Evaluation of Tikrit Dune Sand Soil Enhanced with CKD

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Abstract. Dune sands occupy large parts of Iraq, posing significant challenges for infrastructure building. Geotechnical research and stabilization for dune soils are necessary to determine the engineering features of these soils as a foundation material in consideration of the global growth in construction activities, especially in Iraq. The compressibility and collapsibility of dune soils are key soil features in the design and construction works, which must be carefully analyzed. In this study, selected geotechnical properties, including compaction, compressibility, and collapsibility characteristics, of compacted dune soil samples from the city of Tikrit were evaluated in the laboratory using a specific range of "cement kiln dust (CKD)" concentrations as a stabilizing agent. The amounts of CKD used in this study were 4, 8, 12, 16, and 20% by dry weight of dune soil. The results showed that adding CKD to Tikrit dune soil improved the compaction properties, decreased the compressibility, and amazingly eliminated the collapsibility. The quality of Tikrit dune soils treated with CKD is very high, and it is recommended for use in the construction of geotechnical engineering works.

Keywords: Dune sands; collapsibility; CKD; compaction; compressibility; consolidation parameters.

1. INTRODUCTION

Due to a combination of climate change, poor land management practices, and unsustainable water usage, many areas have become drylands, increasing desertification and developing dunes [1-2]. More than 35% of the entire Earth's surface area is drylands. Figure 1 illustrates their global distribution, including Southern and North Africa, Australia, Central Asia, the Middle East, and North America. It is important to note that the drylands are home to more than 2500 million people worldwide [3-5]. The wind's sorting activity tends to sweep the sandy soil away, depositing the soil wherever the wind stops moving. Aside from deposition, large amounts of drifting sand can cause significant damage to channels, roads, drainage ditches, agriculture, and the environment, diminishing their productivity and necessitating expensive clearance [6-8].

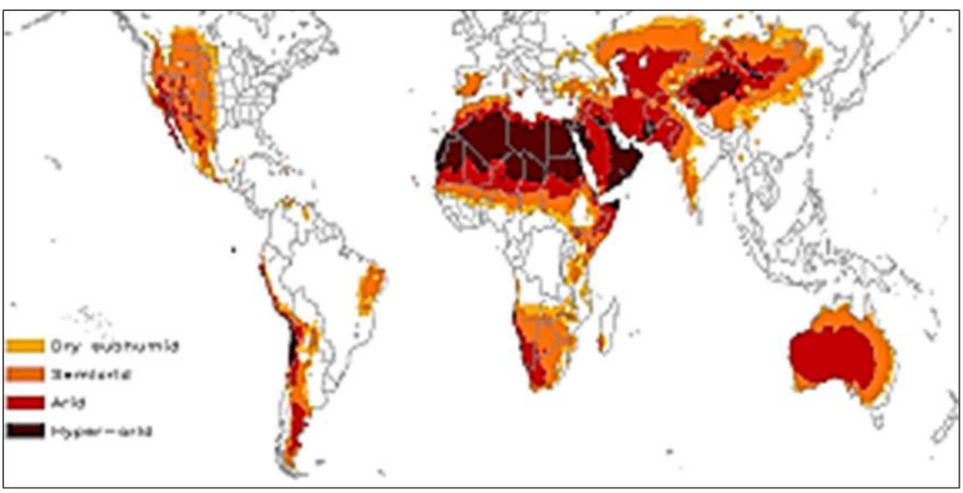

Figure 1: Drylands' global distribution (from Feng and Fu [4]).

According to the country's surface area, more than 30% of Iraq's land is desert [9]. Geotechnical research and stabilization for dune soils are necessary to determine the engineering features of these soils as a foundation material in consideration of the global growth in construction activities, especially in Iraq [10-11]. In general, from an engineering regard, soils from semi-arid and arid zones may be problematic and not easy to work with [12-13]. The soil of sand dunes exhibits special characteristics. Due to the sorting activity of the wind, dune soil has a well-sorted size distribution throughout the dune area with few fine materials. In its field state, the relive density of this soil varies widely based on its location. On the leeward side of the dune, the sand exhibits very low relative density, while on the windward side, the soil is medium dense to dense. Studies considered poorly graded granular soils not proper for engineering use due to their sensitivity to the effects of wind and water action. Such studies suggested adopting a suitable improvement method to enhance their properties [14-18]. Several kinds of soil stabilizers have been used in different regions of the globe for various civil engineering projects. A number of these materials are unavailable in some regions, while others are impractical for local-building reasons [19-20]. The potency of recycling and/or reusing byproduct waste in engineering construction has recently attracted the attention of many researchers; doing so would reduce the environmental issues related to waste disposal and the costs of materials [21-29]. There is a kind of industrial waste called cement kiln dust (CKD), created when exhaust gases from a cement kiln. This material is collected by the kiln's "air pollution control system". Mainly, when CKD includes a lot of free lime, its mineral components can probably be useful materials for enhancing different soils [30-35].

Baghdadi and Rahman [36] investigated the impact of incorporating "cement kiln dust" (CKD) into desert-blown sands for potential application in high-road buildings. Employing a combination of 30 percent CKD and 70 percent sand was advised as a foundation material. Freer-Hewish et al. [37] used chemical additives to stabilize desert sands as basis and sub-base road materials. Because considerable quantities of (CKD) were required, sodium metasilicate and "calcium chloride" were used as chemical additives to lower the amount of CKD required. Al-Aghbari et al. [38] investigated the influence of adding Portland cement and (CKD) to the desert sands of Oman to use as a soil bearing for a foundation due to their limited bearing capacity and tendency to collapse when wet. They were added, by dry-weight of soil in percentages, five different contents of dust ranging from 2% to 12%. The "unconfined compressive strength," "maximum dry density," and "strength parameters" (c and ∅) all exhibited significant improvements. So, these authors stated that employing "cement" and (CKD) to enhance desert sand's properties, compressibility, and shear strength is possible.

Albusoda and Salem [39] added CKD to dune soil (with a considerable amount of fine) to determine the possibility of construction of a shallow foundation on a stabilized dune bed. The findings showed that byproduct dust produced an uneven drop in liquid limit values, LL when combined with the soil. The (CKD) mixture enabled soil compaction at greater optimum water contents and lower maximum dry unit weights. The amount of (c and ∅) was increased by cement dust**.** The compressibility and collapsibility of dune soils are key soil features in the design and construction of geotechnical engineering works, which must be carefully analyzed. In this study, selected geotechnical properties, including compaction, compressibility, and collapsibility characteristics, of compacted dune soil samples from Tikrit were evaluated in the laboratory using a specific range of "cement kiln dust" concentrations.

2. MATERIALS AND TESTING

2.1 Sand Dune Soil

The dune soil sample utilized in the present study was obtained from dryland in Tikrit City in Salah Al-Din Governorate, shown in Figure 2. Tikrit is located on the left of the Tigris River, 180 km from northern Baghdad, Iraq. The results of the primary soil tests are shown in Table 1. All soil properties were determined as per ASTM [41] (for water-content ASTM-D2216, for specific-gravity ASTM-D854, for Atterberg limits ASTM-D4318, for grain-size analysis ASTM-D422, for soil classification ASTM D2487, and for maximum and minimum unit weights ASTM (D4253 and D4254). As presented, the collected soil is non-plastic granular; it is poorly graded and semi-dry in the field. On the other hand, chemical analysis of the sample indicated that the soil is mainly composed of 55% silicon with less amount of calcium, aluminum, and magnesium.

Table 1: Compaction and basic properties of Tikrit sand dunes.

Soil property	**Value of the property**
Field water content	<1%
Specific gravity	2.68
Plasticity value	Non-plastic
Sand particles	98%
Fine-grained particles	2%
Soil classification/Unified soil classification system	Poorly-graded sand, SP
Maximum dry density, g/cm^3	1.7
Minimum dry-density, g/cm^3	1.4
Silicon content, %	55

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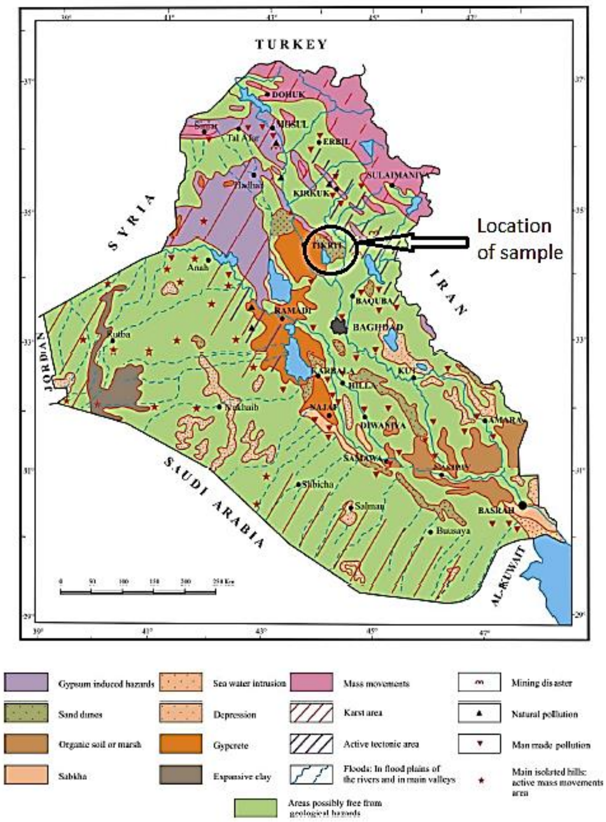

Figure 2: Location of the collected dune soil sample [40].

2.2 Cement Kiln Dust, CKD

The cement kiln dust, denoted as (CKD), was used in this study as a stabilizer. It was obtained from Kubaisa Cement Factory in Heet District, Anbar Governorate, western Iraq. In fact, almost 15 cement factories in Iraq manufacture millions of tons of cement annually [39]. When Portland cement production is completed, the CKD that is left behind is a byproduct of the process. It is produced in the kiln as part of the calcining process. The kiln's exhaust gases carry the dust particles out of the kiln when heating the raw materials in the kiln. Effective dust-collecting devices catch the gaseous dust particles and cool them. Cement kiln dust's composition varies greatly from source to source because of the different raw materials and processes utilized [38]. The CKD used in this investigation is a nonelastic fine-grained material of solid density equal to 2.54.

2.3 Samples Preparation and Experimental Methods

Five different CKD contents were selected to mix with sand samples in the dry process. The CKD contents ranged from 4% to 20%, with an increment of 4%. Firstly, the untreated samples were compacted in a standard compaction mold to evaluate the maximum dry unit weight (γd) and optimum water content (OM); then, the same method was adopted to evaluate the γd and OM for soil mixed with CKD (4%, 8%, 12%, 16%, and 20%). According to the determined values of γd and OM, a testing program was carried out on samples of soil and CKD prepared at γd and OM. The prepared samples were tested using the oedometer device to investigate the compression properties, the consolidation parameters, and the collapsibility. The tests were carried out for samples in their molding water content and after soaking in water.

3. RESULTS AND DISCUSSION

3.1 Evaluation of Compaction Properties

The compaction test results of this study are summarized in Table 2 and shown in Figure 3 for treated and untreated sand. It can be noted that the compaction curve of Tikrit dune sand is irregular, with more than one peak. The unit weight first decreased at low moisture content before gradually rising to its highest value. Beyond this value, the unit weight fell sharply. The low unit weight at low water content is attributed to capillary forces that prevent soil grain rearrangement [42-44]. Furthermore, the influence of (CKD) on the compaction

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properties of Tikrit dune sand can be noted from the data in Table 2 and the curves in Figure 3. Adding CKD to dune soil increased its maximum dry unit weight. The maximum increase in weight values is achieved at a CKD content of 20%. Furthermore, the OM looks less affected by adding CKD; up to 8% CKD, the OM is not changed, then the OM increases to a maximum value at CKD of 12%, then it decreases with more CKD content.

Table 2: Maximum dry unit weight and optimum moisture content of sand-CKD mixtures.

Percentage of CKD	γ_d (kN/m^3)	OM (%)
Natural soil	16.10	12.0
4	18.60	12.0
8	18.80	12.0
12	18.53	14.9
16	18.77	13.5
20	18.81	12.5

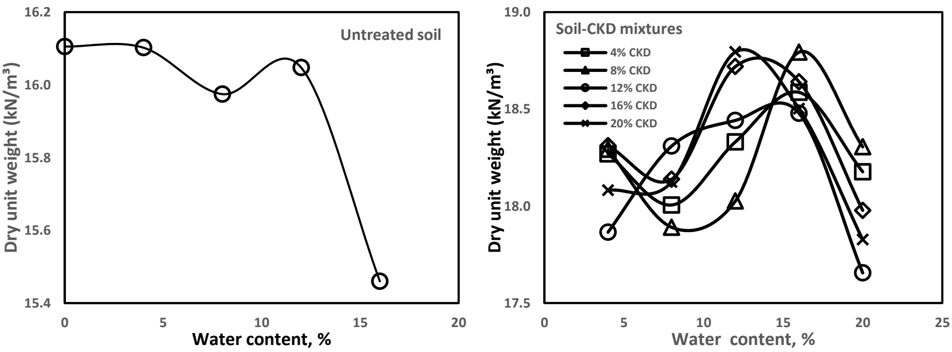

Figure 3: Compaction result for untreated and treated dune samples.

3.2 Evaluation of Soil Compressibility and Collapsibility

Tikrit dune samples with varying percentages of CKD were tested using the oedometer device. To learn more about how untreated and treated dune soil behaves and compresses under saturation conditions. The consolidation characteristics of dune samples were examined. The consolidation test (confined compression test) results for samples made from compacted soil and soil treated with (4, 8, 12, 16, and 20%) CKD. The result is analyzed and plotted as a void ratio (in normal scale) versus the logarithm of vertical stress (Figure 4). Under different (CKD) contents, the stabilized dune soil exhibited the same behavior (i.e., consolidation curves with the same shape) but with different values of the void ratio. This is mainly due to the influence of (CKD) on the dry unit weights of the stabilized dune, which causes a rise in the dry unit weight and reduced soil voids.

On the other hand, the result shown in Figure 4 was used to define the values of stabilized dune soil compression indices. i.e., the compression and swelling index ("Cc" and "Cs"). The variation of these indices under different contents of CKD is plotted in Figure 5. Notably, the compression index of the stabilized Tikrit dune samples was more affected by CKD than the swelling index. However, The Cc values were negatively affected at low CKD content (less than 8%). With further CKD content, the Cc decreased until it reached its minimum value at CKD content of 20%. At the same time, the values of Cs are inversely proportional to the CKD content. A reexamination of Figure 5 can conclude that stabilized dune soil with various contents of CKD is a low-compressible geomaterial. Also, this material is less affected by saturation. As a result, it can serve as a very well-stable geomaterial.

The double-oedometer was used to examine the collapsibility of treated and compacted dune soil. Two identical dune samples were made for each percentage of CKD and for soil only. The first was examined in a one-dimensional consolidation test as it was wet, while the second was loaded after soaking in water for 24 hours. In Figure 6, the results of this series are plotted and utilized to calculate the change in strain and potential of soil collapsibility due to the inundation effect. The double oedometer test results reveal that compacted dune soil has a relatively low probability of collapse and very low sensitivity to saturation, where the curves of wet compacted soil and soaked compacted soil are almost equal. The calculated values of collapse potential are shown in Figure 7. These values are presented for selected applied stress (50, 100, and 200 kPa). The first note from this figure is that, under different applied loads, the compacted dune samples exhibit low collapse potential value, which can be classified as "slight" as per ASTM D 5333 [41]. The second note from Figure 7 is the important positive effect of CKD on the collapsibility of treated dune soil. In fact, amazing results are obtained as the CKD eliminates the collapsibility at which the collapse potential shows negative values. In other words, the soils became stiffer under soaked conditions. Such behavior on soil collapsibility may be caused by the reaction of the (CKD) as a pozzolanic material [45], which was activated during the inundation of compacted treated dune samples.

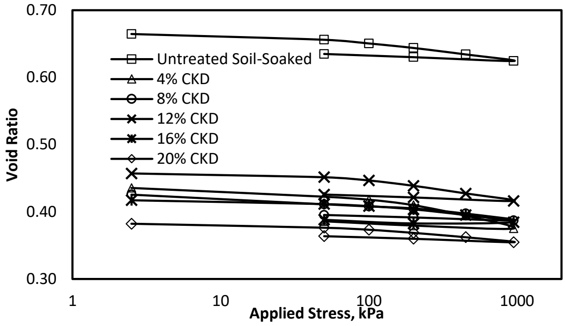

Figure 4: Consolidation curves for stabilized Tikrit dunes sand.

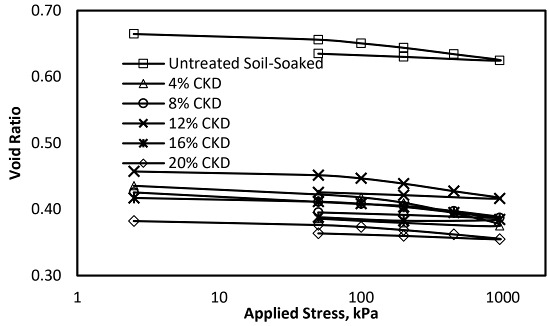

Figure 5: Variation of compression indices of stabilized Tikrit dunes sand.

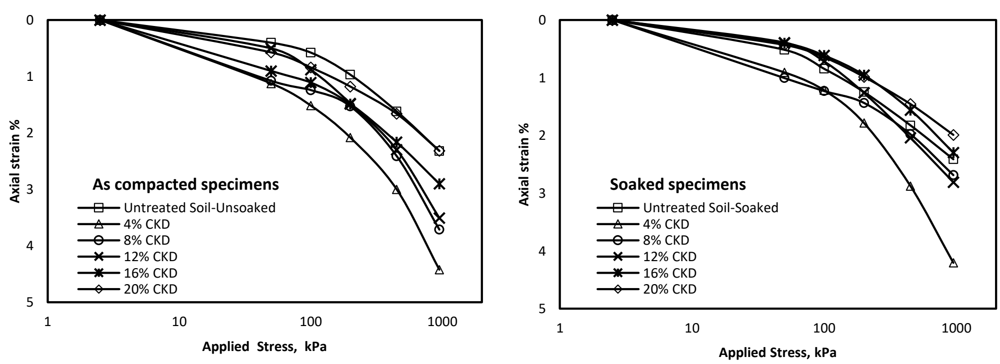

Figure 6: Result of double oedometer for compacted Tikrit dune sand.

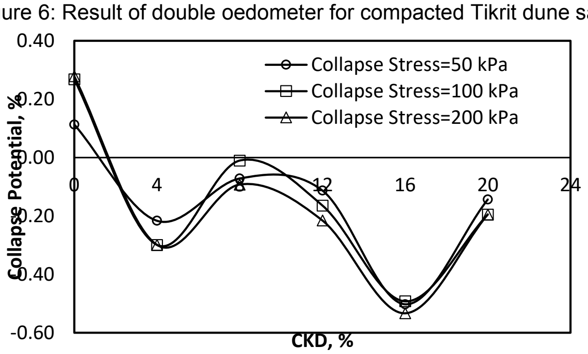

Figure 7: Variation of collapse potential with (CKD) content under different loading values.

4. CONCLUSIONS

- Mixing (CKD) with the Tikrit sand dune sample led to a rise in the dry unit weight because CKD filled between the sand particles' voids. The highest value of γd appears when 20% CKD, equal to 18.81 kN/m^3.
- The compressibility of compacted specimens of dune soil is very low. It shows very low compression indices (Cc= 0.04 and Cs=0.01).
- The initial void ratio decreases as cement kiln dust concentration rises, which lowers the compression index. The dune soil with 20% CKD had extremely low compressibility (Cc = 0.021 and Cs = 0.005).
- The addition of CKD to Tikrit dune soil eliminates the collapsibility of the soil at which the collapse potential shows negative values. In other words, the soils became stiffer under soaked conditions.
- The compressibility and collapsibility qualities and behavior of Tikrit dune soils treated with CKD are very high, and this mixture of dune soil with CKD is recommended for use in the construction of geotechnical engineering works.

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