ENHANCING ENGINEERING PROPERTIES OF SANDY SOIL WITH CEMENT KILN DUST: A SUSTAINABLE APPROACH FOR CONSTRUCTION INDUSTRY

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ABSTRACT

Industrial processes exacerbate environmental contamination, which produces a large amount of waste materials. Cement kiln dust (CKD), which is produced in cement plants all over the world, is one of these wastes. Due to its wide availability and low cost, the study emphasizes how crucial it is to use CKD in the construction industry, addressing the need to reduce CKD waste and lessen its environmental impact. This research specifically focuses on sandy soil, widely used in construction for its easy accessibility and affordability. Despite its widespread use, sandy soil poses several challenges related to its engineering properties, including a low bearing capacity, insufficient shear strength, and high permeability. The safety and long-term viability of projects are jeopardized by these characteristics, which make it difficult to build stable foundations, roadways, and other crucial infrastructure. To tackle these issues associated with sandy soil, this study investigates the potential of CKD to enhance its engineering properties. The research seeks to determine the most effective CKD mixing percentage and lining depth to enhance sandy soil's shear strength, bearing capacity, and permeability. This was accomplished by experimenting with different CKD percentages (4%, 8%, and 12%) and various CKD lining depths (4, 8, and 12 mm). The study's findings revealed that an optimal 12% CKD mixture with sandy soil, combined with a 12mm CKD lining, substantially improved shear strength and bearing capacity, increasing them by 1.37 times. Additionally, permeability was reduced by 2.38 times compared to untreated soil. To further assess these improvements, the study analyzed the bearing capacity of both untreated and treated soil using Terzaghi and Meyerhof equations identifying optimal mixing percentages and lining depths, promoting a stable foundation solution. In conclusion, it is said that CKD enhances the engineering properties of sandy soil beneficial to both the construction industry and the environment by promoting safer and more sustainable construction practices.

Keywords: *Cement Kiln Dust (CKD), Sandy Soil, Stabilization, Lining CKD, Sustainable Construction*

1. INTRODUCTION

The ever-increasing global demand for cement production generates significant quantities of cement kiln dust (CKD) as a by-product, which poses environmental concerns due to disposal challenges. In order to address this problem, research efforts have been initiated in many countries to investigate efficient ways to use CKD for a range of uses, including soil stabilisation, road construction, cement production, and agricultural purposes.

The size of the sand particles in sandy soil, which normally ranges from 0.06 mm to 2.0 mm, is what distinguishes it from other soil types. The properties of sandy soil, particularly its low cohesion and high permeability, present challenges for construction and foundation projects. Settlement due to the lack of cohesion between sand particles and increased water penetration can weaken foundations and leads to soil erosion (Shilar et al., 2023).

Various techniques have been employed to enhance the engineering properties of sandy soil, including mechanical, chemical, and electrical stabilization methods. Among chemical stabilizers, cement, fly ash, and rice husk ash have been commonly used. It is observed that stabilized clayey soil with CKD and rice husk ash improved mechanical properties in addition to durability. CKD stabilized soils displays advanced improvement of soil properties than to their RHA equivalents. Previous studies have demonstrated that CKD can greatly enhance the compressive and shear strengths of sandy soil (Lindh & Lemenkova, 2022).According to studies, CKD can increase the strength of sandy soil by up to 50% (Yuliet et al., 2023).The degree of CKD added depends on the desired engineering property improvements and entails combining a specified amount of CKD with sandy soil to make a homogeneous mixture (Almuaythir & Abbas, 2023).

According to a study by(Saeed et al., 2022),sandy soil stabilised with CKD was stronger when compaction energy was doubled. Additionally, lining with CKD entails "cement kiln dust dusting," which is the application of a thin coating of CKD on the top of sandy soil before to construction operations. This process serves to reduce dust emissions during construction by binding sandy soil particles, preventing them from becoming airborne, and mitigating dust pollution.

The research in question aims to enhance the engineering properties of sandy soil by combining both mixing and lining techniques with cement kiln dust. This approach addresses a research gap by integrating two distinct methods for soil improvement. The study examines the impacts of CKD when it is lined with diverse CKD depths (4, 8, and 12 mm) and mixed with sandy soil at various percentages (4%, 8%, and 12%). The study aims to identify the optimal CKD mixing percentage and lining depth to improve shear strength, bearing capacity, and permeability by evaluating the effects of CKD on the engineering parameters of sandy soil. The study's findings suggest that 12% is the ideal CKD mixing percentage, which leads to appreciable increases in shear strength, bearing capacity, and permeability. The optimal CKD lining depth is also 12mm, which results in significant improvements in engineering parameters, such as a 1.37-fold increase in shear strength, a 1.37-fold increase in bearing capacity, and a 2.38-fold decrease in permeability when compared to untreated soil. Utilising cohesion and friction values from direct shear testing for the best mixing percentages and lining depths, bearing capacity estimates were made using the Terzaghi and Meyerhof equation.

2. MATERIALS AND EXPERIMENTAL METHODS

2.1 Materials

The silty soil sample was collected from the river bank of Rupsha near Dighalia upazila, Khulna, Bangladesh. The soil lumps were broken into small pieces and passed through 4.75 mm size sieve to make it free from roots, gravel etc. At a temperature of 110 degrees Celsius, the soils were dried in the oven for 24 hours. The soil had dried in the appropriate oven for the appropriate amount of time, and was ready for experimentation. The CKD was collected from the Lafarge cement factory and was subjected to further processing. To remove the moisture content from the CKD, it was oven-dried. Once the material was dried, it was found to contain a mixture of large and small particles of CKD. To obtain a fine form of CKD, the material was sieved using a #50 sieve size, which has a mesh opening size of 0.6mm. Sieving is a process that separates particles based on their size. In this case, the #50 sieve size was used to remove the larger particles of CKD, which are not desired in the final product. The remaining material that passed through the sieve is the fine form of CKD. The fine form of CKD obtained after sieving has a uniform particle size and is typically used as a cement substitute in concrete mixtures. The properties of soil sample determined through moisture content, specific gravity test, standard proctor test, sieve analysis according to the ASTM D2216, ASTM-D4318, ASTM D698 and ASTM-D6913 respectively (ASTM-D6913, 2007; D698, 2007; D2216, 2007; D4318, 2007).

2.2 Sample Preparation

2.2.1 Cement Kiln Dust Mixing Method

The CKD mixing process involves blending a specific quantity of CKD with the sandy soil to create a homogenous mixture. The mixing is done using a suitable mixer that can uniformly distribute the CKD throughout the soil. The soil sample was mixed with sandy soil at 3 different percentages that is 4%, 8%, 12%. For direct shear test the soil sample was only mixed with CKD at dry condition but for the other test like UCS (unconfined compression test), Standard proctor test, Permeability test the mixing was done at wet condition.

2.2.2 Cement Kiln Dust Lining Method

Lining with CKD involves applying a thin layer of CKD on the surface of the sandy soil before construction work begins. This process is known as "cement kiln dust dusting," and it is used to reduce the dustiness of the soil during construction. The soil sample was lined with CKD at 3 different depth that is (4mm, 8mm, 12mm). The depth was given for 2 layers. The bottom layer filled with sandy soil then CKD lining depth maintained then again filled with sandy soil make it like a sandwich.The thickness of the layer of lining was fixed to 0.017B (1 mm), where B is the width of container (Amhadi & Assaf, 2021).

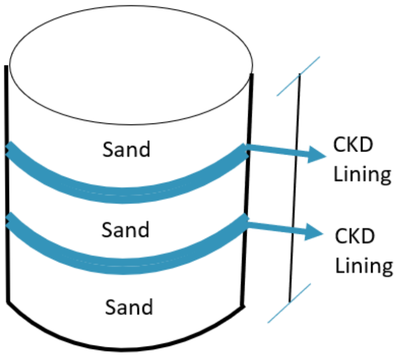

Figure 1: Cement kiln dust Lining method

2.2.3 Moisture content (ASTM 2216)

A representative soil sample was taken from the field or laboratory and weight (W1) recorded to the nearest 0.1 g. The soil sample was placed in an oven and dry it at a temperature of 110±5°C until the weight of the sample remains constant. This weight was recorded as W2. The moisture content was calculated (M) using the following formula:

$$M = [(W1 - W2) / W2] \times 100 \quad (1)$$

Where, M = moisture content (%)

W1 = weight of the wet soil sample (g)

W2 = weight of the dry soil sample (g)

2.2.4 Standard proctor test (ASTM D698):

A representative sample of soil was collected and weighed. The sample was placed in a metal mold with a known volume, typically 1/30 cubic feet (944 cc) or 1/13.33 cubic feet (1,870 cc), and compacted in three equal layers using hammer. The weight of the mold with the compacted soil was recorded, and the bulk density and moisture content of the soil were calculated. The test was then repeated for different moisture contents, typically ranging from dry to slightly above the natural moisture content of the soil. The data obtained from the test was used to create a compaction curve, which showed the relationship between the moisture content and dry density of the soil. The maximum dry density and optimum moisture content of the soil were determined from the curve. The test was performed for both untreated and treated sandy soil.

2.2.5 Specific Gravity Test (ASTM-D4318)

Soil sample was collected from the field or laboratory weight and recorded to the nearest 0.1 g.Then the sample was oven dried at a temperature of 105°C to 110°C until it reacheed a constant weight. The weight of the dry soil sample was recorded.A pycnometer was cleaned and dried, and its weight (W1) was recorded to the nearest 0.1 g.The pycnometer filled with distilled water at room temperature, and recorded as weight (W2) to the nearest 0.1 g. The dry soil sample was placed in the pycnometer weight (W3) was recorded to the nearest 0.1 g.The pycnometer was filled with distilled water at room temperature to the same level as before, and its weight (W4) was recorded to the nearest 0.1 g.
The specific gravity (G) of the soil is calculated using the following formula:

$$G = [(W3 - W1) / (W4 - W2)] \times [(1 + e) / (1 + e - f)] \quad (2)$$

where:
G = Specific gravity of soil
W1 = Weight of pycnometer
W2 = Weight of pycnometer filled with distilled water
W3 = Weight of pycnometer filled with soil and distilled water
W4 = Weight of pycnometer filled with distilled water and soil
e =Buoyancy correction factor for pycnometer
f = Moisture correction factor for soil

Figure 2: Standard proctor test

Figure 3: Specific Gravity Test

2.3 Experimental Methods

2.3.1 UCS (Unconfined Compressive Strength) Test (ASTM D3080)

The test is conducted from cylindrical soil sample trimmed and prepared to a specific diameter and height, typically 50mm in diameter and 100mm in height. For each mixing percentage the UCS test was performed for 3 times. So total number of samples needed was 27. The machine applies a vertical load to the sample at a constant rate, typically 1.27mm/min (0.05 in/min) until the sample failed. The test was performed for both untreated and treated sandy soil. For treated, the test was done only for mixing method.

2.3.2 Direct Shear Test (ASTM D3080)

The test was conducted by, a rectangular soil sample with a specific size, typically 60 mm x 60 mm x 25 mm (2.36 in x 2.36 in x 1 in) prepared in the laboratory. The sample was then placed in a shear box with a divided top and bottom section. . The sample was subjected to normal stress, which was applied by adding weights (10kg, 20kg, 30kg) to the top section of the shear box. The shear force and deformation data were recorded throughout the test. Then a graph was plotted shear stress vs normal stress. From the graph cohesion and friction value were found. The test was performed for both lining and mixing method. The ultimate bearing capacity of sandy soil was calculated using various equations such as Terzaghi's ,Meyerhof's and Vesic's bearing capacity equation using cohesion and angle of friction data from direct shear test.

2.3.3 Permeability Test (ASTM D2434)

The Permeability Test, also known as the constant head test, assesses the permeability of a sandy soil sample following ASTM D2434 standards. A cylindrical soil sample was placed in a permeameter, where water flows through at a constant rate, creating a hydraulic gradient. The test measured the flow rate to calculate the soil sample's permeability. During the test, water was added to the permeameter and allowed to flow through the soil sample at a constant rate. The rate of flow is measured by collecting the water that flows out of the drainage outlet over a specific time period. The rate of flow was then used to calculate the permeability of the soil sample. The test was conducted on untreated sandy soil and repeated for various mixing percentages and lining lengths to determine optimal conditions.

2.3.4 Bearing Capacity of Soil Determination

Bearing capacity was calculated by assumeing a footing size (2m x 2m) and the depth of the footing from the ground was 1m. Then using Terzaghi and Meyerhof’s bearing capacity equation was calculated the bearing capacity.

Terzaghi's bearing capacity equation is given as:

$$Qu = c\,Nc + q\,Nq + 0.5\,\gamma\,B\,N\gamma \quad (3)$$

Meyerhof's bearing capacity equation is an extension of Terzaghi's equation and is given as:

$$Qu = cNcScdc + qNqSqdq + 0.5\gamma B'N\gamma S\gamma d\gamma \quad (4)$$

where,

Qu = ultimate bearing capacity

c = cohesion of soil= founding from the direct shear test.

Nc, Nq, Nγ = dimensionless bearing capacity factors for cohesion, surcharge, and soil weight respectively.

q = surcharge or applied load= γ*B

γ = unit weight of soil = founding from the standard proctor test.

B = width of the foundation.

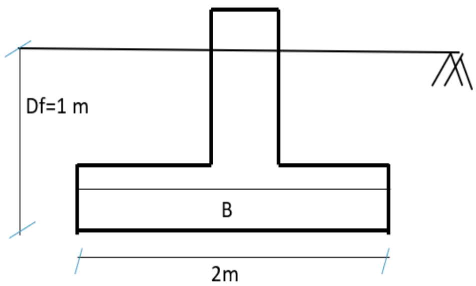

Figure 4: Model of Foundation.

3. RESULT AND DISCUSSIONS

3.1 Properties of Soil sample and Cement Dust

The Curing effect was observed through keeping the specimen 7,14,28 day and then tested accordingly. For engineering property testing, first index property of sandy soil (moisture content, specific gravity, grain size analysis) was performed .Specific gravity (Gs) of soil was found to be 2.66, a minimum dry unit weight (γd min) of 14.5 kg/m^3, a relative density (RD) of 88.71%, a maximum dry density (γd) of 16.78 kg/m^3, an optimum moisture content (OMC) of 12.58%.. The total oven-dried sample used for the analysis was 600 grams which consists of gravel 2.75%, sand 79.97% and silt and clay 17.28%. Here uniformity co-efficient (Cu) is greater than 4 and co-efficient of curvature (Cc) is in between more than 1 and less than 3. So,the sample resulted as well- graded sand.Cement kiln dust (CKD) primarily consists of calcium carbonate and silicon dioxide which are main raw materials in cement production. However, CKD often contains higher levels of alkalis, sulphate, and chloride compared to the raw materials fed into the cement kiln. The increase in maximum dry density occurs because the CKD-cementitious compounds formed create a denser packing of soil particles, resulting in a higher dry density. From figure 4 it can be seen that the decrease in optimum moisture content is due to the cementitious compounds reducing the soil's affinity for water, making it less susceptible to saturation and reducing the water content required to achieve maximum compaction.

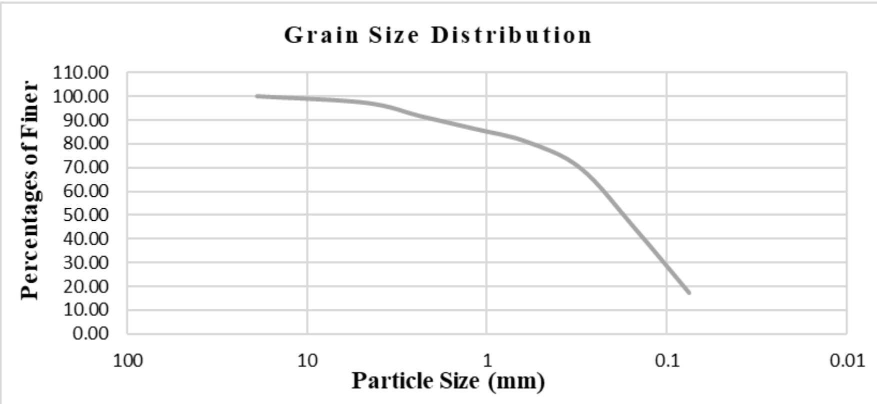

Figure 5: Grain Size Distribution Curve of Soil

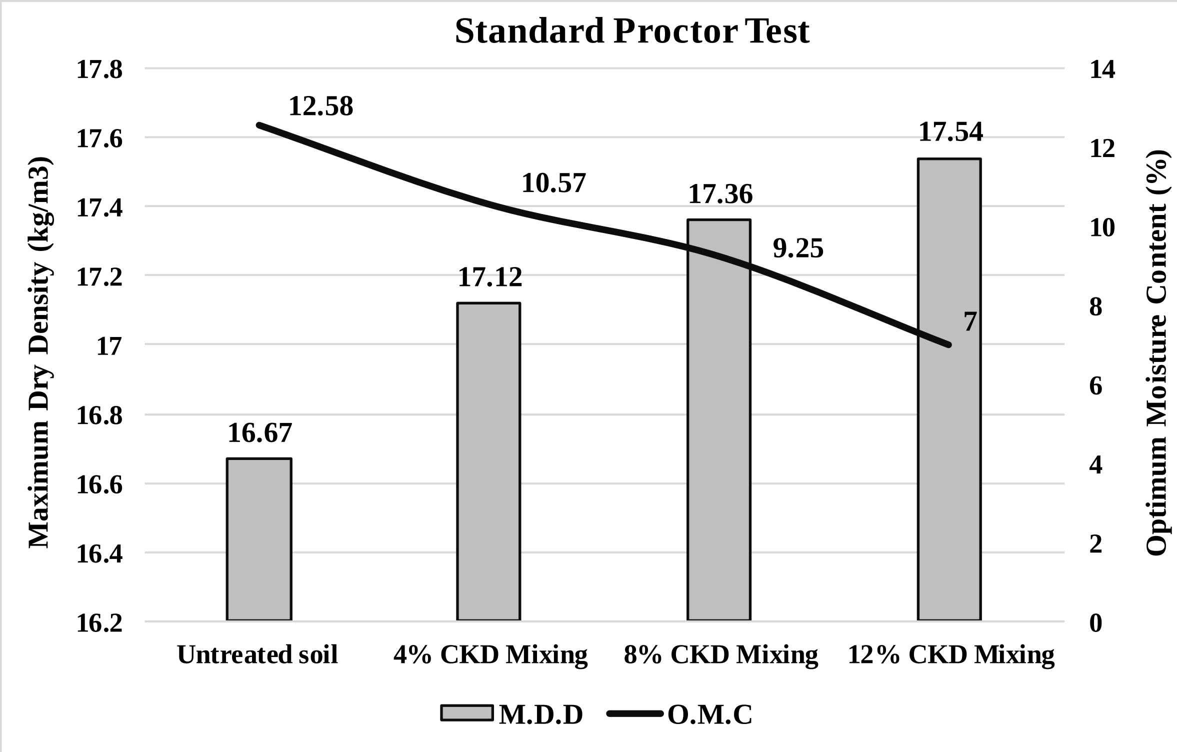

Figure 6: Standard Proctor Test Result

Table 1: Chemical composition of CKD (Amin et al., 2017)

Constituents	Percent by weight
SiO2	36.81
CaO	32.24
Fe_2O_3	7.82
Al_2O_3	5.89
SO_3	2.48
Na_2O	1.55
L.O.I	9.73

3.2 Influence of CKD on Shear Strength of Sandy Soil

The strength test assessed the impact of adding Cement Kiln Dust (CKD) at varying percentages (4%, 8%, and 12%) to soil, showing that the highest strength value (0.795 MPa) occurred after 28 days of curing at 12% CKD. For 8% and 4% the strength value was found 0.635 and 0.364 respectively as shown in figure 5. As CKD reacts with soil moisture, forming cementitious compounds, the mixture's strength increases over time. This increase is due to ongoing chemical reactions forming compounds that enhance the mixture's strength. Additionally, drying shrinkage contributes to increased density, further enhancing the soil-CKD mixture's strength. The Unconfined Compressive Strength (UCS) tests further confirmed that as curing days increased (0, 7, 14, and 28 days), the UCS values also increased for all percentages (4%, 8%, and 12%) of the CKD ingredient, showcasing the strengthening effect of curing duration on the soil-CKD mixture. The failure pattern observed in figure 9 is shearing failure (Khanlari et al., 2015).

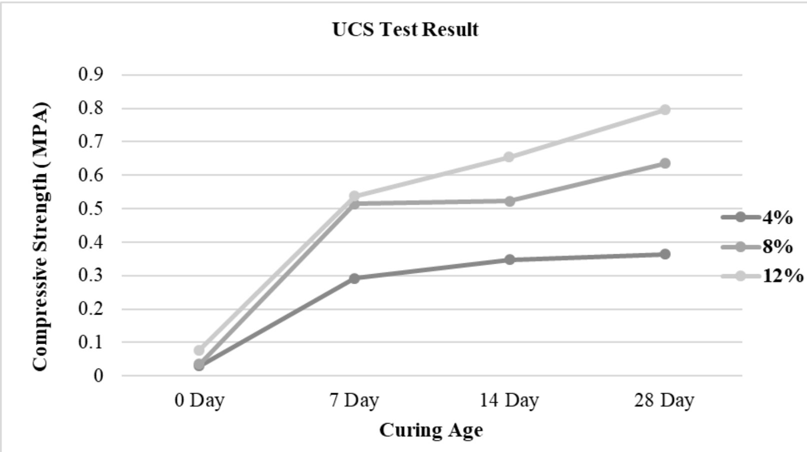

Figure 7: UCS Test Result

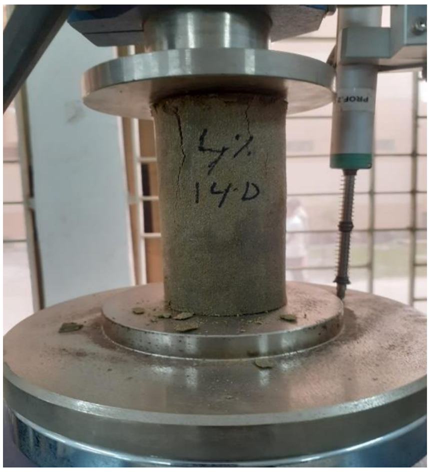

Figure 8: Testing the mould in UCS machine

Figure 9: Failure pattern after testing the mould

3.3 Influence of CKD on Cohesion and Friction Angle of Sandy Soil

The figure 10 and 11ad shows the friction angle value of the material increased as the percentage of the added ingredient increased. The friction angle values for 0%, 4%, 8%, and 12% ingredient percentages were 32.61, 33.42, 32.98, and 35.26, respectively. The highest increase in friction angle value was observed for the 12% ingredient percentage. The friction angle value of the material also increased as the lining depth increased as shown in table 3. The friction angle values for lining depths of 0 mm, 4 mm, 8 mm, and 12 mm were 32.61, 33.92, 40.99, and 44.92, respectively. The highest increase in friction angle value was observed between the lining depths of 8 mm and 12 mm. The cohesion values for lining depths of 0 mm, 4 mm, 8 mm, and 12 mm were 0, blank, 0.82, and 0.35, respectively. The cohesion values for 0%, 4%, 8%, and 12% ingredient percentages were 0, 0, 0, and 1.0063, respectively. The highest cohesion value was observed for the 12% ingredient percentage.

Table 2: Soil Type and Corresponding Cohesion Value

Soil Type	Cohesion Value
Untreated soil	0
4mm lining	2.53
8mm lining	0.8285
12mm lining	0.307
Untreated soil	0
4% mixing	0
8% mixing	0
12% mixing	1.63

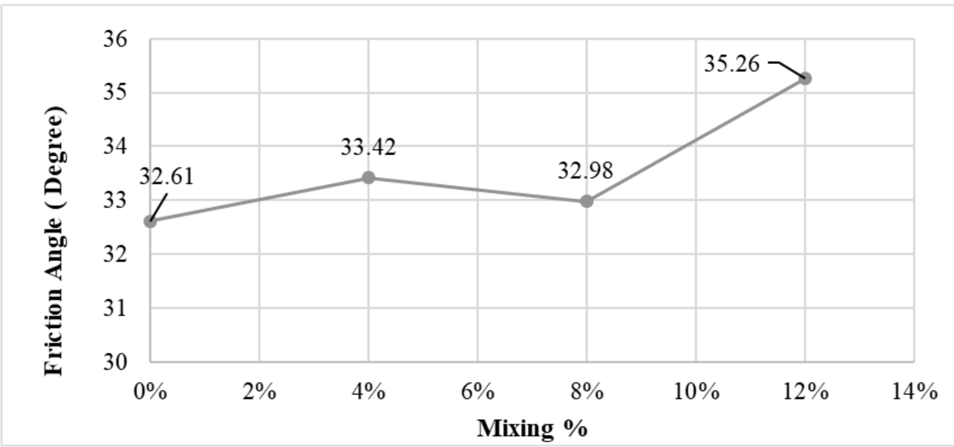

Figure 10: Friction angle for 4%,8%,12% mixing

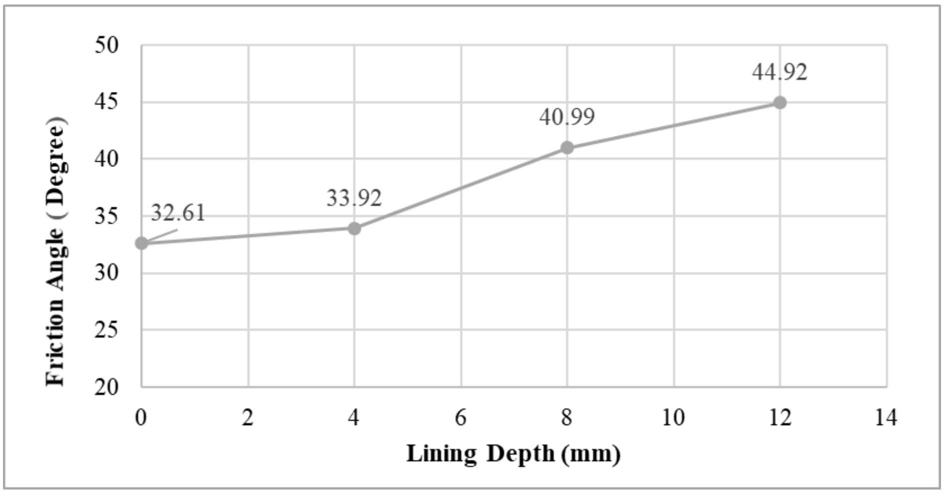

Figure 11: Friction angle for 4mm,8mm,12mm mixing

3.4 Influence of CKD on Permeability Test of Soil

The table 4 displays the values of hydraulic conductivity (K) for untreated soil and for soil with an optimum mixing percentage of 12% and an optimum lining depth of 12 mm. The values are given in units of cm/s. The results show that adding the optimum mixing percentage of 12% and the optimum lining depth of 12 mm resulted in a significant decrease in hydraulic conductivity compared to untreated soil. In summary, the results suggest that adding a certain percentage of a material and increasing the lining depth can significantly reduce the hydraulic conductivity of soil.

Table 3: Permeability value of treated and untreated sandy soil

Soil Type	**Coefficient of Permeability K (cm/s)**
Untreated soil	3.94*10^-4
optimum mixing percentage (12%)	2.20*10^-4
Optimum Lining Depth (12mm)	1.65*10^-4

3.5 Bearing Capacity of Treated and Untreated Sandy Soil

From direct shear test optimum mixing percentages and optimum lining depth found was 12% and 12mm accordingly. The bearing capacity was calculated by using Terzaghi and Meyerhof equation. Table 3 shows that the bearing capacity of untreated sandy soil is significantly lower than that of the soil with a mixing percentage of 12% and a lining depth of 12 mm, regardless of the equation used.

Table 4: Bearing Capacity of Treated and Untreated Sandy Soil

Equation	**Untreated sandy soil (KPa)**	**Optimum mixing percentage (12%) (KPa)**	**Optimum Lining Depth (12mm)**
Terzaghi	937.90	1465	6480
Meyerhof	1212.91	1989	10840

4 CONCLUSIONS

The research findings highlight the significant impact of Cement Kiln Dust (CKD) on enhancing the engineering properties of sandy soil. When CKD is added to soil, the CaO reacts with water to form calcium hydroxide Ca(OH)2, which is a strong base. This base reacts with the soil particles and forms cementitious compounds that bind the soil particles together, resulting in denser and more stable soil. The Unconfined Compressive Strength (UCS) showed an increase as curing days progressed, peaking at 0.795 after 28 days with a 12% CKD mixture. Additionally, the friction angle values and bearing capacity improved notably with increasing CKD percentages and lining depths. Optimal percentages (12%) and depths (12mm) amplified the friction angle by 1.08 times and the bearing capacity by 1.56 and 6.90 times, respectively, compared to untreated soil. Comparative analysis between the lining and mixing methods revealed that the lining method significantly outperformed the mixing method in enhancing shear strength, bearing capacity, and permeability. The coefficient of permeability (K) for untreated soil was 3.9410^-4 cm/s. The optimum mixing percentage of 12% CKD resulted in a lower coefficient of permeability of 2.2010^-4 cm/s, and the optimum lining depth of 12 mm resulted in an even lower coefficient of permeability of 1.65*10^-4 cm/s. The hydraulic conductivity (K) decreases by 1.79 and 2.38 times respectively for the optimum mixing percentage and optimum lining depth compared to untreated soil. Ultimately, the study concludes that CKD application presents a sustainable and cost-effective approach to fortifying sandy soil, offering an efficient solution for construction projects necessitating a stable foundation.

REFERENCES

Almuaythir, S., & Abbas, M. F. (2023). Expansive soil remediation using cement kiln dust as stabilizer. *Case Studies in Construction Materials*, *18*, e01983.

Amhadi, T. S., & Assaf, G. J. (2021). Improvement of pavement subgrade by adding cement and fly ash to natural desert sand. *Infrastructures*, *6*(11), 151.

Amin, S. K., El–Sherbiny, S., El–Magd, A. A., Belal, A., & Abadir, M. (2017). Fabrication of geopolymer bricks using ceramic dust waste. *Construction and building materials*, *157*, 610-620.

ASTM-D6913. (2007). Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis. In.

D698, A. (2007). Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft3 (600 kN-m/m3)). In.

D2216, A. (2007). Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass. In.

D4318, A. (2007). Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils. In.

Khanlari, G., Rafiei, B., & Abdilor, Y. (2015). Evaluation of strength anisotropy and failure modes of laminated sandstones. *Arabian Journal of Geosciences*, *8*, 3089-3102.

Lindh, P., & Lemenkova, P. (2022). Shear bond and compressive strength of clay stabilised with lime/cement jet grouting and deep mixing: A case of Norvik, Nynäshamn. *Nonlinear Engineering*, *11*(1), 693-710.

Saeed, S., Abdulkareem, A. H., & Abd, D. M. (2022). The Effect of CKD and RAP on the Mechanical Properties of Subgrade Soils. *Anbar Journal of Engineering Sciences*, *13*(1), 98-107.

Shilar, F. A., Ganachari, S. V., Patil, V. B., Almakayeel, N., & Khan, T. Y. (2023). Development and optimization of an eco-friendly geopolymer brick production process for sustainable masonry construction. *Case Studies in Construction Materials*, *18*, e02133.

Yuliet, R., Silvy, A., Hakam, A., Mera, M., & Syuhada, S. (2023). The influence of various parameters of physical and mechanical properties on susceptibility to liquefaction of sandy soils. IOP Conference Series: Earth and Environmental Science,