Stabilization of Clayey Soil using Cement Kiln Waste

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Abstract: Day by day increasing demand of cement results in intense collection of kiln dust from cement plants. The disposal of this fine dust becomes an environmental threat. In order to overcome this problem, research is being carried out in different parts of the world to find out the economical and efficient means of using cement kiln dust (CKD). Various applications of soil stabilization, cement production, pavements, waste product stabilization, and agriculture and cement products, etc. Keeping in mind the need for bulk use of these solid wastes in India, it was thought expedient to test these materials and to develop specifications to enhance the use of these industrial wastes in soil stabilization. In the course of the study, this research has been able to establish the reactions between soil and cement. It has been established that the chemical compounds found in soil; quartz, feldspar, dolomite, calcite, montmorillonite, kaolinite etc. react with the chemical constituents found in different identified chemical stabilizers. The purpose of using CKD, and the other additives, is to improve the texture, increase the strength and reduce the swell characteristics of the various soils. This paper represents the stabilization of clayey soil using cement kiln waste. The soil taken from Ravendrapadu in Andhra Pradesh containing different properties in various percentages is mixed with CKD in different proportions and parameters like dry density and moisture content are found out. By examining the values obtained ideal values are obtained at 50% proportional mix of CKD in total percentage.

Key words: Cement Kiln Dust (CKD), Soil Stabilization, Industrial Wastes

Introduction

Soils with low-bearing capacity can be strengthened economically for building purposes through the process of “soil stabilization” using different types of stabilizers [1]. Soil bed should bear all generated stresses transmitted by shallows or piles. The soil often is weak and has no enough stability in heavy loading. In this regard, it is necessary to reinforce and stabilize the soil. To design of reinforcement, analysis of the generated deformation, stress and strain as well as stability of soil structures is the main objective of many geotechnical analyses at long term service condition. In building systems, every displacement can be led to generate internal stresses which have not been predicted in analysis and design of structures which should be anticipated. Generally, clayey soils are very weak soils. So, they definitely need stabilization for the better usage.

Billions of dollars in damages are attributed to expansive soils in many countries each year. Geotechnical design and analyses in/on/with expansive soils may involve additional complications that otherwise would not have to be dealt with if expansive soils were not present. Traditional methods for chemical stabilization of soils include the addition of lime, class-C or class-F fly ash, Portland cement, or other industrial by-products such as cement kiln dust, steel or copper slag. Physical stabilization techniques aim at reducing the potential swell pressure and swell percent of the expansive soil without altering the soil chemistry (Carraro et al., 2008). Several reinforcement methods are available for stabilizing expansive soils [2]. Here, stabilization of soil is done using CKD.

Cement kiln dust is created in the kiln during the production of cement clinker. The dust is a particulate mixture of partially calcined and unreacted raw feed, clinker dust and ash, enriched with alkali sulphates, halides and other volatiles. These particulates are captured by the exhaust gases and collected in particulate matter control devices such as cyclones, bag houses and electrostatic precipitators.

Several factors influence the chemical and physical properties of CKD. Because plant operations differ considerably with respect to raw feed, type of operation, dust collection facility, and type of fuel used the use of the terms typical or average CKD when comparing different plants can be misleading. The dust from each plant can vary markedly in chemical, mineralogical and physical composition [3].

Cement kiln dust is a cogenerated product of Portland cement manufacturing. More than six million tons of postconsumer roofing shingles and about one million tons of preconsumer are generated in the USA annually. Most of the waste shingles are deposited in landfills, creating a sizable disposal problem and gradual loss of landfill space. On the other hand, about 12.90 million metric tons of CKD, that are not suitable for recycling, are disposed-off annually by cement manufacturing companies in Canada.

The obvious and best use of CKD is its re-inciporporation in the clinker production cycle. However, this can only be done when the existing restrictions on the alkalis and chloride concentrations in cement are revised. From alkalis point of view, it
is estimated that most of the CKD could be utilized in the clinker-making process if the cement alkali levels could be raised by around 0.1%. Similarly, the limits on the required chloride concentration on the performance of cement in reinforced concrete construction need to be evaluated. The use of CKDs as soil stabilizers might potentially consume the bulk of the CKDs being generated every year. Such use could significantly enhance the engineering characteristics of unsuitable and marginal soils, allowing their use for improved sub-grade, sub-base, or related applications.

The degree of enhancement of soil properties due to modification or stabilization depends both on the type of the soil and the type and amount of the additive used. The effectiveness of a stabilizer additive to modify and potentially stabilize a particular soil can be studied by measuring the changes in properties, essentially its moisture-density relationship, Atterberg limits, swell potential, and unconfined compressive strength (UCS)[4].

**Objectives:**
This paper mainly emphasizes on stabilization of expansive soil using locally cement kiln waste. This infers the following objectives which can be put forth as follows:
1) Efficient use of CKD for stabilization of clayey soil
2) Increase parameters of soil like strength using cement kiln waste in various proportions

**Research Review on stabilization of clayey soils using various kinds of wastes:**
Fly ash can be used in concrete admixtures to enhance the performance of concrete roads and bridges. Fly ash and lime can be combined with aggregate to produce a quality stabilized base course. Portland cement may also be used in lieu of lime to increase early age strengths. Cement kiln dust has a chemical composition similar to that of element; therefore, the primary value of cement kiln dust is its cementitious properties. Its alkalinity and particle size also provide value for a variety of beneficial use option [5] The compaction characteristic of the sand was improved by cement dust. Considering the seepage control, compressive strength, cement dust was approved to have more pronounced effect on the reduction of the sand permeability and enhance of the compressive strength of sand.[6] analyse the effect of different stabilizing agent at different soil condition. This study shows that soil stabilization is beneficial for improving weak soil in a cost-effective way. For stabilizing weak soil, most waste material like fly ash, rice husk and egg shale is used which one of the waste utilization and also works as stabilizing agent which gives better results. The proportion of fly ash and lime is decided by considering moisture content and density. After soil stabilization by these stabilizing agents there is drastic improvement in strength parameter of sub grade. [7]

It is obvious that the stabilization of soils (i.e., chemical stabilization) for engineering works is achieved through the chemical reaction (commonly exothermic reaction) that takes place between the chemical components of the soil and the stabilizers or modifiers. Results and experience show that lime as a chemical stabilizer is yields better results than the others but cement is commonly used because of its cost effectiveness. These stabilizers are used depending on the type of constructions. It is recommended that geotechnical engineers consider the reactive effects of chemical stabilizers on the soil matrix before making the choice of any chemical method of stabilization. [8]

The compressive strengths results showed continued increase with the amount of CKD and curing duration. The curing temperature level affected the compressive strength of sand CKD mixtures, such that at high temperature levels the gain in strength was higher at early ages. For light applications, it was expected that 12-30% CKD should be sufficient to upgrade dune sand; however, for heavily loaded applications, it was expected to raise the CKD content to about 50%. Specimens of CKD revealed high compressive strength but failed the freeze-thaw durability requirement. [9]

**Table 1 Basic Properties and Typical Oxide Composition of the Cement kiln dust [10]**

<table>
<thead>
<tr>
<th>Oxide</th>
<th>CaO</th>
<th>Al₂O₃</th>
<th>SiO₂</th>
<th>Fe₂O₃</th>
<th>MnO</th>
<th>Na₂O</th>
<th>K₂O</th>
<th>pH</th>
<th>Gs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration%</td>
<td>50.81</td>
<td>4.71</td>
<td>0</td>
<td>1.92</td>
<td>0.002</td>
<td>0.001</td>
<td>1.35</td>
<td>11.2</td>
<td>2.22</td>
</tr>
</tbody>
</table>

**Cement Kiln Dust Characteristics:**
CKD consists primarily of calcium carbonate and silicon dioxide which is similar to the cement kiln raw feed, but the amount of alkalies, chloride and sulphate is usually considerably higher in the dust. CKD from three different types of operations: long-wet. Long-dry, and alkali by-pass with precalciner were characterized for chemical and physical traits by Todres et al. (1992). CKD generated from long-wet and long-dry kilns is composed of partially calcined kiln feed fines enriched with alkali sulphates and chlorides. The dust collected from the alkali by-pass of precalciner kilns tend to be coarser, more calcined, and also concentrated with alkali volatiles. However, the alkali by-pass process contains the highest amount by weight of calcium oxide and lowest loss on ignition (LOI), both of which are key components in many beneficial applications of CKD. Table1 provides the composition breakdown for the three different types of operation and includes a typical chemical composition for Type I Portland cement for comparison.
The suitability of cement kiln dust for treatment of black cotton soil in waste containment facility produced successful results. There were changes in the index properties of the cement kiln dust treated black cotton soil specimen. However, the MDD generally increased with increasing CKD content while the OMC decreased with increasing CKD content.\[10\]

When the RHA content was increased from 0 to 12%, unconfined Compressive Stress increased by 97%, and when the RHA content was increased from 0 to 12%, CBR improved by 47%. The optimum RHA content was found at 12% for both UCS and CBR tests.\[11\]

It was observed that with the increase in water content the dry density decreases up to 20-30% moisture content and with further increase in water content the dry density decreases gradually. The maximum dry density is in the range of 1.35 g/cc for 95% soil and 5% fly ash mixture and lowest density was about 0.6g/cc for 70% soil and 30% fly ash mixture\[12\].

There was also an improvement in the unsoaked CBR (18.5% at 6% RHA content) compared with the CBR of the natural soil (8.5%). The soaked CBR also improved. A similar trend of the CBR was obtained for UCS. The UCS values were at their peak at 6-8% RHA. The UCS of the mixes also increased with curing age.\[13\]\[Musa Alhassan AU J.T. 11(4): 246-250 (Apr. 2008)\]

Large increases in compressive strength and stiffness were obtained for the clay by CKD treatment. The improvements of these properties were more noticeable, in general, with the increase in CKD content and with lengthening of the curing period.\[14\]\[Sulapha Peethampanar and Jan Olek, Journal of Materials in Civil Engineering © ASCE / February 2008 / 137\]

The use of cement dust extracted from the Cement Qena Cement Company for making bricks that have the appropriate mechanical and chemical properties. It is estimated that the productive capacity of the brick plant would have to be 660,000 bricks per day to use all of 120 tons of CKD generate per day. Some chemical components could be used to ensure that the bricks meet all standards and specifications as the amount of CKD content is increased to the range of 45% -65%..\[15\]\[Mahrous A.M.Ali and Huang-Sik Yang,2011\]

**Materials and Methods**

**Black Cotton Soil**

The Black cotton soil for the study was brought from Ravendhrapadu. The Index & Engineering properties of expansive soil are going to be determined as per IS code of practice.

<table>
<thead>
<tr>
<th>Tests</th>
<th>Untreated</th>
<th>Treated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural water content</td>
<td>29%</td>
<td>32%</td>
</tr>
<tr>
<td>Grain size(gravel)</td>
<td>0</td>
<td>3.5%</td>
</tr>
<tr>
<td>Sand</td>
<td>4.6%</td>
<td>17%</td>
</tr>
<tr>
<td>Silt and clay</td>
<td>95.3%</td>
<td>79.5%</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>2.5</td>
<td>2.7</td>
</tr>
<tr>
<td>Liquid limit</td>
<td>67.3%</td>
<td>50%</td>
</tr>
<tr>
<td>Plastic limit</td>
<td>32%</td>
<td>25%</td>
</tr>
<tr>
<td>Differential free swell</td>
<td>91%</td>
<td>85%</td>
</tr>
<tr>
<td>Compaction(OMC)</td>
<td>22%</td>
<td>16.58%</td>
</tr>
<tr>
<td>MDD</td>
<td>1.4</td>
<td>1.712</td>
</tr>
<tr>
<td>Unconfined compressive strength</td>
<td>57.6 KN/m²</td>
<td>71 KN/m²</td>
</tr>
<tr>
<td>Permeability</td>
<td>4.24*10⁻⁵mm/sec</td>
<td>4.24*10⁻⁵mm/sec</td>
</tr>
<tr>
<td>Swell pressure</td>
<td>88 KN/m²</td>
<td>65</td>
</tr>
</tbody>
</table>

Results:

<table>
<thead>
<tr>
<th>Strain (micron)</th>
<th>Stress (kPa)</th>
<th>Deformation (mm)</th>
<th>Load (kg)</th>
<th>Dry Density (g/cm³)</th>
<th>Moisture content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>99</td>
<td>464</td>
<td>1.398</td>
<td>185</td>
<td>1.864</td>
<td>6.62</td>
</tr>
<tr>
<td>96</td>
<td>583</td>
<td>1.358</td>
<td>232</td>
<td>1.864</td>
<td>6.62</td>
</tr>
<tr>
<td>107</td>
<td>598</td>
<td>1.509</td>
<td>236</td>
<td>1.898</td>
<td>8.12</td>
</tr>
<tr>
<td>89</td>
<td>638</td>
<td>1.260</td>
<td>252</td>
<td>1.898</td>
<td>8.12</td>
</tr>
<tr>
<td>82</td>
<td>685</td>
<td>1.158</td>
<td>272</td>
<td>1.925</td>
<td>9.62</td>
</tr>
<tr>
<td>89</td>
<td>691</td>
<td>1.254</td>
<td>275</td>
<td>1.925</td>
<td>9.62</td>
</tr>
<tr>
<td>89</td>
<td>640</td>
<td>1.258</td>
<td>255</td>
<td>1.892</td>
<td>11.13</td>
</tr>
<tr>
<td>86</td>
<td>662</td>
<td>1.206</td>
<td>262</td>
<td>1.892</td>
<td>11.13</td>
</tr>
</tbody>
</table>

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The following observations can be made from the experimental data on the soil:

1) As the CKD increases from 0% to 50% by weight of soil, the maximum dry density decreased from 1.925 to 1.728 g/cm³. Similarly, the optimum moisture content increases from 9.58% (for 0% CKD) to 14.52% (for 50% CKD).

2) The unconfined compressive strength increased from 684 kPa (for 0% CKD) for the unsealed specimens to 3,870 kPa (for 50% CKD).

3) For the sealed specimens, the strength increased from 214 kPa (for 0% CKD) to 2,752 kPa (for 50% CKD).

The following observations can be made from the experimental data on the low plasticity white marl:

1) The maximum dry density decreased from 1.778 to 1.594 g/cm³ for 0 to 50% CKD additions, respectively. The optimum moisture content increased from 17.10 to 22.50% for 0 to 30% CKD additions.

2) The strength of unsealed specimens increased from 2,742 to 3,877 kPa for 0 to 50% CKD additions; the improvement being 1.41 times (141%). For the sealed specimens, the increase was from 715 to 2,218.

3) The optimum moisture content from strength perspective followed the same trend as for the low plasticity “white” marl. [4]
Stabilization of Clayey Soil using Cement Kiln Waste

Conclusions:

Basing on the above paper by usage of CKDs the soil will definitely get stabilized. The main thing we have to observe is at what percentage mixture of CKDs with soil gives higher stabilization values.

1. Kiln ash has characteristics that can improve the engineering characteristics of tropical lateritic soils;
2. The recorded improvements in the compressibility decrease and permeability decrease of such soils due to admixing with kiln ash increases with curing time; a soil improvement trend to increase with kiln ash content.
3. Specifically, at higher ash contents, soil pH increased significantly; the maximum unconfined shear strength increased; and soil plasticity decreased.
4. CKD has been used as a soil additive to improve the texture, increase strength and reduce swell characteristics.
5. Treatment with cement kiln dust was found to be an effective option for improvement of soil properties, based on the testing conducted as a part of this research. Strength and stiffness were improved and plasticity and swell potential were substantially reduced.
6. These performance-related benefits, besides the environmental and economic benefits associated with the utilization of these wastes and co-generated products in construction, make the use of these wastes in sub grade applications very attractive and support sustainable development in construction.
7. The percentage of cement added for clay soils was determined by the amount of cement needed to lower the PI below 10.
8. For light applications, it was expected that 12-30% CKD should be sufficient to upgrade dune sand; however, for heavily loaded applications, it was expected to raise the CKD content to about 50%. Specimens of CKD revealed high compressive strength but failed the freeze-thaw durability requirement.

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