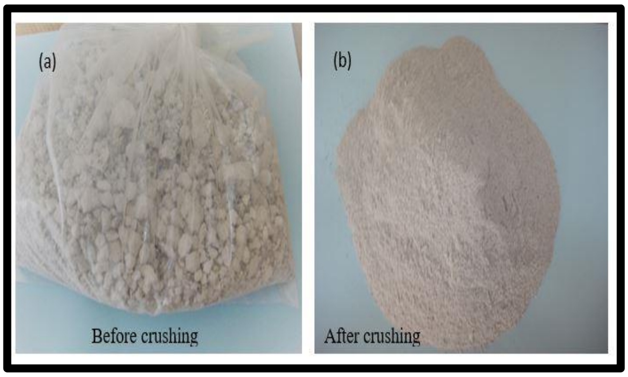

Fig.1. Iron slag

Table 2
The chemical composition of iron slag used in the present study

Chemical components	Percentages (%)
Calcium oxide (CaO)	40.11
Silica, amorphous (SiO_2)	32.11
Aluminium oxide (Al_2O_3)	11.84
Magnesium oxide (MgO)	2.96
ferric oxide (Fe_2o_3)	3.41
Sulfur trioxide (So_3)	0.81
other	8.76

3. RESULTS AND DESCUSSION

3.1. Atterberg limits

The American Society for Testing and Materials (ASTM D4218) was used to determine the liquid limit and plastic limit of untreated and iron slag treated samples. Table.3 shows the effect of adding iron slag on the Atterberg limits of used soil. The liquid limit of soil significantly reduced from 85% to 68, 66, and 63% when soil was mixed with 2, 4, and 6% iron slag respectively. Furthermore, the plasticity index of natural soil considerably reduced when soil was mixed with different iron slag content. The plasticity index reduced from 50% to 16% with increasing iron slag content up to 6%. The reduction in liquid limit and plasticity index of soil with increasing iron slag content could be related to the replacement slag of the clay mineral.

3.1. Unconfined Compression Test (UCS)

In the present work, ASTM (2166) was followed for the unconfined compressive strength UCS test. All specimens were compacted in the steel mold of 102 mm in height and 38 mm in diameter, and they were prepared at the maximum dry density and optimum moisture content. The UCS test was conducted by using the compression device, which consisted of a motorized load frame, proving ring, load dial gauge, and displacement dial gauge. The load was applied at a rate of 0.05 in/min until failure. The stress-strain curve of untreated soil is presented in Fig.2. It can be noted that the untreated soil achieved the maximum stress value of 553.74 kPa at 2.38% axial strain, and then the stress dropped until the end of the test. The results of UCS tests concerning expansive soil treated with various percentages of iron slag are shown in the Fig.3. It is observed that all samples exhibited a gradual increment in stress until they reach the maximum values, and then the stress dropped until the end of the tests. Furthermore, the UCS of samples increased when slag content was 2% and then significantly decreased when slag content increased up to 6%. Samples mixed with 4% and 6% iron slag showed maximum stress values lower than untreated soil. From the data in Fig.3. it is apparent that the all iron slag treated samples achieved the maximum stress at the almost same axial strain. The samples achieved maximum stress values at 2.55%, 2.55%, and 2.6% axial strain when mixed with 2, 4, and 6% iron slag, respectively. The optimum iron slag content is observed to be 2% from the UCS point of view. The maximum UCS value obtained was 598.94 kPa at 2% iron slag content. The UCS values were reduced below the values of untreated soil when soil mixed with 4% and 6% of iron slag. The increase in strength of expansive soil when mixed with 2% iron slag could be related to the iron slag having angular shape particles with a rough surface, which led to a proper interlocking with soil particles then an increase in the frictional angle. However, when iron slag content increased by more than 2%, a considerable number of pores existed inside the treated samples. Pores may cause a reduction in the strength of treated soils.

Table 3
Atterberg limits of untreated and iron slag treated soils

Atterberg Limits	0% slag	2% slag	4% slag	6% slag
L.L (%)	85	68	66	63
P.L (%)	35	42	45	47
P.I (%)	50	26	21	16

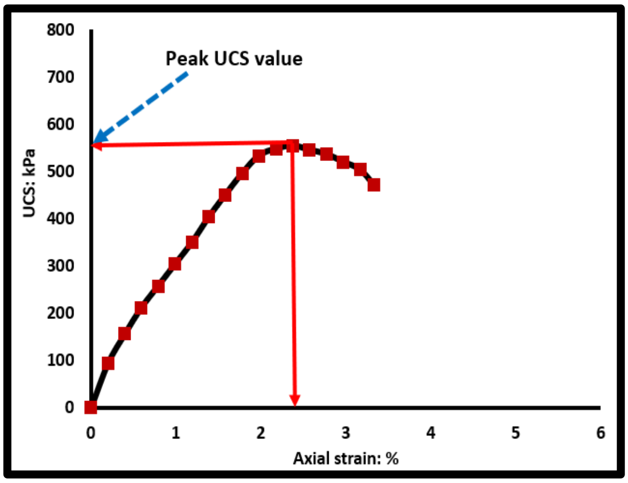

Fig.2. Stress vs. strain relationship of untreated expansive soil sample

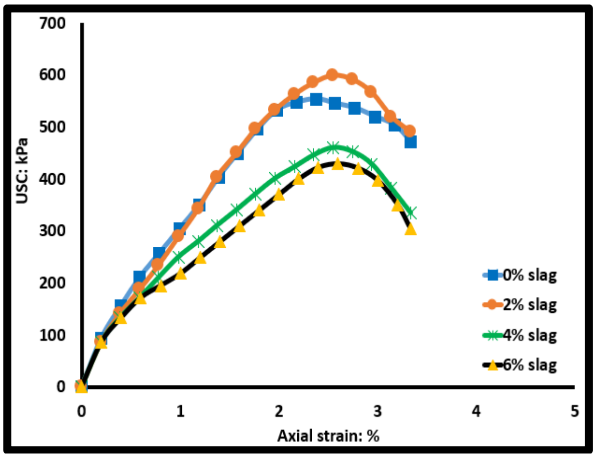

Fig.3. Stress vs. strain relationships of iron slag treated soils.

3.1. Swelling Properties

In expansive soils, the swelling percentage and swelling pressure are the most valuable parameters to recognize the riskiness of the issue generated by this type of soil. In the current study, the free-swelling and swelling-pressure tests for untreated and iron slag treated soils were performed on remolded specimens based on the maximum dry density and optimum moisture content (OMC) using the Oedometer device. Samples were compacted into Oedometer rings (75mm in diameter and 20mm in height), as shown in Fig 4 after that, the compacted samples were placed in the Oedometer for necessary examination, the swell percentage variations of iron slag treated expansive soil are presented in Table 4 and Fig.5, it is noticed that at 2% iron slag, there is a significant reduction in the swelling percentage of the samples, and thereafter, further addition of iron slag is causing a gradual change in variation of swelling percentage. The swelling percentage of the treated soil was reduced from 11.55% for 0% iron slag to 7.35% for 2% iron slag, 6.3% for 4% iron slag, and 5.8% for 6% iron slag. The swelling percentage is defined as the change in the sample height relative to the initial height.

Fig. 4. Soil Sample in the Oedometer test

Fig.5 shows the percentages of reduction of swelling percent (R_{ps}) against the iron slag content. The percentages of reduction of swelling percent (R_{ps}) represent the percentage of difference between swelling percent of iron slag treated the soil and untreated soil to swelling percent of untreated soil, and it used to indicate the amount of reduction in swelling percent with increasing iron slag content. It can be seen from Fig.5 that the iron slag effectively decreased the swelling percent of expansive soil, and the reduction in swelling percent increased with increasing iron slag content. Also, the maximum reduction was recorded with 6% iron slag content. The percentages of reduction of swelling percent (R_{ps}) of treated soil increased from 37% when iron slag was 2% to 46 and 50% when iron slag content increased to 4 and 6%, respectively.

From the data of Fig. 5 the percentages of reduction of swelling percent (R_{ps}) could be calculated using the following equations:

$$R_{ps} = -2.0109\, s^2 + 20.022\, s + 1.1304 \qquad (1)$$

Where s is slag content

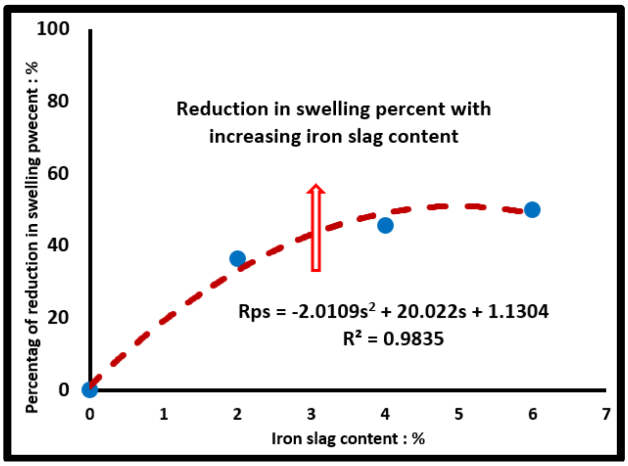

Fig.5. Percentage of reduction in swelling percent vs. iron slag content

The influence of iron slag percentage on the swelling pressure of expansive soil is presented in Table 5 and Fig.7. The swelling pressure represents the amount of stress required to eliminate swelling of soil in which, an increase in swelling pressure indicates reduction in soil strength and an increase in soil deformations and vice versa. From data in Table 5 and Fig.6, it can be seen that as iron slag increased from zero to 2%, the swelling pressure is rapidly reduced from 666.48 kPa to 386.71 kPa. After that, further increases in iron slag content are influencing a gradual reduction in swelling pressure. The swelling pressure of treated soil was reduced to 380.71 kPa and 353.32 kPa when iron slag content increased to 4 and 6%, respectively. In order to present the role of iron slag content in the swelling behavior of expansive soil, the percentage of reduction of swelling pressure is also used here, as shown in Fig.7. The percentage of reduction of swelling pressure represents the percentage of the difference between swelling pressure of treated soil and untreated soil to the swelling pressure of untreated soil. From Fig.7, it can be noticed that the percentage of reduction of swelling pressure (R_{sp}) significantly increased to 42% when slag content increases to 2%. Then, the percentage of reduction of swelling pressure slightly increased to 43 and 47% when iron slag increased to 4 and 6%, respectively.

Data from Figs 6 and 7 can be used to calculate the swelling pressure and percentage of reduction of swelling pressure of Iron slag treated soils by using the following equations:

$$S_p = 15.761\, s^2 - 141.836\, s + 651.7 \quad (2)$$

$$R_{sp} = 0.92s^3 - 10.7s^2 + 38.7 - 3e^{-12} \quad (3)$$

Where Sp is is the swelling pressure, and s is the Iron slag content.

Table 4

Effect of iron slag content on the swelling percent of expansive soil

Iron slag content (%)	Swelling percent (%)	Percentages of reduction of a swelling percent (R_{ps}) (%)
0	11.55	0
2	7.35	37
4	6.3	46
6	5.8	50

Table 5

Effect of iron slag content on swelling pressure of expansive soil

Iron slag content (%)	Swelling pressure (kPa)	Percentages of reduction of swelling pressure (R_{sp}) (%)
0	666.48	0
2	386.71	42
4	380.91	43
6	353.32	47

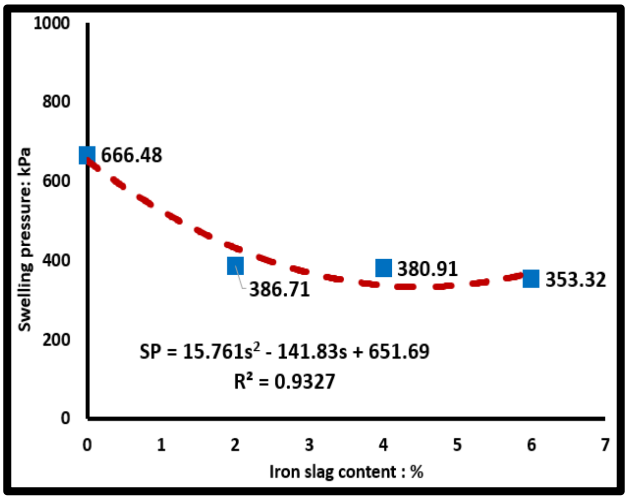

Fig.6. Swelling pressure vs. iron slag content

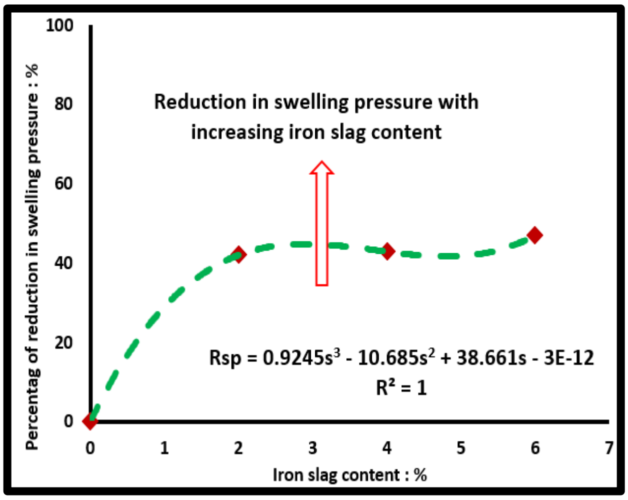

Fig.7. Percentage of reduction in swelling pressure vs. iron slag content

The positive effect of iron slag in the reduction of swelling potential and swelling pressure of expansive soil could be attributed to the effect of iron slag in reducing the plasticity index of expansive soil. Furthermore, the iron slag acts as a mechanical stabilizer by replacing some of the volume held by soil particles.

4. CONCLUSIONS

This paper presents the results of unconfined compression test and swelling properties tests of expansive soil treated with different percentages of iron slag. All samples were prepared at the maximum dry density and optimum moisture content. The main findings of the current research can be summarized as follow:

1-The addition of a 2% iron slag increased the unconfined compressive strength of soil (UCS) significantly. However, with further iron slag content (4% and 6%), the UCS is slightly reduced, and the samples showed values lower than untreated soil. It was found that increasing iron slag content more than 2% causes an increase in the pores inside soil structures, which reduce the strength of the soil.

The addition of iron slag notably improved the swelling properties of the expansive soil. The swelling percent and swelling pressure rapidly reduced when soil mixed with 2% iron slag and then further decreased with further iron slag content up to 6%. It was found that the reduction in swelling percent and swelling pressure was attributed to the role of iron slag in the reduction of plasticity index and clay fraction of untreated soil

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