WARSAW UNIVERSITY OF TECHNOLOGY Index 351733
FACULTY OF CIVIL ENGINEERING
COMMITTEE FOR CIVIL AND WATER ENGINEERING
POLISH ACADEMY OF SCIENCES ISSN 1230-2945

DOI: 10.24425/ace.2021.137183

ARCHIVES OF CIVIL ENGINEERING

Vol. LXVII ISSUE 2 2021

s. 525–536

Research paper

Improvement of a subgrade soil by using EarthZyme and cement kiln dust waste

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Abstract: Soil stabilization techniques are widely used for road construction to improve the properties of the subgrade materials. Using new additives and stabilizers to improve soil properties can reduce the costs of construction and reduce the possible negative effects of these materials on the environment. The purpose of this study was to evaluate the use of a liquid based nano-material called EarthZyme (EZ) and cement kiln dust (CKD) as admixtures to improve the soil properties. A mixture of two soils was used in this study which were prepared from mixing sand soil and fine-grained soil. Compaction tests were performed on the soil that was stabilized with the CKD to determine the density-water content relationships. Unconfined compression tests were also conducted on specimens without treatment, specimen treated with the CKD only, and specimens treated with the CKD and the EZ after curing period for seven days. The obtained results indicated that adding the CKD to the soil decreased the values of the unconfined compression strength (UCS) from 5 to 15 percent. However, adding the CKD reduced the maximum dry density (MDD) from 10 to 12 %. As discussed herein, soil stabilization with the EZ had insignificant effects on the results obtained from the unconfined compression test.

Keywords: Soil stabilization, Unconfined compressions, EarthZyme, Cement kiln dust, Nano material.

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1. Introduction

1.1. Background

Road construction is essential for the economic development of any country. Soil properties are considered one of the factors that affect the cost of road construction. Soil stabilization techniques are applied to improve poor engineering properties of the subgrade soils to achieve the requirements needed for the design and construction [1]. Stabilization methods by using enzyme additives have been used to improve the strength of the subgrade layers because these methods are cost effective compared to the other methods of soil stabilization. Soil stabilization with a variety of additives such as cement, lime, CKD, fly ash and bitumen have been used to improve soils used in road works. Further studies are needed to evaluate using the enzyme in road construction and to evaluate the improvement in the soil properties of the subgrade layers [2, 3, 4 and 5].

A number of researchers have reported a significant improvement in soil properties when enzymatic preparations were used (e.g. [6], [7], [8], [9], and [10]). The enzymatic additives, which have been utilized as soil stabilizers in the past studies, are commercially available under different brand names such as Terrazyme and EarthZym. Many effects of the enzyme additives were reported to range from modest to significant improvement of the soils, depending on the type of enzymes, the type of the soil, and the curing time [6], [11].

By using enzyme, polymer, and ionic stabilizers with five different types of soil, Rauch et. al.[12] observed an improvement in the bearing capacity and unit weight of the treated soils. Furthermore, the study of Rauch et. al. [12] observed lower values of the soil permeability when the enzyme was added. Abdullah et. al.[7] studied the effect of two different types of bio-enzymatic stabilization on the engineering characteristics of sandy and fine grained soils. The study reported that the degree of improvement, as obtained from the unconfined compression test and the California Bearing Ratio (CBR) test, were more significant for the fine-grained soils compared to the sandy soils. Tingle et. al.[13] observed that enzyme stabilization that was applied on granular soils had insignificant effects on the treated soils. Pradeep et. al.[14] conducted a testing program on various soil types to investigate the effect of adding Alkazyme. The results obtained from the aforementioned study indicated a decrease in the UCS and the CBR values as the Alkazyme dosage was increased. Puneet and Suneet [15] reported a significant increase in the values of the UCS up to 200% when the soil was treated with Terrazyme, this was in agreement with the findings from other research in the field of Nanomaterial [16].

1.2. EarthZyme (EZ)

EarthZyme is a non-toxic soil stabilizer that has been used with clayey soils to reduce the cost of road maintenance as it improves the compaction and increases the strength values. The application of the EZ in soil improvement led to higher values of the soil strength which may allow the use of poor soils, thereby reducing the normal dependency on granular soil. The EZ comes in a liquid form with the standard equipment and techniques. The EZ has mainly been used to stabilize subgrade layers of roads. Additionally, the EZ has been used as a soil stabilizer under any form of pavement and has proven to be successful in soil improvement for soils that contain about 20 % fines (passing sieve No. 200) with values of plasticity index higher than 8 [17].

As described by the manufacture of the EZ [17], the product uses an immense ionic exchange capacity to reduce the diffuse double layer that surrounds soil particles and decreases water absorption of the soil. During the compaction process of the mixture, EarthZyme reduces the values of the optimum water content and increases the values of the dry densities. Surfactants facilitate ionic exchange by increasing the penetration of ion solution into the soil capillary structure. Furthermore, the surfactants serve the enzymes as a carrier fluid. Such enzymes promote a greater exchange of ions between various soil minerals; allowing EarthZyme to be versatile in efficacy. Such cumulative results significantly reduce the sensitivity of clay soils to water [17]. The EarthZyme acts as a surfactant that temporarily decreases surface tension and water viscosity. As a result, more lubrication is produced that will lead to a dispersed structure with smaller pore spacing, as shown in Fig. 1, [17].

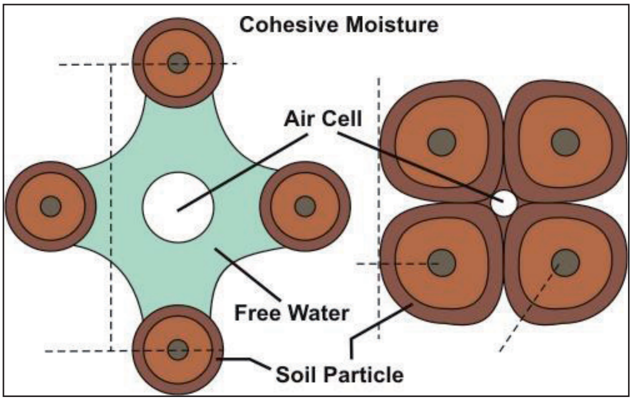

Fig. 1. Additional moisture removed by incorporation of EarthZyme into the free water [17]

1.3. Cement kiln dust (CKD)

For a specific chemical material to be used as a soil stabilizer, the material has to be environmentally friendly, easy to be utilized, locally accessible and cost effective. The CKD is a side product of the production process of Portland cement. The CKD is made by burning the raw materials in the rotary kiln to manufacture clinker [18]. A mix of about 2.6 to 2.8 tons of raw materials is required to produce one ton of cement. In general, a typical kiln produces from 0.06 to 0.07 tons of CKD for each ton of clinker [18]. The CKD generation is estimated to be approximately 30 million tons annually [19]. In the United States, more than four million tons of the CKD, unsuitable for recycling in the cement production process, is annually disposed [19]. The CKD is mainly composed of raw feed and calcite in addition to some volatile salts. The raw materials for the CKD are similar to those for the Portland cement. However, the CKD chemically varies from the Portland cement as part of the CKD has not been completely burned. The chemical composition of the CKD can vary with the type of manufacture of the cement and the type of raw materials [19]. The CKD can be utilized as an alternative to lime, Portland cement, and fly ash which have been conveniently used in road construction. The use of the CKD is not only effective in improving the strength of the soil, but also in minimizing the cost of the construction [20]. Several studies have been conducted to evaluate the use of the CKD for treatment of both clay and sand as an alternative to the aforementioned conventional materials. The possibility of using the CKD to stabilize soil materials has been investigated by [21], [22], [23].

1.4. Research objective

In this research, a testing program was conducted on a mixture of two soils, which prepared from mixing of sand soil and fine-grained soil, to evaluate the effectiveness of the EZ and the CKD as admixtures to improve the soil properties. The values of the maximum dry density (MMD) and the UCS were obtained for the treated and untreated specimens.

2. Materials and methods

2.1. Materials

In this study, a testing program was conducted on mixtures of two types of soil that was treated with EZ and the CKD to evaluate the effect of the treatment on the engineering properties of soils. The soils were collected from the Quarry of Zangora located west of Ramadi, Al-Anbar Province, Iraq. The curves of the particle size distribution for the two soils were determined in accordance with the ASTM D2487-11, as shown in Fig. 2. The main physical properties of these soils are also listed in Table 1. Soil-1 was mostly poor graded sand with less than 1% of fines. Soil-2 was a fine-grained soil that contained silt and clay.

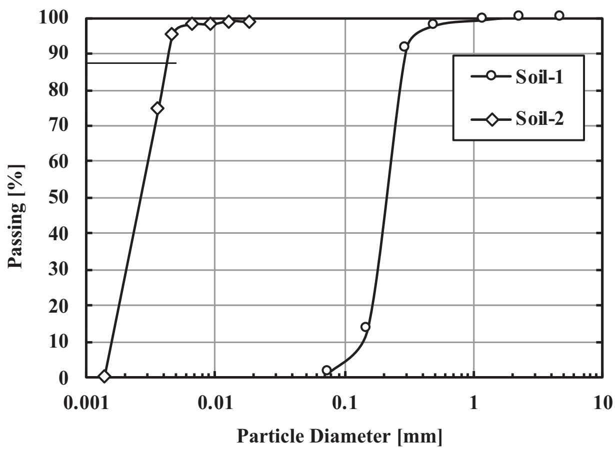

Fig. 2. The curves of the grain size distribution of Zangora soils

Table 1. The physical properties of Zangora soils.

Physical property	Soil Type	
	Soil-1	Soil-2
Gravel (%)	15.8	0.0
Sand (%)	83.6	0.0
Silt (%)	0.6	55
Clay (%)	0.0	45
C_u	1.64	-
C_c	1.01	-
Specific gravity G_s	2.58	2.6
LL (%)	-	55
PL (%)	-	32
PI (%)	-	23
Soil Classification USCS (ASTM D-2487-11)	SP	MH
ASHHTO Classification (M-145)	A-3	A-7-5

The CKD, which was used as admixture, was obtained from Kubaisa Cement Factory. For this type of the CKD, the particle sizes were less than 0.6 mm (passing sieve No.30), as shown in Fig. 3 which represents the curve of the particle size distribution for the CKD [24]. The specific gravity test was conducted according to the ASTM D854-02. The physical properties of the CKD are as listed in Table 2, [24]. The chemical composition of the CKD is presented in Table 3, [24].

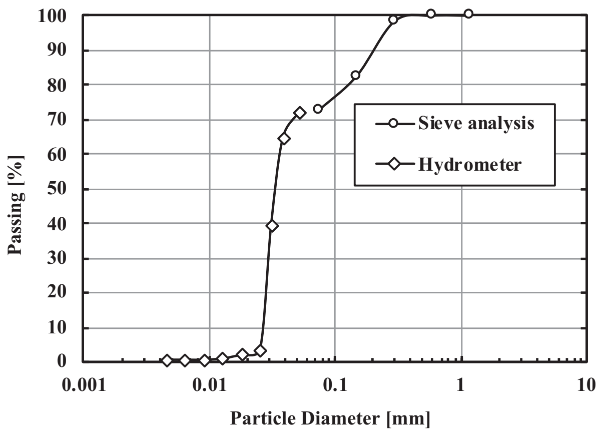

Fig. 3. Particle size distribution for the CKD [24]

Table 2. Physical properties of the CKD [24]

C_c	C_u	D_{50} (μm)	Specific Gravity
1.23	1.00	34	2.527

Table 3. Chemical compositions of CKD [24]

Element	CaO	SiO_2	Al_2O_3	Fe_2O_3	SO_3	MgO	L.O.I
%	49.65	14.82	5.25	1.98	6.33	3.35	9.77

The EZ that was utilized in the treatment was a natural non-toxic, dark viscous liquid with a taste similar to molasses. The preparation process of the EZ was performed as recommended by the commercial distributors of the EZ. The dosage of the EZ was taken as 0.003% (i.e. 0.07 ml for each soil sample of (12cm × 24cm × 8cm)).

2.2. Soil preparation

Soil-1 and Soil-2 were dried in the oven at 105 °C for 24 hours. A mixture of 60 % of Soil-1 and 40% of Soil-2 was then prepared in order to obtain the standard proportions approved with the additives, as shown in Table 4. The obtained mixture is referred to as Zangora Mixture (ZM). The

ZM was classified as clayey sand (SC). The Proctor test was performed on the ZM, according to the ASTM D698-12, to obtain the maximum dry density (MMD) and the optimum water content (OMC).

Table 4. Physical properties of ZM soil

Gravel %	Sand %	Silt %	Clay %	LL %	PI %	γ_{dmax} gm/cm^3	O.M.C, (%)	USCS
0.0	60.0	22.0	18.0	33	16	1.876	13.57	SC

2.3. Methods

A testing program was conducted on the ZM to evaluate the engineering properties and the resistance characteristics of the soil before and after the treatment with the EZ and the CKD. The Proctor test was performed on the ZM stabilized with the CKD in accordance with the ASTM D698-12. The unconfined compression test was conducted on specimens prepared from the ZM that was stabilized with the CKD and the EZ according to the ASTM D2166M-16. The unconfined compression test was conducted on the specimens after one week of curing period. All the aforementioned tests were also conducted on control specimens that were prepared from the untreated ZM. The methods of stabilization are presented in the following sections.

2.3.1. Soil stabilization with CKD

The required quantity of the ZM was determined for the stabilization with the CKD. The percentage of the CKD by weight of soil was 10 and 20. The percentage of the CKD was mixed with the amount of molding water that was calculated from the OMC of the ZM, as determined from the compaction test.

2.3.2. Soil stabilization with CKD and EZ

At this process, the CKD was mixed with the ZM soil at 10 % and 20 % by soil weight. The EZ solution was prepared to achieve the required concentration at the optimum moisture content of ZM. The prepared EZ solution was then added to the soil as molding water during the compaction test.

2.3.3. Specimen preparation for the unconfined compression test

The UCS is one of the fundamental parameters of the soil that is used for the determination of mechanical properties needed for mix design of the road base. The unconfined compression test was performed by using a modified apparatus to determine the strength improvement following the soil treatment with the stabilizers. A prefabricated mold of (12cm × 24 cm × 8 cm) was used for the preparation of the specimens that were used for the unconfined compression test. The mixture of the ZM and the CKD was poured into the mold and compacted using static pressure at a rate of 5mm/min. The specimens for the UCS were prepared at different values of the dry density. These different values were achieved by using 90, 95 and 100 % of the soil weight that was required for the maximum dry density of the untreated soil. The ZM-CKD specimens were taken from the mold and kept at room temperature in the sealing bag for 7 days before conducting the compression test. The details of the prefabricated mold are shown in Fig. 4. Three replicates of each mix were prepared and tested for UCS.

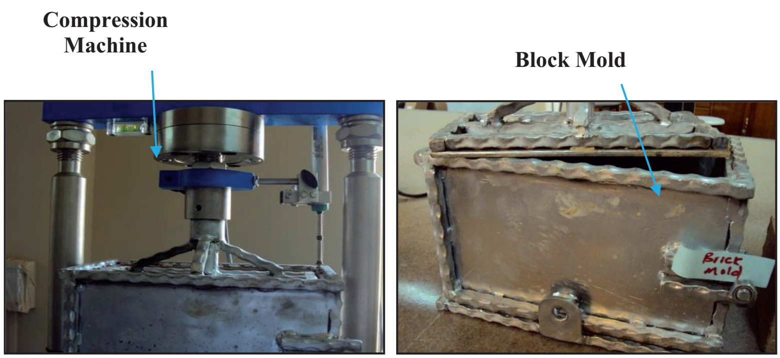

Fig 4. Photographs of the fabricated mold and the details of the pressing setup

3. Results and discussion

3.1. Compaction properties

The compaction test was conducted on ZM-CKD mixture to evaluate the degree of improvement in the values of the MDD and OMC, as shown in Fig. 5. The values of the MDD were 1.876 gm/cm^3, 1.687 gm/cm^3, and 1.647 gm/cm^3 for the specimens with 0, 10, and 20 percent of the CKD, respectively. The obtained results indicated that adding the CKD to the soil reduced the MDD of the soil by 10 to 12 %. These results were similar to those reported by [25]. The decrease in the MDD with the addition of the CKD may be attributed to the very fine particles of the CKD that dislocated the granular structure of the treated soil and allowed the soil particles to float in the CKD. Similar observations of this phenomena were reported by [26], [27], [28]. Moreover, the lower values of the dry density of the treated soil may be caused by the low value of the specific gravity of the CKD. Furthermore, Fig. 5 shows that the values of the OMC increased when the CKD content increased. The values of the OMC were 13.57%, 20.67% and 19.56% for specimens with 0, 10, and 20 percent of the CKD, respectively. The increase in the OMC can be also attributed to the very fine particles of the CKD that led to an increase in the demand for compaction water.

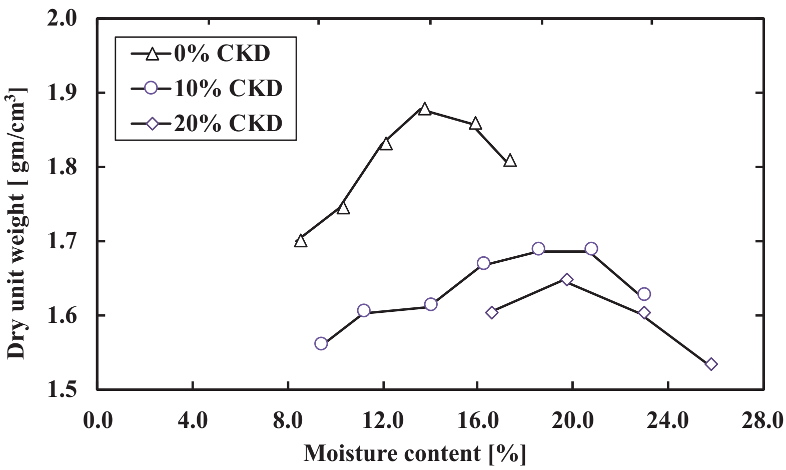

Fig. 5. Moisture content-dry density relationships for ZM before and after the treatment with the CKD

3.2. Unconfined compressive strength (UCS)

The specimens were prepared following the procedure described previously using a mold of (12 cm × 24 cm × 8 cm) as in Fig. 4. The specimens for the UCS were prepared at different values of the dry density. These different values were achieved by using 90, 95 and 100 % of the soil weight that was required for the maximum dry density of the untreated soil. The UCS values after curing period of the specimens, for different weights of ZM, with and without EZ are shown in Fig. 6. A clear relationship between the UCS values and the stabilization with the EZ was not observed. The minor influence of the EZ on the UCS values is due to the characteristics of the EZ which required high clay content that may require longer period for biological degradation. The effect of the CKD on the UCS results with and without EZ is shown in Fig. 7. The UCS values decreased by 5 to 15 % as the amount of the CKD increased in the mixture from 10 to 20 %. This effect may be attribute to the calcium silicates content in the CKD, as described by [29].

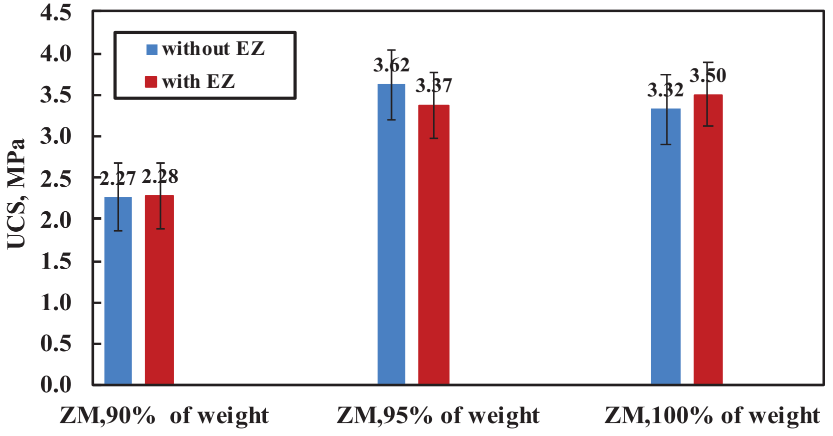

Fig. 6. The variation of the UCS values with and without the EZ at different weights of the soil

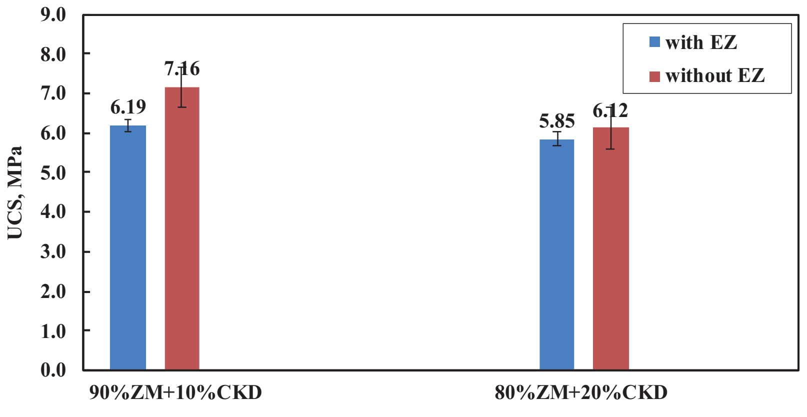

Fig. 7. The variation of the UCS values for the soil with and without the EZ at different percentages of the CKD

4. Conclusions

The compaction and unconfined compression strength properties of a subgrade soil, stabilized with EZ and CKD additives, were evaluated from the results of the Procter test and the unconfined compression test. The following conclusions and recommendations were drawn based on the results obtained from the testing program:

i. The MDD decreased as the percentage of the CKD increased.
ii. The OMC increased as the CKD content in the soil increased.
iii. Soil stabilization with the EZ had insignificant effects on the UCS values.
iv. Soil stabilization with the CKD decreased the UCS values by 5 to 15 % as the amount of the CKD increased in the mixture from 10 to 20 %.
v. The EZ solution should be used for soils that have a high clay content to make the improvement process more effective.
vi. The EZ solution required a long period for the biological degradation in order to determine the EZ effectiveness as a stabilizer for road materials.
vii. The best performance of the stabilized soil was obtained by using the CKD which may indicate a potential use of this additive in the treatment of subgrade soils.

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Received: 16.12.2020, Revised: 09.03.2021