Strengthening Soft Clayey Subgrade Soil Layer Using Cement Kiln Dust and Palm Kernel Ash Materials

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Abstract. The product materials which are generated from industrial manufacturing are used to enhance the engineering and chemical properties of soil. There are three phases of soil improvement: improvement without the addition of any other material, adding certain materials, and providing reinforcement. This study used materials product from industrial and waste materials as additives to improve the physical properties and strength of clayey soil subgrade under foundation and flexible pavement structure. This study has been investigated the effect of isolated and combined Cement Kiln Dust (CKD) and Palm Kernel Ash (PKA) materials on strength of clayey soil as tested by California Bearing Ratio (CBR) test. Various percentages of CKD and PKA materials were added to clayey soil samples to determine the optimum percent of CKD and PKA. The results showed that CKD and PKA have improved soil strength at the optimum compound percent of CKD content was 8% and PKA was 2% by weight of dry soil.

Keywords: Clayey soil, CBR, CKD, flexible pavement, and PKA.

1. Introduction

The soil at a construction site may not always be suitable for supporting structures such as buildings, bridges, highways, and dams. Soil stabilization deals with physical and chemical properties to make the stabilized soil. Soil stabilization results from the changes in soil drain ability, decreased volume changes, improved soil undesirable effects which are contained clay will be controlled, reduced soil settlement, increased sharing resistance, and increasing soil bearing capacity [1]. Soft Clay soil can be considered as a week material when has low strength and is influenced by water, after the addition of water to the clay, it will be a plastic liquid. This is due to the low permeability of this type of soil [2]. Clayey soils can be considered as the material that causes problems in the future; the structures founded on it will be damaged. The clay minerals are very sensitive to water; this leads to swelling or expansion problems. The swelling mechanism is affected by many factors such as the type of clay, the amount of clay minerals in the soil, and the mechanism of swelling is relatively complex [2].

In Iraq, Cement Kiln Dust (CKD) is generated from PC plants which are available for free. Al-Hdabi et. al. [3] considered (CKD) is a very good additive in this domain. As a result, CKD is used in order to develop or improve poor subgrade soil properties based on a series of California Bearing Resistance (CBR) tests. A modern method [4] was conducted by reinforcing granular soil with CKD as classless of a certain thickness. The sand was presented and tested in four statuses which included CKD at depth of (0.15, 0.2, 0.25, 0.5, and 1) from the width of the box in the instrument, and the thickness CKD was certain to 10% of the width. The outcomes showed that the better depth of the positioning layer is half-width, and the $q$, in this case, excess about 241%.
The behavior of soils treated with fly ash after improving the soft soil by adding different amount of fly ash ranging from 9 to 46% by weight of the soil, this study has indicated the most effective to improve soil shear strength parameters (\(c\) and \(\phi\)) and California bearing ratio (BRC) [5]. The main goal of this research is to enhance soft clayey soil properties by adding two product materials are Cement Kiln Dust (CKD) and Palm Kernel Ash (PKA). The second stage of this study including by adding mixing two product materials CKD and PKA in soft clayey soil to increase the bearing capacity of the soil under foundation structures.

2. Effect of CKD and Palm Kernel Ash on Soil Strength

The use of CKD materials in soil stabilization involves environmental advantages, CKD is produced in large quantities around the world as a by-product material. Consequently, CKD is considered a very good additive in this domain. In Iraq, annually about 350000 tons of CKD are generated from PC plants which are available for free. As a result, CKD is used in order to improve poor subgrade soil properties [6]. Ibhadode and Dagwa [7] Considered PKA as waste material from oil processing. He indicates that in developing countries, the waste product if treated could be beneficial for use as an additive of the pavement [8]. The addition of these ashes as a stabilizer soil is beneficial, this is due to many factors such as reducing the consequences and quantity costs of stabilization of weak soil and reducing compressibility, lowering the ashes effect as waste materials that pollute the environment. So, it is widely required to consider the usage of PKA to improve the soft clay soil.

3. Materials

The materials used in this study include pure clay, CKD, and PKA. A series of tests conducted on clay soil to investigated physical and chemical properties.

3.1 Clay Soil

The pure clay soil was obtained from Al-Barakia in Najaf city which is located in the south of Iraq. The physical and chemical properties of clay soil are summarized in Table 1.

| Test description                  | Results | Specification          |
|-----------------------------------|---------|------------------------|
| Water content (%)                 | 4       | ASTM D2216 – 10        |
| Liquid limit (%)                  | 70      | ASTM D 4318/AASHTO T 90|
| Plastic limit (%)                 | 38      |                        |
| Max. dry unit weight (kN/m^3)     | 14      | ASTM D1557/AASHTO T180|
| Optimum moisture content (%)      | 14      |                        |
| CBR (%)                           | 4.015   | ASTM D1883 and AASHTO T193|
| Soil type (AASHTO)                | (A-7-5) | ASTM D-3282 and AASHTO M145|
| Soil type (USCS)                  | MH      | ASTM Test D-2487       |
| \(F_{200}\)                       | 35      | -                      |

| Chemical Properties               | Results | Specification          |
|-----------------------------------|---------|------------------------|
| pH                                | 8.22    |                        |
| Sulfate                           | 0.2     |                        |
| Chloride (ppm)                    | 875     |                        |
| \(E_c\)                           | 4000    |                        |
| TDS (ppm)                         | 2100    | BS standards            |
| Alkalinity (ppm)                  | 20      |                        |
| Organic matter (%)                | 2.8     |                        |
| Carbonate (ppm)                   | 1350    |                        |
| Gypsum content (%)                | 0.4     |                        |
3.2 Cement Kiln Dust (CKD)

Cement Kiln Dust, as the name indicates, is a fine powder like the by-product materials of Portland cement production. They are collected from the pools of high-temperature rotary kilns by the dust collection systems. Preliminary chemical and physical experimental studies were conducted on a CKD collected from a local cement factory, New Kufa Cement Plant. The chemical composition is presented in Table 2. On the other hand, from the physical properties represented by sieve analysis which is reported that all CKD sample is passed through 0.15 mm sieve size and the specific gravity is 2.75 [3].

| Constituents | SiO₂ | Al₂O₃ | Fe₂O₃ | CaO | MgO | SO₃ | L.O.I | Na₂O | K₂O | Cl |
|--------------|------|-------|-------|-----|-----|-----|-------|------|-----|----|
| Composition  | 13.38| 5.87  | 1.61  | 40.35| 3.08| 8.83| 21.8  | 2.63 | 4.23| 0.188|
| (%) by weight|      |       |       |     |     |     |       |      |     |    |

3.3 Palm Kernel Ash (PKA)

Palm kernel ash (PKA) is a product of materials that are provided in a large amount everywhere, in this study the PKA were obtained from Al-Dabes factory at University of Kufa, it has been collected and washed in order to remove dust and other sustained materials, then it’s burned in the burning oven until 700°C, then grinding into fine materials and finally sieved on sieve No. 200 = 15%, as shown in Fig. 1.

![Sample of PKA material.](image)

4. Experimental Work

Six samples with 0, 2, 4, 6, 8, and 10 % of CKD were tested in order to specify the best CKD ratio that enhancement properties and shear of soil, after that, with different CKD percent to obtain optimum CKD content by California Bearing Ratio (CBR) test, then, optimum CKD content is admixed with a varied ratio of PKA to obtain optimum PKA content by CBR test. California Bearing Ratio admixed designing method was utilized to determine optimal CKD and PKA contained and determined the strength of the admixed in Lab and other properties of the admixed. A clayey soil was mixed with different percents of CKD (2, 4, 6, 8, and 10%) and admixed with optimal moisture contained. The admixed was then placed in California Bearing Ratio mold at 3 layers, each layer is compacted with fifty-six blows, after compaction, each mold is weighed, then soaked in water for 4 days, after soaking each mold is tested in California Bearing Ratio test in order to find optimal CKD contained which is reached maximum California Bearing Ratio value, after determining optimum CKD contained, clayey soil was mixed with optimal CKD contained and different percents of PKA (1, 2, 3, 4, 6, and 8%) at optimal moisture contained and the same above steps are repeatable in order to find optimal PKA which enhance soil strength and CBR value.
5. Results and Discussion
5.1 Effect of CKD

CKD material was added to the soil in 5 varied percents, after the California Bearing Ratio test for all molds, optimal CKD contained was detected 8% which represents the maximum percent of CKD that enhances soil strength as shown in Fig. 2.

![Figure 2. Effect of CKD ratio on CBR (%)](image)

The engineering properties of soil with 8% CKD used in this research are presented in Table 3, and Fig. 3, after reviewing the results in Table 3, show the improvement of engineering properties of soil after mixing 8% CKD with clay soil, whereby the values of liquid limit, plastic limit, and plasticity index are decreased while the values of maximum dry density and CBR are increased.

![Figure 3. Compaction test for Soil with 8% CKD.](image)

| Test description                  | Results before adding CKD | Results after adding CKD |
|-----------------------------------|---------------------------|--------------------------|
| Liquid limit (%)                  | 70                        | 47                       |
| Plastic limit (%)                 | 38                        | 27                       |
| Plasticity index (%)              | 32                        | 20                       |
| Maximum dry unit weight (kN/m$^3$)| 14                        | 16.6                     |
| Optimum moisture content (%)      | 14                        | 21                       |
| CBR (%)                           | 4.015                     | 33.126                   |
5.2 The PKA Effects

Using the optimum CKD percentage that has been obtained depended on soil properties, PKA was added to the soil at various percentages by the weight of soil, 6 samples with 1, 2, 3, 4, 6, and 8% of PKA were investigated to find optimal PKA percent that enhance soil strength. The test results show the optimum PKA contained is 2% which represents the maximum percent of PKA, then the two optimum ratios are added (8% CKD + 2% PKA) to improves the soil engineering properties were summarized in Table 4 and Fig. 4 show the effect of adding (8% CKD + 2% PKA) 2% of PKA on the relation between water content and dry density. The soil behavior can be justified as this due to an increase of treated soil strength because of the chemical reaction of CKD with components of soil produced chemical bond, increase of the amount of the additional materials can increase chemical bond as a result, it increases soil strength and also increases in treated soil CBR values, besides, the results showed that PI of the soil treated with CKD decreases at optimal CKD contained on the other way, PI of soil treated with 2% PKA and 8% CKD increases at optimal PKA contained, the results are shown in Fig. 5.

| Test description       | Results before adding PKA and CKD | Results after adding PKA and CKD |
|------------------------|-----------------------------------|----------------------------------|
| Liquid limit (%)       | 70                                | 68                               |
| Plastic limit (%)      | 38                                | 35                               |
| Plasticity index (%)   | 32                                | 33                               |
| Max. dry density (kN/m³) | 14                              | 13.8                             |
| Optimum moisture (%) content | 14                             | 17                               |
| CBR (%)                | 4.015                             | 41.67                            |

Figure 4. Water content-density relation with 2% PKA and 8% CKD.

Figure 5. Effect of CKD and PKA addition on Atterberg limits.
6. Structural Design of Proposed Highway Section

The design criteria and procedures presented in this study follow [10] guide for the design of pavement structures. The type of pavement which has been adopted in this project is flexible pavement. The structural number (SN) which will be used in finding the thickness of each course and according to the equation:

$$SN = a_1D_1m_1 + a_2D_2m_2 + a_3D_3m_3$$  \hspace{1cm} (1)

Where $a_1$, $a_2$, and $a_3$ are the layers coefficients for surface (two layers), base, and subbase respectively. $D_1$, $D_2$ and $D_3$ are the thickness for the same layers in inches. According to the Flexible Pavement Design: pavement design, the general required information is [9]:

| Table 5. General information. |
|-----------------------------|
| Property                    | Value  |
| Initial Serviceability, Po  | 4.2    |
| Final serviceability, Pt    | 2.0    |
| Reliability level, R        | 95%    |
| Overall standard deviation, $S_o$ | 0.45  |
| Design life                 | 20 years |

| Table 6. Traffic data and analysis. |
|-------------------------------------|
| Property                     | Value |
| AADT                          | 3000  |
| Heavy trucks, %              | 20    |
| Heavy trucks factor (SCRB, 2005) | 3.5   |
| Year                         | 20    |
| Days                        | 365   |
| Directional distribution, %  | 55    |
| Design lane, %               | 80    |
| Traffic projection factor    | 36.79 |

Accumulated ESAL over 20 years:
$$W_{18} = AADT \times \% HT \times HTF \times TPF \times DAYS \times DD \times DL$$
$$W_{18} = 3000 \times (0.20 \times 3.5) \times 36.79 \times 365 \times 0.55 \times 0.8, W_{18} = 12,407,795$$
Roadbed Soil Resilient Modulus Data: MR = 1500 CBR.

- **Clayey Soil**
  Subgrade CBR value = 4.015%, MR = 1500 x 4.015 = 6022 psi.
  Required Design Structural Number: SN = 4.0.
  Total available SN = 4.262 is greater than design SN, so the design is acceptable.

| Table 7. Flexible pavement layers. |
|------------------------------------|
| Layer | Material              | Layer coefficient | Drainage coefficient | Thickness (cm) | Structural Number, SN |
|-------|-----------------------|-------------------|----------------------|----------------|----------------------|
| 1     | HMA Type III, Wearing course | 0.44              | 1                    | 4              | 0.693                |
| 2     | HMA Type II, Binder course | 0.40              | 1                    | 6              | 0.945                |
| 2     | HMA Type I, Base Course | 0.34              | 1                    | 10             | 1.338                |
| 3     | Granular Material, Subbase | 0.11              | 0.80                 | 40             | 1.286                |
• **Soil with 8% CKD**
Subgrade CBR value = 33.126%.
MR= 3000 × (33.126)^0.65 = 29190 psi.
Required Design Structural Number: SN = 3.2.
Total available SN = 3.416 is greater than design SN, so the design is acceptable.

| Layer | Material | Layer coefficient | Drainage coefficient | Thickness (cm) | Structural number, SN |
|-------|----------|-------------------|----------------------|----------------|----------------------|
| 1     | HMA Type III, Wearing course | 0.44 | 1 | 4 | 0.693 |
| 2     | HMA Type II, Binder course | 0.40 | 1 | 5 | 0.787 |
| 2     | HMA Type I, Base Course | 0.34 | 1 | 8 | 1.07 |
| 3     | Granular Material, Subbase | 0.11 | 0.80 | 20 | 0.866 |

• **Soil with 8% CKD and 2% PKA**
Subgrade CBR value = 41.67%.
MR= 3000 CBR^0.65, MR = 33885 psi.
Required Design Structural Number: SN = 2.5.
Total available SN= 2.55 is greater than design SN, so the design is acceptable.

| Layer | Material | Layer coefficient | Drainage coefficient | Thickness (cm) | Structural number, SN |
|-------|----------|-------------------|----------------------|----------------|----------------------|
| 1     | HMA Type III, Wearing course | 0.44 | 1 | 4 | 0.693 |
| 2     | HMA Type II, Binder course | 0.40 | 1 | 5 | 0.787 |
| 2     | HMA Type I, Base Course | 0.34 | 1 | 8 | 1.07 |

**Table 10. Summary of the effect of additives on pavement thickness.**

| Material          | Pure clay | Soil with 8% CKD | Soil with 8% CKD and 2% PKA |
|-------------------|-----------|------------------|-----------------------------|
| Wearing course    | 4         | 4                | 4                           |
| Binder course     | 6         | 5                | 5                           |
| Base course       | 10        | 8                | 8                           |
| subbase           | 40        | 20               | 20                          |
| Total             | 60        | 37               | 17                          |

In the case of using additive (CKD and PKA) we can neglect the subbase course layer, and in the case of using CKD only will reduce total pavement thickness by 38%.

**7. Conclusions**
This study has focused on investigating the effect of using Palm Kernel Ash with Cement Kiln Dust as a by-product material to improve soil engineering properties. This study has come up with the following results:

- Soil strength, CBR is increased with an increase of CKD percent until 8%.
- The addition of CKD and PKA in the clayey soil samples is considered an eco-friendly material and it can enhance soil properties.
- Referring to the CBR test results, the process of using CKD and PKA enhances it when using the CKD as 8% from weight of soil and 2% of PKA.
- Optimum Moisture Content decreases for soil stabilized with optimum percent of PKA.
The stabilization of soft soil with CKD Plus PKA will reduce the thickness of the flexible pavement thickness to 57% when comparing with pavement thickness constructed on the local soil.

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