Cement Kiln Dust Soil Stabilization for Subgrade Layer of Erbil Ring Highway (150m)

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Abstract: Pavement damage is an inevitable phenomenon, it can be resisted by solutions that strengthen the embankment and they don't increase the costs greatly. One interesting solution regarded, is the addition of cement kiln dust (CKD) to increase California bearing ratio (CBR) of soil. The main objective of this investigation is to enhance poor soil in the subgrade layer located in the 150 m ring road Erbil. The poorer soil was identified as TP1, located near the junction of Ganjan - Bahrka, 120 meters from the intersection. To achieve these objectives, cement kiln dust (CKD) was added to the soil at five different rates (0.5%, 1%,1.5%,2%, 2.5%) and it was found that 2% CKD was capable of achieving the targeted CBR rate of 25%. The results of this study also confirmed that the applied method has many positive aspects from technical, economic and environmental point of view, that will contribute to improve the design procedures of roads, bridges, service ways, shoulders and culverts.

Keywords: California Bearing Ratio (CBR), Cement Kiln Dust (CKD), Stabilization, Poor Soil, Subgrade Layer

1. Introduction

The control of soil bedding characteristics plays an important role in the design of pavement structures, especially for freeways (Shafabakhsh et al., 2014). In the construction of freeways, the exploitation of all types of natural materials is often inevitable due to technical, economic, and environmental considerations (Ferber et al., 2009). As a result, identifying poor soils become a vital goal in order to best determine the requirements of such planning efforts. Weak soils are enhanced through various means to make them meet the requirements.

The most common and effective methods for enhancing and improving the poor-quality soils are using lime, Portland cement, and other chemicals stabilizers (Puppala, 2016; Hashemian et al., 2014; Ismail & Ryden, 2014). Using of such materials may lead to further cost increase. Due to the high volume of freeway construction projects, such enhancements may sum up to great economic burdens for the stakeholders and sometimes become outright infeasible.

In recent years, the use of peripheral products to address the problem of improper soils is in heavy demand. This approach supposedly makes constructions more sustainable and reduces cost (Higashiyama et al., 2016; Shafabakhsh & Sajed, 2014).

In pavements, the soil at the bottom supports the upper layers of the structure. Soil-static methods are commonly used in the design and analysis of traditional pavements. Dynamic testing methods, however, are more suited for the testing of the pavement materials, as these methods can measure and record the tension of the pavements under load conditions (Liu et al., 2019). When such a soil is the only material provided at the site of construction, certain characteristics of the soil must be strengthened to meet the requirements of the site (Rimal et al., 2019). Poor soil conditions may also result in inadequate structural support for the upper layers and cause reduced structural life.

Soils can be improved by adding various chemical or cement derivatives. These chemical additives range from waste products to materials such as lime, C-type ash, cement kiln, and various chemical stabilizers. Application of these leads to enhancement of the intrinsic strength characteristics of the soil. These enhanced soils are then used in various types of structures such as highways, runways, embankments, and dams.

The main objective of the study is to improve the subgrade layer for 150m ring road Erbil, through enhancing the soil and increasing the CBR to 25% according to the design of the Jordanian company, which designed a 150 m road commissioned by the Ministry of Tourism and Municipalities. The applied methods were performed by increasing the CBR to 25%, since the road is an express way with high traffic volume and consists of 6 junctions. CKD material which is a by-product of cement factories was chosen to add with the subgrade to enhance the subgrade. Selection of CKD belongs to availability of the material and less cost is required for transporting, manipulating and constructional process.

The paper presents an experimental study to investigate the effects of CKD on the characteristics of poor soil substrates by testing their California Bearing Ratio (CBR) and re-designing alternate substrates by obtaining new a structural number (SN) for them. SN is represented with the formula below:

$$SN=a_1D_1m_1+a_2D_2m_2+ a_3D_3m_3 \quad [1]$$

A new (SN) would mean a new method of designing layers in a certain thicknesses (D) that could potentially reduce the costs and increase the environmental tolerance. The T.P1 location in the 150m ring highway was selected as the a sample location, as it was determined to be the location with the poorest soil structure with the lowest California Bearing Ratio, as show in Figure 1 below.

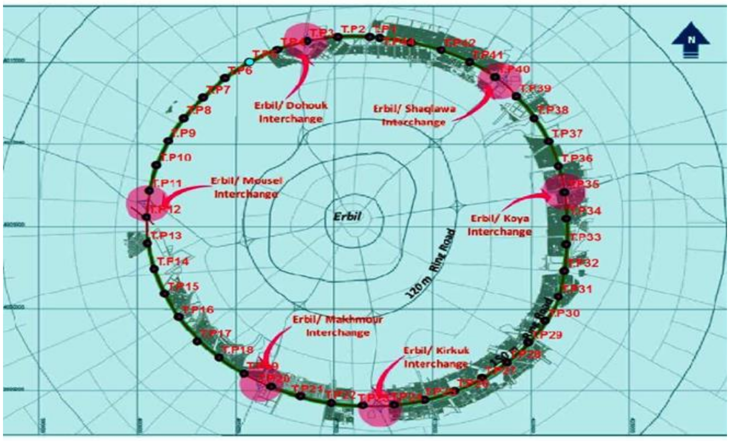

Figure 1: Test point one (TP1) in the 150m ring highway (Ministry of Municipalities and Tourism)

Cement Kiln Dust (CKD) is a waste by-product of portland cement manufacture. This material poses a health hazard, storage problem, and a potential pollution source, as shown in Figure 2 below.

Figure 2: Cement kiln bypass dust (https://www.cementkilnbypassdust.com)

Urban roads, in particular, are one of the basic needs for the development of urban communities. According to international standards, every 100 people in a square kilometer area require a road of one-kilometer length. In reality, the road density in the Erbil region is about 0.1 km / km^2 and this ratio should reach at least 0.4 km / km^2 to meet international standards, which means the length of the road network should increase to approximately 44.720 km. For this reason, the 150-meter highway project was initiated by the Kurdistan Regional Government (KRG, 2013). The municipality of Erbil, a subsidiary of the Kurdistan Regional Government (KRG), has co-operative companies that are trying to implement some engineering studies and perform joint designs in order to sign a contract for the 150-meter ring road around Erbil. The ring road is approximately 70 kilometers long and 150 meters wide, includes 6 intersections which are: Kirkuk intersection, Makhmour intersection, Al-Masul intersection, Koya intersection, Shaklawa intersection, and the Dohuk intersection (KRG, 2013) as shown in Figure 3.

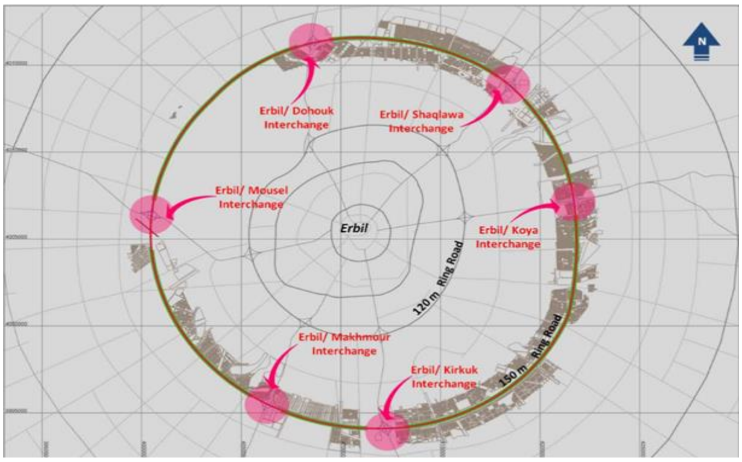

Figure 3: Erbil ring 150 m highway (Ministry of Municipalities and Tourism)

2. Materials and Methods

To improve the weak soil of the subgrade layer, several experiments were conducted at the Erbil Structural Laboratory. The poorest soil was determined and named test point one (TP1) which is located near to the Junction of Ganjan City- Bahrka, 120m distant from the junction. Next, the sample taken to the laboratory and many tests have been analysed which the results were tabulated. The most important applied test was CBR which revealed that the CBR is 3.2% which is very low according to the Iraqi, and standard specifications and AASHTO which the CBR is 4%. Therefore, it was decided to add CKD (cement kiln dust) in diversified ratios including (0.5%, 1%, 1.5%, 2%, and 2.5%) the results confirmed that the 2% CKD will improve the soil of subgrade layer and escalate the CBR to 25% which is very effective value on reducing the stabilizer layers and it is also more economic and environmentally friendly.

The physical and chemical properties of CKD vary from plant to plant, depending on the raw materials used and type of collection process in the production which affects the CBR score of the resulting mixture. Thus, in order to have the highest reliability, the weakest soil sample was selected and tested in Erbil Construction Laboratory.

2.1 Atterberg Limit (LL, PL, PI)

It is used to measure water content of a fine-grained soil and it has been classified as shrinkage limit, plastic limit, and liquid limit as illustrated in Figure 4 below.

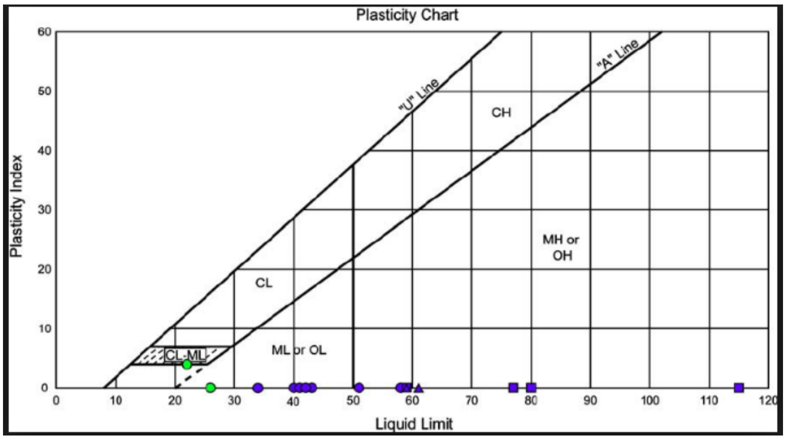

Figure 4: Atterberg limits (ASTM)

2.2 California Bearing Ratio (CBR)

It is a penetration test used to assess the subgrade strength of roads and pavements? The California Bearing Ratio is, in fact, a penetration test to assess the mechanical/shear strength of the soil (Figure 5), which was developed and used by the US State Department of Railways in 1929. With this test, the shear strength of the soil is determined at a specific moisture content and specific load. This groundbreaking experiment is of great importance for expressing the relative quality of the soil under the pressure, in reflecting the shear strength of the soil and its tolerance to traffic loads, as well as deciding on the design and the thickness of the layers the road construction (Onyelowe et al., 2019).

Figure 5: CBR Test (ASTM) and (AASHTO)

2.3 Sieve Analysis and Hydrometer Test

It is used to determine the particle size distribution of fine-grained soils passing 75 µ sieve as shown in Figure 6.

Figure 6: Sieve analysis and hydrometer test

2.4 Specific Gravity Test

The specific gravity of the soil particles lies within the range of 2.65 to 2.85 as shown in Figure 7.

Type of Soil	Gs value
Sand	2.65 -2.67
Silty sand	2.67–2.70
Inorganic clay	2.70 –2.80
Soils with mica or iron	2.75 –3.00
Organic soils	< 2.00

Figure 7: Specific gravity test

2.5 Modified Proctor Test

(Optimum Moisture OMC), and Maximum Dry Density (MDD) tests: is a laboratory technique of experimentally determining the top moisture content at which a specified soil category will become densest and achieve its peak dry density (MDD). Compaction of soil is done by dropping a standard ram 25 times for each layer of soil from a standard distance. Typically, soil is placed in five layers and compacted Figure 9.

2.5.1 Maximum Dry Density (MDD)

This value represents the amount of water for which the soil becomes denser as a result of energy inflow (Liu et al., 2019).

2.5.2 Optimum Moisture Content

Density obtained by soil compaction in its optimum moisture content Figure 8, (Ng et al., 2015).

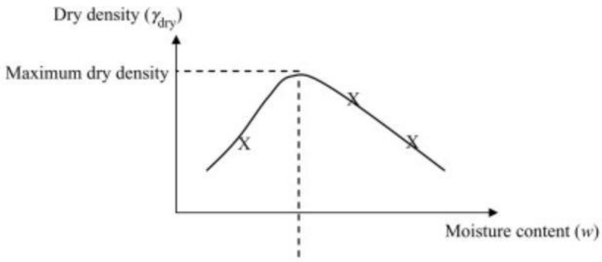

Figure 8: Relationship between MDD and OMC

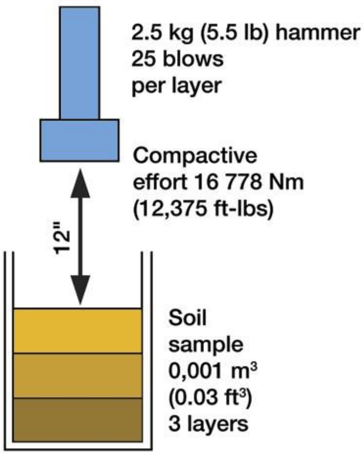

Figure 9: Proctor Test (ASTM)

2.6 Unified Soil Classification System (USCS)

It is a soil classification system used in engineering and geology to describe the texture and grain size of a soil.

2.7 Chemical Tests

Samples of cement waste were taken from the Kirkuk cement factory. Then, the samples were examined in Erbil laboratory in the chemistry department and the results are shown in Table 1.

Table 1: Chemical Properties for cement kiln dust *(Directorate of construction laboratories Erbil)*

Na_2O	0.2392 Wt%
MgO	2.3842 Wt%
Al_2O_3	3.77 Wt%
SiO_2	19.14 Wt%
SO_3	3.85 Wt%
K_2O	0.8783 Wt%
CaO	68.36 Wt%
Fe_2O_3	3.268 Wt%
$CaCO_3$	90 Wt %
Insoluble material	12.65 Wt %
Loss On Ignition (LOI)	18.73 Wt %

3. Results and Discussion

3.1 Properties of the Materials Used

The soil used in the study was obtained from Erbil, T.P1 position on the 150m ring highway known to have the weakest soil, located in the central region of Kurdistan. The properties of the soil were studied by a series of tests, the results of which are presented in Table 2. Cement kiln dust was obtained free of charge from the Kirkuk cement plant located in Kirkuk Governorate, Iraq. A number of tests were performed to determine its physical and chemical properties, the results of which are shown in Table 3.

Table 2: Properties of Soil (Directorate of construction laboratories Erbil)

Property	Value %	Type of test	Standard
Liquid Limit- (L.L)	42	Liquid Limit	ASTM4318/AASHTO T90
Plastic limit- (PL)	23	Plastic Limit	
Plasticity Index- (PI)	19	Plasticity Index	
Maximum Dry Density (MDD)	1.796	Maximum Dry density	ASTM D1557 / AASHTO T 180
Optimum Moisture Content -(OMC)	15.6	Optimum Moisture Content	
CBR Value	3.2	California Bearing Ratio	ASTM D1883 / AASHTO T 193

Table 3: Physical and Chemical Properties of CKD (Directorate of construction laboratories Erbil)

Physical Properties	
Liquid Limit	25%
Plastic Limit	Nonplastic
Specific Gravity	2.67
Chemical Properties	
Na_2O	0.2392 Wt%
MgO	2.3842 Wt%
Al_2O_3	3.77 Wt%
SiO_2	19.14 Wt%
SO_3	3.85 Wt%
K_2O	0.8783 Wt%
CaO	68.36 Wt%
Fe_2O_3	3.268 Wt%
$CaCO_3$	90%
Insoluble material	12.65%
Loss On Ignition (LOI)	18.73%

The results of the CBR, OMC and MDD tests performed on the selected weakest soil are presented in Table 3. Following the initial laboratory test, results were obtained for different percentages of CKD mixtures (0 % to 2.5 %) which are illustrated in Table 4.

Table 4: Laboratory Test Results (Directorate of construction laboratories Erbil)

Percentage of additive material (CKD)	OMC%	MDD%	CBR%	L.L%	P.L%	P.I%
Soil with 0% CKD	15.6	1.796	3.2	42	23	19
Soil with 0.5% CKD	15.5	1.792	10.45	40	22	18
Soil with 1% CKD	15.6	1.790	13.3	40	22	18
Soil with 1.5% CKD	15.7	1.789	17.4	38	21	17
Soil with 2 % CKD	15.8	1.788	25.2	37	21	16
Soil with 2.5% CKD	16	1.787	51.9	36	21	15

It can be observed from Table 4 that CBR without any CKD is quite below 25%. As mentioned in the previous section, CKD in this study is added to the soil sample with five different rates of (0.5%, 1%, 1.5%, 2%, 2.5%). The CBR, OMC, and MDD levels of the soil sample after the addition of the CKD are presented in Table 3.

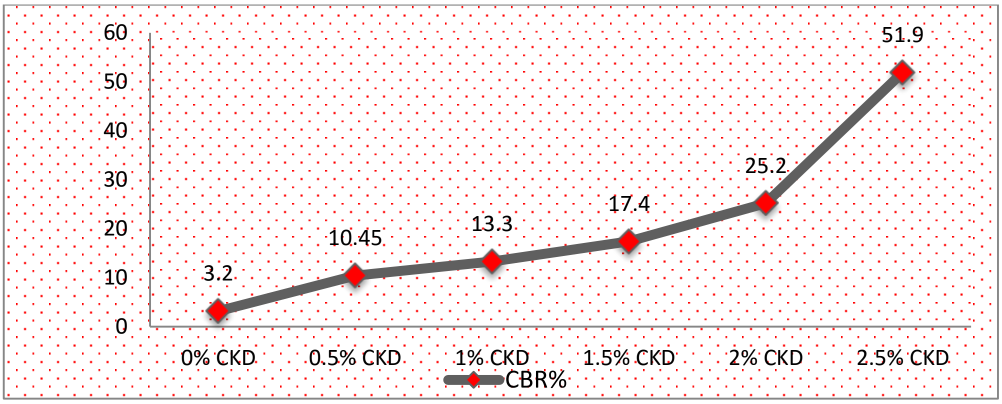

Figure 10: Effects of different percentages of CKD on poor-quality soil

As can be seen in Table 4 and Figure 10 as the CKD percentage of the soil increases, the CBR also increases. The CBR increase is very strong with higher CKD ratios. However, the requirement benchmark for CBR is 25%, which can already be achieved between 1.5% to 2.5% CKD ratio. Due to this result, 2% CKD was selected as the mixture ratio for the soil sample and the tests were repeated with this mixture rate. As can be seen from Table 4, by adding 2% CKD to the soil, the CBR was increased to 25% reliably.

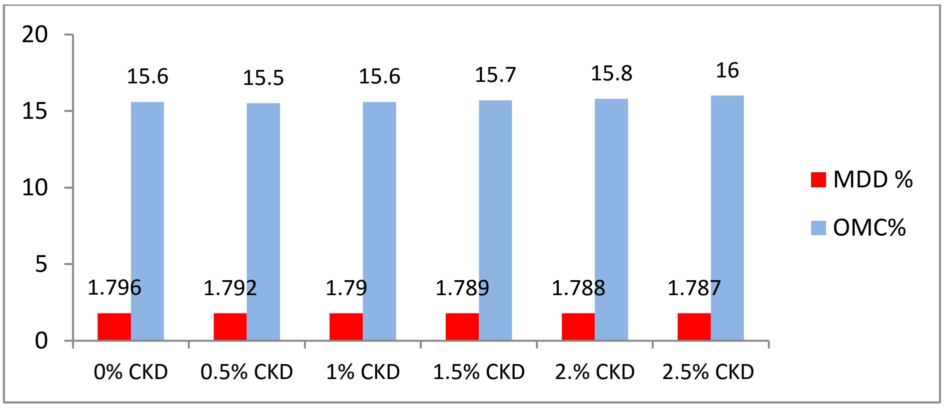

Figure 11: Effect of CKD on OMC and MDD

According to the Table 4 and Figure 12, it can be seen that as the CKD percentage increases, MDD rate slightly decreases. Arguably addition of CKD causes a shift of mass distribution between moisture and dry material towards the latter, causing a slightly decreased MDD (as MDD is moisture content subtracted from mass bulk). This is perhaps also related to the slightly increased OMC obtained by increased CKD ratio, which can also be observed in Figure 12.

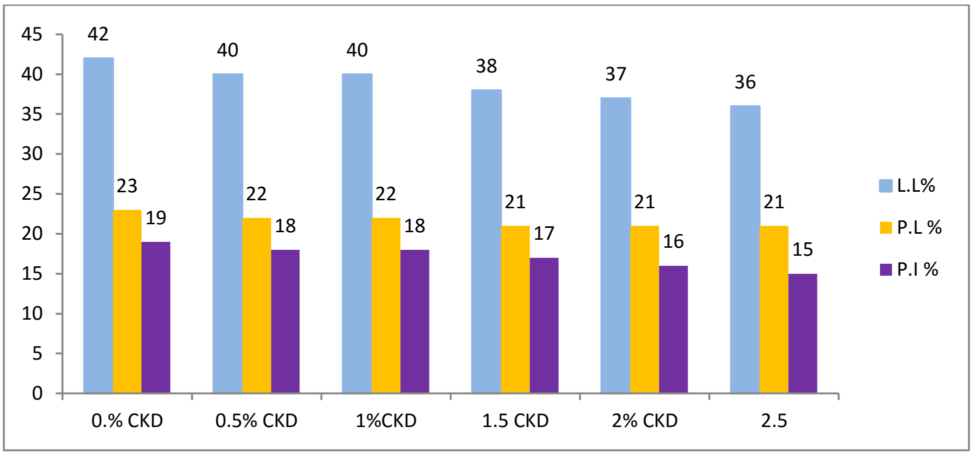

Figure 12: Liquid Limit, Plastic Limit & Plasticity Index at different Percentages of CKD

The effects of different rates of CKD addition to the subject material in terms of LL, PL and PI are given in Figure 3.3. As can be seen, all three properties decrease as the CKD ratio increases. These changes can be attributed to the change in total chemical composition of the material, as total amount of oxide compounds that are the primary factors for these values change. The change can also be due to changing physical properties, as the addition of the fine-particle CKD causes a reduction in coarse particle amount in the subject matter, which influence the LL, PL, and PI.

4. Conclusion

- The purpose of this study is to evaluate the effects of adding CKD to poor soil bed material, and to obtain the required CBR of 25% with that soil material.
- As a result of analysis and interpretation of the results, we concluded the following: firstly, the results show 2% CKD introduction is quite sufficient to reach 25% CBR.
- CKD material is also very cost effective (can be acquired almost for free, the CKD used in the present study was obtained for free). The results of this study are similar to those of (Mosa et al.,2017) and (Rimal et al., 2019). It should be noted that the CKD was found to be sufficient to strengthen the road and there is no need to spend on different and expensive materials. Next, the use of CKD as a free and available product in Iraq is quite significant in terms of technical and economic reasons and environmental benefits.
- In addition, the results show a significant increase in CBR score, which means increasing the amount of CKD causes an increase CBR, indicating a significant improvement in soil bed properties.
- Another consequence of increasing the amount of CBR is that the designer can design layers of the pavement with less thickness and without having a negative effect on the structural performance of the pavement system. This fact should further contribute to cost reductions.
- The effect of an increase in CKD also has a direct increase in OMC. MDD however, decreases with increased amounts of CKD. Furthermore, Increased CKD had inverse relationship with soil

properties such as LL, PL and PI. This means that with increasing CKD, (L.L, P.L and P.I) decreased.

5. Recommendation

- Recommend the engineers, designers, and technicians specialized in road design, to adopt the mentioned strategy for enhancing poor soils by Residues of the cement factories named Cement Kiln Dust (CKD) for increasing the CBR of effective subgrade layer.
- CKD material is also very cost effective, We recommend using it for strengthen the structural of the road because it is a material without a price, which makes the construction of the road at a low cost and high quality.

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