Research Article

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Improvement of CBR of gypsum subgrade soil by cement kiln dust and granulated blast-furnace slag

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Abstract: Most construction projects face the problem of a high percentage of gypsum in the soil. To get rid of the unwanted effects of gypsum, which lead to the dissolution of gypsum in the presence of water and the settlement of the foundations of buildings and subsoil of roads, the researchers used several materials that can be added to the soil to improve its properties in resisting loads. This research presents a study of the effect of adding cement kiln dust (CKD) and ground-granulated blast-furnace slag (GGBS) on the California Bearing ratio (CBR) of gypsum sandy soil. The percentages of 2.5, 5, 7.5, and 10% of additives by the weight of the soil sample were collected, and CBR tests were performed on dry and soaked samples. The main results showed that the ideal CKD ratio, which improves the CBR soil in a dry state, is 5% and in a soaked condition is 7.5%. Also, CBR in dry and soaked states increases slightly when the GGBS percentage increases reaching 10%. The use of GGBS gives an increment in CBR, which is around 1.6 times in a dry condition and 4 times in a soaked state.

Keywords: soil improvement, cement kiln dust, GGBS, CBR improvement

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1 Introduction

The gypsum soil covers nearly 32% of Iraq [1]. Many structures are constructed on this soil subjected to the total or differential settlement, mainly when the water attacks these sites. This article studies the effect of adding cement kiln dust (CKD) and ground-granulated blast slag (GGBS) separately and investigates if these additives can improve the California Bearing ratio (CBR) to increase the strength of this soil. Before delving into the stages of this research, it is necessary to review previous research and studies dealing with this topic.

Khattab [2] reported that sulfate-resisting cement improved the unconfined compression strength of granular gypsum soil but showed a substantial amount of reduction in power and stiffness upon immersion in water.

Muthumari et al. [3] presented an experimental study investigating the effects of CKD and ceramic dust (CD) on soil expansivity. The results showed that the liquid limit, plasticity index, optimum moisture content, and free swell index were decreased with an increase in CKD and percent of CD.

Choobbasti et al. [4] studied the effect of adding nano-silica and cement on sandy soil's unconfined compressive strength and compaction. About 5, 9, and 14% cement by the dry weight were mixed with 0, 5, 10, and 15% by weight of cement. The results showed that the maximum dry density increases when the cement percent increases and the optimal percentages of nano-silica can improve the properties of cement sand.

Mosa et al. [5] used CKD with percentages of 5, 10, 15, 20, 25, and 30% by dry weight of soil to improve the CBR of poor subgrade soil properties. The results showed that the use of 20% of CKD with curing for 2 weeks increases the CBR from 3.4% for untreated soil to 48% for treated soil, and there is a significant increase in CBR if the curing period varies from 2 to 4 weeks. Also, the saving in the cost of pavements reached 25.8 $\$/m^2$ due to the subgrade treatment by CKD.

Aziz et al. [6] evaluated the effective use of a mixture of asphalt powder and the waste oil of vehicles on the shear strength of sandy clay gypsum soil – 3, 5, and 7% percentages by dry weight of the soil sample. The main results are that the mixture of waste materials improves the shear strength, and there is a sound reduction in the permeability, which reduces the collapse.

Eisa et al. [7] presented an experimental study to stabilize weak soil layers using lime, CKD, fiberglass, and Addicrete 11 in ratios of 2, 4, and 6% of the clayey and sandy soil sample weight. The results showed that the maximum dry density increased from 1.65 to 1.86 g/cm^3, and the swelling in the earth decreased with a significant value of shear strength with 6% CKD.

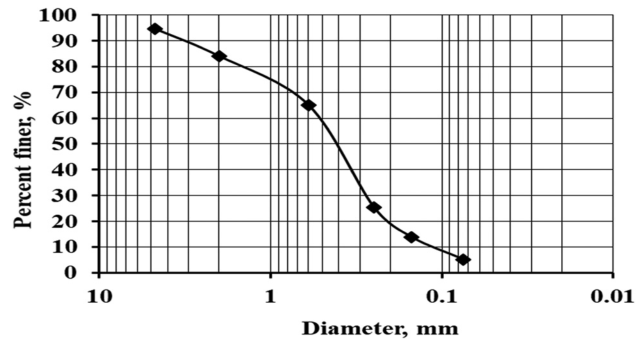

Figure 1: Grain size distribution of used soil.

2 Materials and testing

2.1 Used soil

The soil used in the laboratory tests was brought from an area in northwest of Al-Najaf governorate in Iraq. Most of the physical and chemical properties of this soil are drawn in Table 1. The grain size distribution is illustrated in Figure 1. The sample was classified as SP (poorly graded sands) according to the Unified Soil Classification. The used soil can be classified as highly gypsum soil, according to Al-Barazanji [8], as in Table 2.

2.2 CKD

CKD is known as a heterogeneous powder. In this research, CKD was collected from Al-Kufa Cement Plant, which lies in Kufa, Al-Najaf governorate, Iraq. The chemical properties of CKD are shown in Table 3.

Table 1: Physical and chemical properties of used soil

No.	Physical properties	Values	Specification
1	Specific gravity	2.68	ASTM D792-20 [9]
2	Optimum water content	16%	ASTM D698-12 [10]
3	Maximum dry density (kN/m^3)	17.22	ASTM D698-12 [10]
4	C_u	4.17	ASTM C136-06 [11]
5	C_c	1.4	ASTM C136-06 [11]
6	Soil type	SP	ASTM D2487-17 [12]
No.	**Chemical properties**	**Values**	**Specification**
1	Organic material	2.4%	ASTM D2974-20 [13]
2	$CaSO_4 \cdot 2H_2O$ (gypsum content)	26.1%	ASTM C471M-20 [13]
3	SO_4 (sulfate content)	10.7%	ASTM C1580-05 [14]

2.3 GGBS

GGBS is a material used mainly in concrete and is a by-product of iron industry. Blast furnaces at 1,500°C use a carefully controlled mixture of limestone, coke, and iron ore. The iron ore is demoted into iron, and the remaining materials form a slag that floats over the iron. If it is to produce GGBS, the slag is periodically tapped off as a molten liquid and has to be quickly quenched in a large quantity of water. The quenching operation improves the characteristics and makes granules similar to coarse sand. The final granular slag is then dried and formulated into a fine powder. In the UK it is usually named as "GGBS." It is also called as "GGBFS" or "slag cement." The properties of GGBS are shown in Table 4 [16].

2.4 CBR test

The investigation of CBR was divided into three main stages: the first stage investigated the performance of the reference soil sample and carried out the CBR test for dry and soaked conditions. The second stage contained a CBR

Table 2: Classification of gypsum soil [8]

Gypsum content (%)	Classification
0–0.3	Non-gypsum
0.3–3	Very slightly gypsum
3–10	Slightly gypsum
10–25	Moderately gypsum
25–50	Highly gypsum
>50	Sandy gypsum

Table 3: Chemical analysis of CKD [15]

Constituents	Percent by weight
SiO_3	15.4
Al_2O_3	3.5
Fe_2O_3	3.2
CaO	42.88
MgO	2.9
SO_3	6.3
K_2O	2.5
Na_2O	1.48
Loss of ignition	27.7
Chlorides	0.89

Table 4: Properties of GGBS

Chemical properties	Value (%)
Calcium oxide	40
Silica	35
Alumina	13
Magnesia	8
Physical properties	**Value**
Color	Off-white
Specific gravity	2.9
Bulk density	1,000–1,100
Fineness	>350 m^2/kg

test using CKD with 2.5, 5, 7.5, and 10% as an additive to soil mass for dry and soaked conditions. In the third stage CBR test was performed using GGBS for the exact percentages of CKD to compare the two added materials. The CBR test was carried out according to the ASTM D1883-21 [17]. This test calculates the sub-base, base materials, and sub-base to use its value in pavement design. In the laboratory, a circular piston penetrates a compacted material in a mold at a constant penetration rate. The CBR represents the ratio of the unit load on the sample required to punch 2.5 mm (1 in) and 5.1 mm (2 in) into the unit load needed to punch a standard material of well-graded crushed stone. The CBR test machine is shown in Figure 2.

Figure 2: CBR test machine.

3 Results

3.1 CBR testing for reference sample

CBR test was conducted according to the ASTM D1883-21 [17] on the reference sample in dry and soaked conditions. For soaked state testing, the samples were soaked in water for 7 days. The results of the CBR test are shown in Figure 3. From this figure, CBR values were found to be 9.5 and 7.1% for dry and soaked samples, respectively.

3.2 CBR testing for CKD/soil mixture

Many previous researchers adopted 2.5, 5, 7.5, and 10% of CKD/soil percentages, significantly improving this range. These percentages were collected to investigate the effect

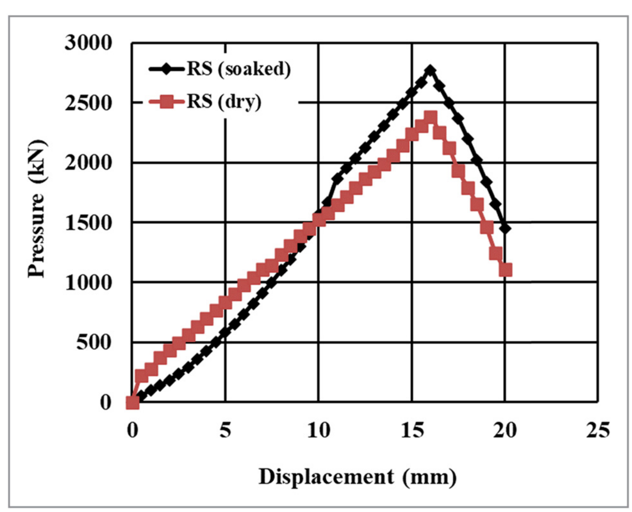

Figure 3: Relationships between load and displacement for the dry and soaked reference samples.

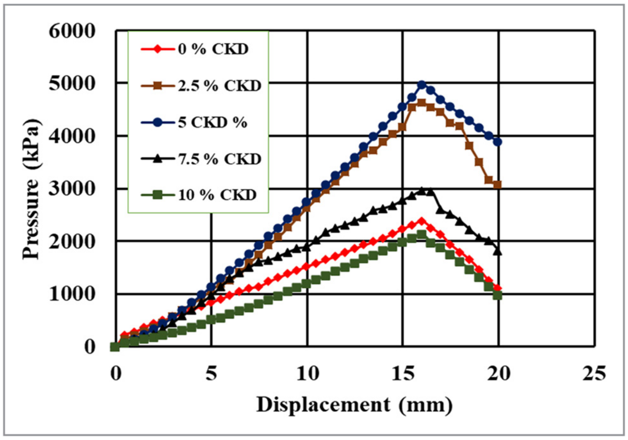

Figure 4: Relationships between load and displacement for CKD/soil mixture in the dry condition.

of adding CKD as a percentage by the weight of the soil. The CBR tests for dry and soaked conditions were carried out. Load–displacement relationships are shown in Figures 4 and 5, respectively. From these relationships, the CBR values for the dry state were calculated as 12.2, 14, 12.5, and 5.9%. For soaked conditions, CBR values were 10.5, 19.7, 23.4, and 9.2%.

3.3 CBR testing for GGBS/soil mixture

The effect of adding GGBS material to the soil as a percentage of the weight of soil on CBR is studied for the exact percentages of CKD. The dry and soaked conditions are also adopted. Load–displacement relationships are shown in Figures 6 and 7, respectively. The CBR values were calculated as 12.6, 17, 18,

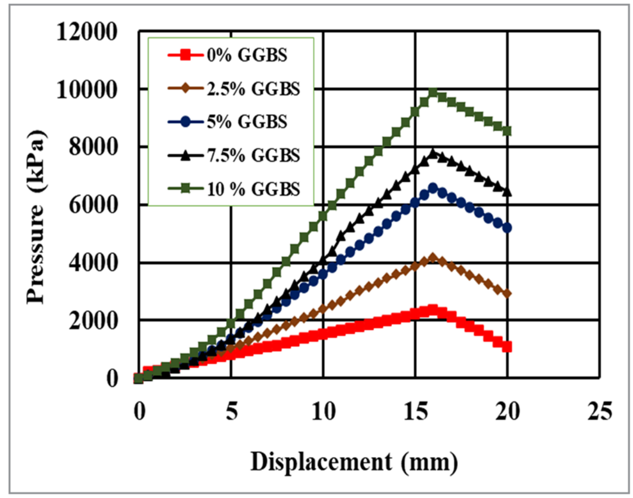

Figure 6: Relationships between load and displacement for GGBS/soil mixture in the dry condition.

and 24.8% for dry conditions and 7.4, 13.3, 22.8, and 36.4% for soaked conditions.

The final results of all cases are summarized in Table 5.

4 Discussion of the results

4.1 Dry condition

The final results of CBR for the dry condition are shown in Figure 8, and it can be seen that the use of GGBS increases the CBR within the range of collected percentages while the use of CKD increases the CBR up to 5% and thereafter

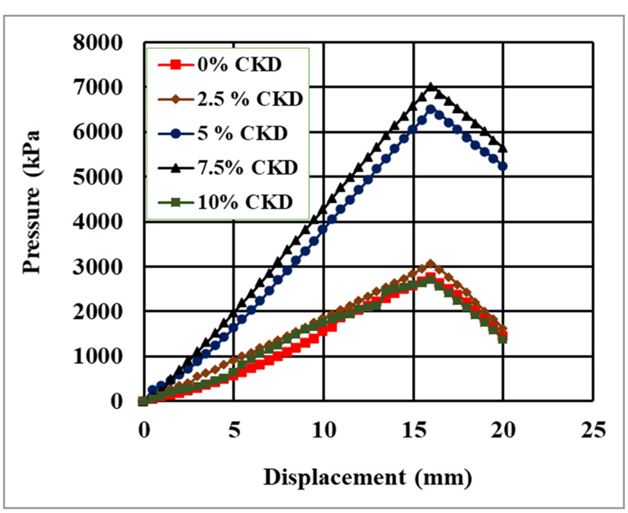

Figure 5: Relationships between load and displacement for CKD/soil mixture in the soaked condition.

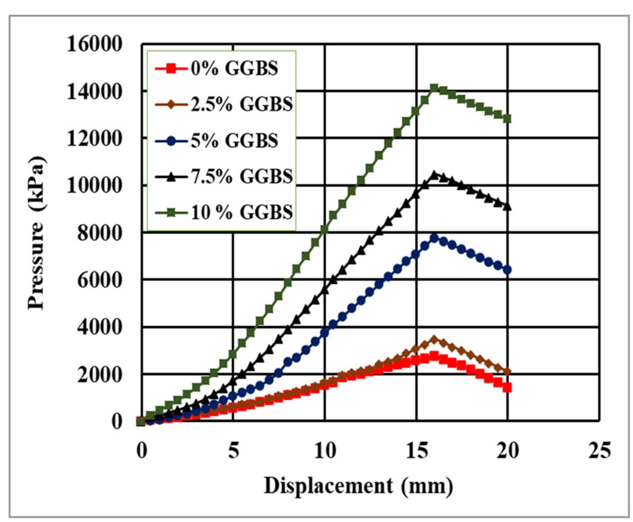

Figure 7: Relationships between load and displacement for GGBS/soil mixture in the soaked condition.

Table 5: Summary of results

Percent	CBR for CKD	CBR for GGBS
Dry condition		
0	9.5	9.5
2.5	12.2	12.6
5	14	17
7.5	12.5	18
10	5.9	24.8
Soaked condition		
0	7.1	7.1
2.5	10.5	7.4
5	19.7	13.3
7.5	23.4	22.8
10	9.2	36.4

decreases. From these results, it can be concluded that the use of GGBS up to 10% (in the present study) is more effective in increasing the CBR of gypsum soil. The use of GGBS higher than 10% can be studied in future works.

4.2 Soaked condition

For the soaked condition, Figure 9 shows the final results of CBR. It can be seen that the use of GGBS, same as in dry conditions, increases the CBR but with higher values than in dry after 7.5%. The use of CKD increases CBR up to 5% and for higher than this percentage decreases but with a little value of CBR, then it can be concluded that the use of GGBS with GGBS higher than 7.5% in the soaked state gives a higher CBR than the dry state, while using CKD, the CBR

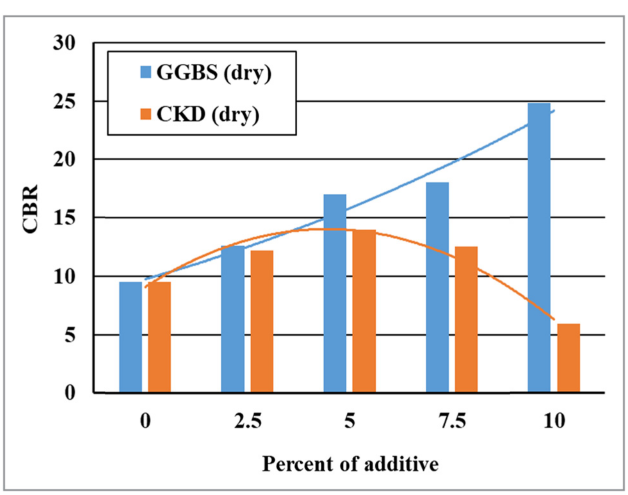

Figure 8: Percent of additive and CBR values relationship in the dry condition.

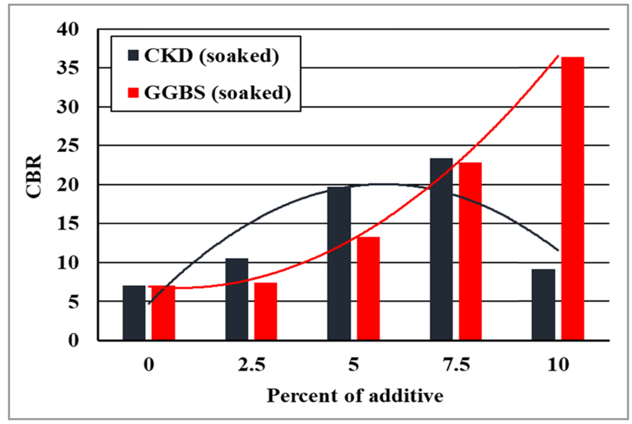

Figure 9: Percent of additive and CBR values relationship in the soaked condition.

decreases for 2.5% and then increases for 5, 7.5, and 10%, respectively, with the comparison of dry state.

4.3 Comparison between dry and soaked

To study the effect of soaking of the additives separately, Figures 10 and 11 show the effect of soaking on CKD and GGBS, respectively. The use of CKD in the soaked condition decreases CBR by up to 2.5% after which the CBR increases as compared to the dry state, as shown in Figure 10. The use of GGBS in the soaked condition decreases CBR by up to 5% after which CBR increases in comparison with the dry state as shown in Figure 11. It is worth mentioning here that the soaking process has great importance on the results, and therefore must keep the samples soaked in water throughout the week, as water is added to the samples whenever they dry.

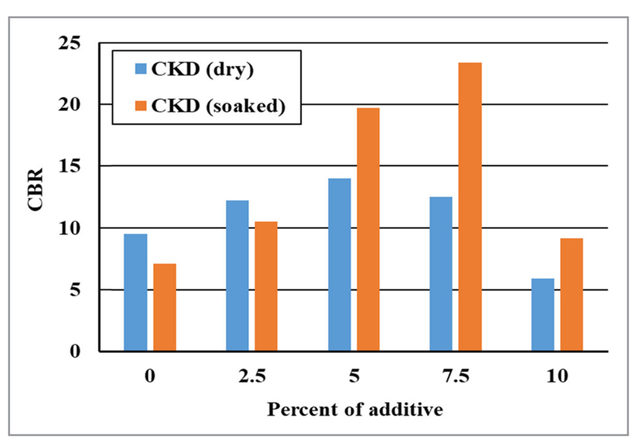

Figure 10: Percent of additive and CBR values relationship for CKD in dry and soaked conditions.

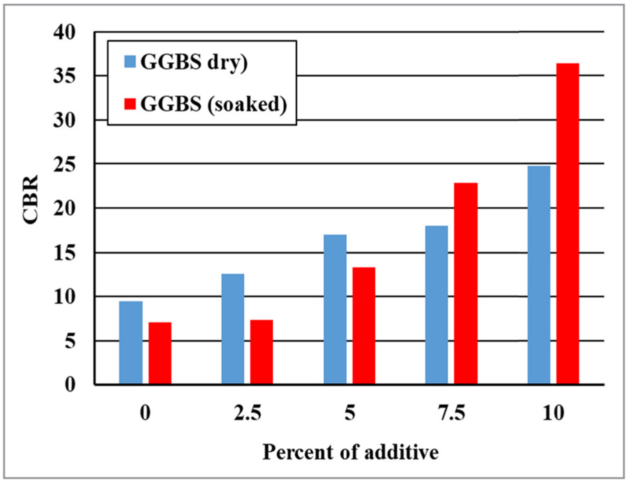

Figure 11: Percent of additive and CBR values relationship for GGBS in dry and soaked conditions.

5 Conclusions

In this study, a series of laboratory tests were carried out to investigate the effect of adding CKD and GGBS on CBR of gypsum sandy soil in dry and soaked conditions. The following conclusions are drawn:

1. The ideal CKD ratio, which improves the CBR of gypsum sandy soil in a dry state is 5%.
2. In a soaked state, the CBR of gypsum sandy soil improves optimally when it is mixed with a CKD at a percentage of 7.5%.
3. The CBR of gypsum sandy soil in dry and soaked states increases slightly when the GGBS percentage increases reaching the maximum collected value in this study (10%).
4. In dry conditions, the CBR of gypsum sandy soil increases using CKD higher than using GGBS by up to 5%, after which the CBR decreases with CKD and continues to rise with GGBS.
5. In soaked conditions, the CBR of gypsum sandy soil increases using CKD higher than using GGBS by up to 7.5%, after which the CBR decreases with CKD and continues to rise with GGBS.
6. The use of GGBS gives an increment in CBR, which reaches 1.6 times in a dry state.
7. The use of GGBS gives an increment in CBR, which reaches 4 times in a soaked state.

Conflict of interest: The authors state no conflict of interest.

Data availability statement: Most datasets generated and analyzed in this study are comprised in this submitted manuscript. The other datasets are available on reasonable request from the corresponding author with the attached information.

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