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Utilization of Kiln Dust in Clay Stabilization

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ABSTRACT Kiln dust is a waste material produced in considerable quantities during the manufacture of portland cement. This paper presents results of a testing program to explore the effect of kiln dust on plasticity, compaction and strength characteristics of clayey soils. Results indicated a considerable decrease in plasticity and marked increase in compressive strengths as a result of the addition of kiln dust. Also, kiln dust enhanced compressive strengths of cement-soil or lime-soil mixtures.

Introduction

Large amounts of kiln dust are being collected during the manufacturing process of portland cement. It is considered as a waste material and poses environmental and disposal problems in the cement industry. The cement company, that supplied the kiln dust for this study, produces 1000 metric tons of kiln dust per day, all of which are being dumped in the desert. Dust collectors are located at the top end of the kiln, which means that the dust material is subjected to temperatures that vary from 240 to 450°C (480 to 840°F) and the dust may be considered to be partly calcined.

Ramakrishnan[1] conducted a study on utilizing kiln dust in concrete. The following findings were reported in that study:

1. The mortar specimens made of masonry sand and kiln dust showed that the kiln dust does not possess any cementitious property. The blended cement-kiln dust mortar specimens showed slighlty lower values for compressive and split tensile strengths than those of plain cement mortar specimens.

2. The addition of kiln dust slightly retarded the setting time of cement and the fresh concrete properties of blended cement concrete mixes were almost the same as those of plain cement concrete mixes. Blended cements did not adversely affect most of the hardened concrete properties.

With the rapid depletion of good quality soils for use in engineering projects, such as highways, roads and fills, there is an urgent need to improve the engineering properties of poor soils. The objective of this paper is to explore the possibility of utilizing kiln dust in improving properties of low quality clays. Positive results should enhance the feasibility of using such soils as construction or foundation materials.

Material

The material used in this research was:

1. Kiln dust provided by the Arabian Cement Co., Jeddah, Saudi Arabia, was utilized in this investigation. It was collected by means of electrostatic precipitators. It is a very fine material with particle size between 6 to 100 microns, specific gravity of 2.75, and consisting mainly of a mixture of calcium carbonate (calcite), free calcium oxide, clay, sulphates and chlorides of sodium and potassium, clinker dust (burnt material) and iron oxide, as given in Table 1. The *x*-ray trace of the dust given in Fig. 1 shows that calcium carbonate (calcite) is the predominant constituent.

TABLE 1. Chemical analysis of kiln dust and pure kaolinite.

	Kiln dust[a]	Kaolinite[b]
Loss on Ignition	26%	13.32%
SiO_2	13.94%	46.29%
Al_2O_3	4.74%	35.67%
TiO_2	......	2.52%
Fe_2O_3	2.36%	0.72%
CaO	45.9%	0.83%
MgO	.2.15%	0.15%
SO_3	2.14%	.....
NA_2O	1.03%	0.38%
K_2O	1.71%	0.12%
Total	99.97%	100%
Free CaO	5.33	......
SO_4^-	......	0.38%
Cl^-	2.48%	0.14%
Finess (4900%)	6.0%	......
Blaine cm^2/gm	3303	......

a : Provided by Arabian Cement Co.
b : Provided by Saudi Ceramic Co.

2. Kaolinite, both processed and pure, obtained from the Saudi Ceramic Company (PIT-B). Its specific gravity, liquid limit, and plasticity index are found to be 2.62, 40 and 9, respectively. The chemical composition is given in Table 1.
3. Tye I Portland cement, produced by Rolaco plant in Greece.
4. Hydrated lime, $Ca(OH)_2$ manufactured by Riyadh Cement Company, Saudi Arabia.

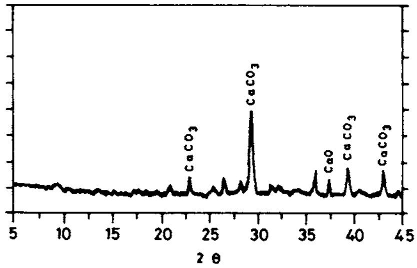

FIG. 1. *X*-ray trace of kiln dust.

5. Bentonite. Commercially available bentonite was used for Atterberg limits tests.
6. Distilled water was used in mixing the materials.

Testing Program

The first phase of the testing program deals with studying the effect of kiln dust on Atterberg limits. Kiln dust was first added in different amounts to kaolinite to investigate changes in plasticity index. But, since the plasticity index of the pure kaolinite was low, 9, little changes in the plasticity indices of the mixtures were recorded. These results prompted the author to use bentonite. The bentonite material was chosen due to its high plastic nature so that any changes due to the treatment could be easily detected. For this purpose, kiln dust percentages of 0.5, 1.0, 4.0 and 8.0 by weight were added to the bentonite. Distilled water was then added to the dry mixtures and statically compacted in 51mm diameter and 102mm height steel molds. The extruded samples were waxed and kept at room temperature (21°C) for seven days[2]. The specimens were then dried in a vacuum desiccator pulverized and the Atterberg limits tests were performed according to ASTM D-423 (Liquid limit) and ASTM D424 (Plastic limit).

The second phase of the work deals with the effect of kiln dust on compaction properties. Standard Proctor tests (ASTM D-698) were conducted on pure kaolinite and kaolinite-kiln dust mixtures (6, 12 and 30% of kiln dust by dry weight of soil). These amounts of dust were selected to cover a reasonable range of treatment.

The final phase of the program explores the effect of addition of kiln dust on compressive strength of kaolinite clay. This phase consisted of two parts. In the first part kiln dust percentages of 0, 1, 4, 8, 12, and 16 by weight of soil were added to the pure kaolinite. Also, specimens made of pure kiln dust were prepared at the material's maximum dry density and optimum moisture content. The required amounts of distilled water were added to the dry mixtures and the samples were statically compacted in steel molds (51mm dia and 102mm height). The unit weight and water content of the soil-kiln dust samples were the same for all and corresponded to the maximum unit weight and optimum water content of the untreated kaolinite according to standard Proctor. The compacted specimens were extruded, waxed and kept at room temperature of 21°C for curing periods of 2, 7 and 28 days.

Specimens of the 12% kiln dust treated kaolinite were taken for pH measurements according to a procedure given by Head[3] using Philips PW 9418 electric pH meter. The readings were taken 30 minutes after mixing and after 2, 7, 14 and 28 days of room temperature curing.

In the second part of the third phase, the goal was to establish if kiln dust could increase or accelerate strength development in cement or lime-kaolinite mixtures. A similar procedure as above was followed to prepare specimens of kaolinite treated with 3% and 6% portland cement by weight of soil. Pre-selected amounts of kiln dust (0.5, 1, 2, 4 and 6%) were added to the cement-treated specimens. Another group of specimens treated with 3 and 6 percent of lime with different amounts of kiln dust, as with cement, were prepared. Specimens of this phase were cured for 7 and 28 days at room temperature. It should be mentioned that for every percentage of cement or lime-kiln dust and for every curing period a set of 3 to 5 specimens were prepared. All strength tests were conducted using the unconfined compression apparatus, a motorized ELE 25-20 tritest 10, at a rate of 1.5mm/min.

Results and Discussion

It was observed that addition of kiln dust to bentonite affected its plasticity. The liquid limit values decreased considerably with increasing amounts of kiln dust, while plastic limit values decreased but at a slower rate. The net effect was a considerable reduction in the plasticity index of bentonite from 513% to 326% as a result of adding 8% kiln dust as shown in Fig. 2. This conforms with the results reported by Datta *et*

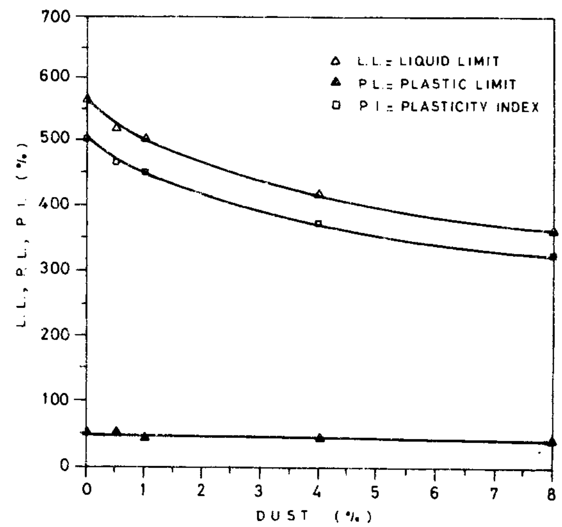

FIG. 2. Effect of kiln dust treatment on liquid limit, plastic limit and plasticity index of bentonite.

al.[4] where removal of carbonates from fine grained soils increased their liquid limits and plastic limits resulting in considerable increase in plasticity indices. It may be recalled that in lime treatment the decrease in plasticity index was attributed to large increase in plastic limit[5,6].

This reduction in plasticity indicates that kiln dust could be used to increase the workability of highly plastic soils. Improved workability expedites subsequent manipulation and placement of the treated soil.

Standard Proctor tests were performed on pure kaolinite and kaolinite treated with 6, 12 and 30% kiln dust. As shown in Fig. 3 for the levels of treatment employed, the maximum unit weight is improved while the optimum water content is slightly reduced. This indicates that addition of kiln dust results in somewhat higher compaction values of the treated soil at the peak of the curve. The high specific gravity of the dust relative to the kaolinite may explain this observation.

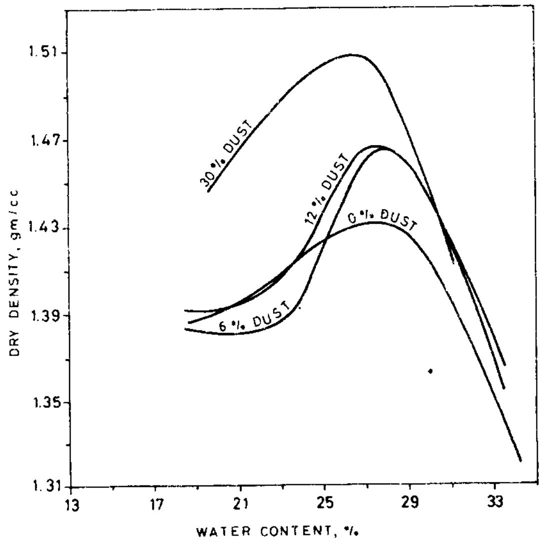

FIG. 3. Standard Proctor compaction curves of kaolinite and kaolinite treated with kiln dust.

As mentioned earlier, compressive strength tests were conducted on specimens treated with 1, 4, 8, 12 and 16 percent of kiln dust in addition to specimens consisting of pure kiln dust. The results of these tests revealed that kiln dust improved the strength of kaolinite. It is evident from Fig. 4 that the compressive strength of treated specimens increases with increasing amount of kiln dust, for all curing periods. The 28-day strength of the 16% treated specimens (1115 kPa) is more than five times that of the untreated specimens (210 kPa) which proves that kiln dust has a cementation effect when added to kaolinite clay. The same data in Fig. 4 are shown in Fig. 5, where it can be seen that a substantial part (more than 80% of the 28-day strength) of strength gain is developed in the first seven days of curing, after that the strength gain is slower. As for pure kiln dust, the compressive strengths are given in Table 2. The values are considerably high.

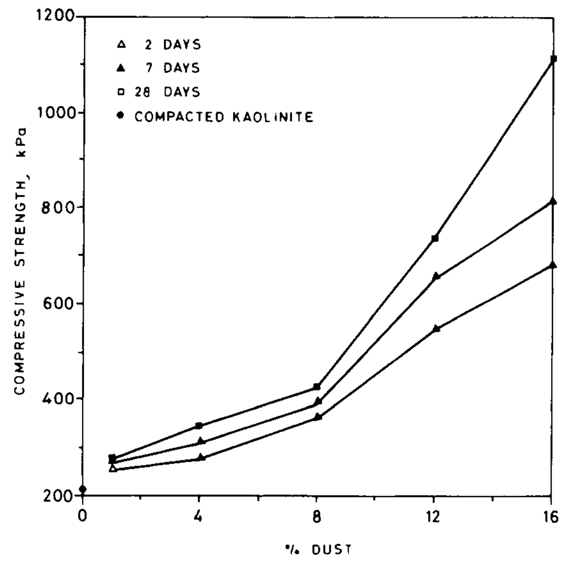

FIG. 4. Compressive strength of kaolinite treated with kiln dust and cured for 2, 7 and 28 days.

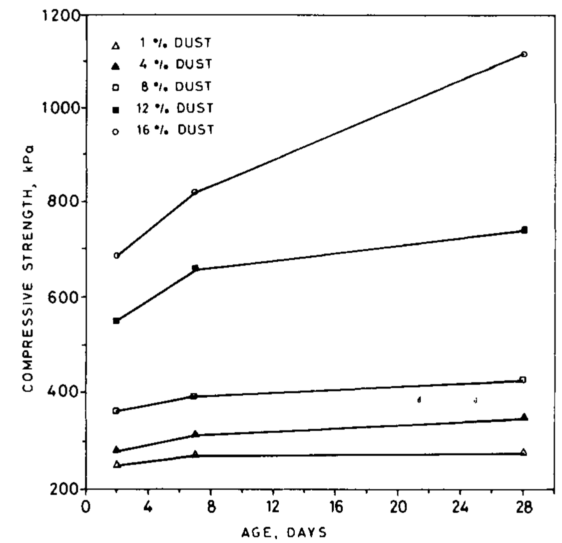

FIG. 5. Compressive strength of kaolinite treated with dust against curing time.

TABLE 2. Compressive strengths of cured kiln dust specimens.

Curing period in days	2	7	28
Compressive strength, kPa	2.56×10^3	5.63×10^3	8.80×10^3

Measurements of pH values of kaolinite and 12% kiln dust mixtures (30 gm of mixture in 75 gm distilled water) taken 30 minutes after mixing, and after 2, 7, 14 and 28 days of room temperature curing showed a steady decrease from 12.5 to 11.1. This high alkalinity provides the environment for silica and alumina dissociation from the clay[6,7], which combines with the available free calcium to form a cementing material. This effect along with the weak cementing action of the calcium carbonate may account for the increase in strength of the treated kaolinite. The cementation effect, however, is not as pronounced as in cement or lime treatment since the amount of free calcium oxide in kiln dust is small. No calcium hydroxide was detected in x-ray traces of cured specimens of both, pure dust and dust-kaolinite, which could be due to its quick consumption in the process.

In the last stage of the investigation, amounts of kiln dust (0.5, 1, 2, 4, and 6%) were added to two groups of mixtures. The first group consisted of two series, A and B. Specimens of series A were prepared of kaolinite and 3% cement, while of those series B consisted of kaolinite and 6% cement. The second group were also divided into series C and D. Specimens of series C and D were prepared of kaolinite and 3% lime and kaolinite and 6% lime, respectively.

The results shown in Figs. 6 to 9 indicate that at low levels of dust up to 2%, the compressive strengths of kiln dust-treated specimens of both groups when compared to specimens prepared of kaolinite and cement or lime only, fluctuate in a range of ±12% to −10%. Beyond 2% the compressive strengths increase to considerable extents, and the dust is more effective with cement than lime. Most of the data indicate little or no gain of strength beyond 4% of kiln dust. Hence, this value, of about 4% of kiln dust, might produce best results with cement and lime. It may be concluded that, for less than 2% of kiln dust, there is no or very little effect in accelerating or increasing the compressive strength of the cement or lime stabilized mixtures, but for higher doses of dust considerable gains in strengths are obtained.

Conclusion

The following conclusions are drawn from this study:

1. Addition of kiln dust to bentonite, a highly plastic soil, reduced its plasticity and hence its workability was improved.
2. Kiln dust resulted in improved maximum dry densities and reduced optimum water contents of kaolinite clay.

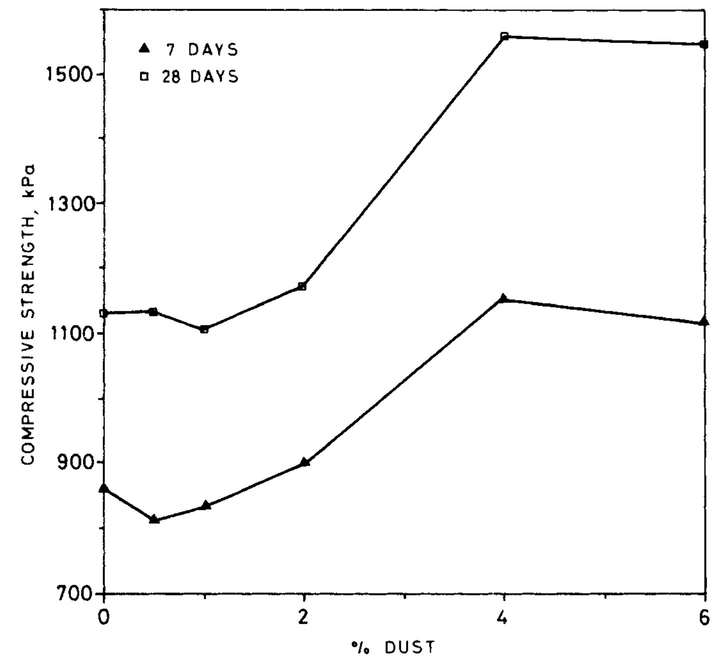

FIG. 6. Compressive strength of kaolinite mixed with 3% cement and kiln dust, Series A.

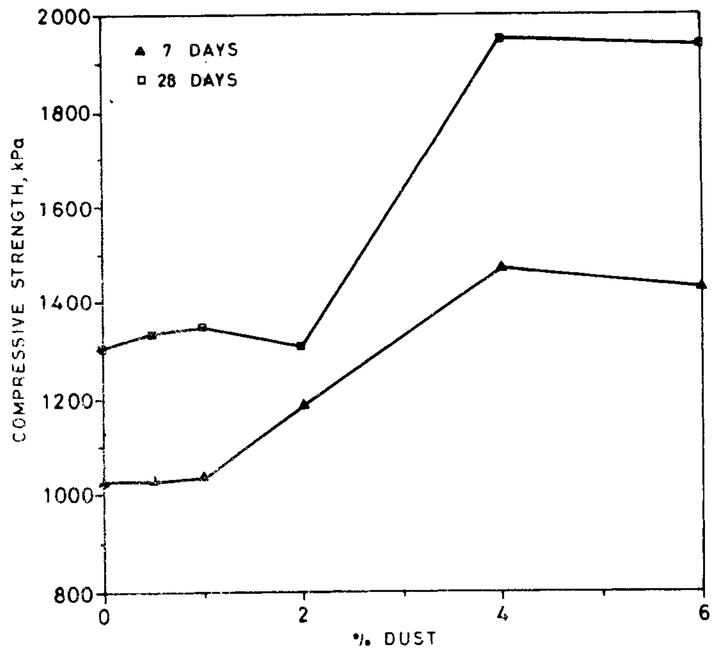

FIG. 7. Compressive strength of kaolinite mixed with 6% cement and kiln dust, Series B.

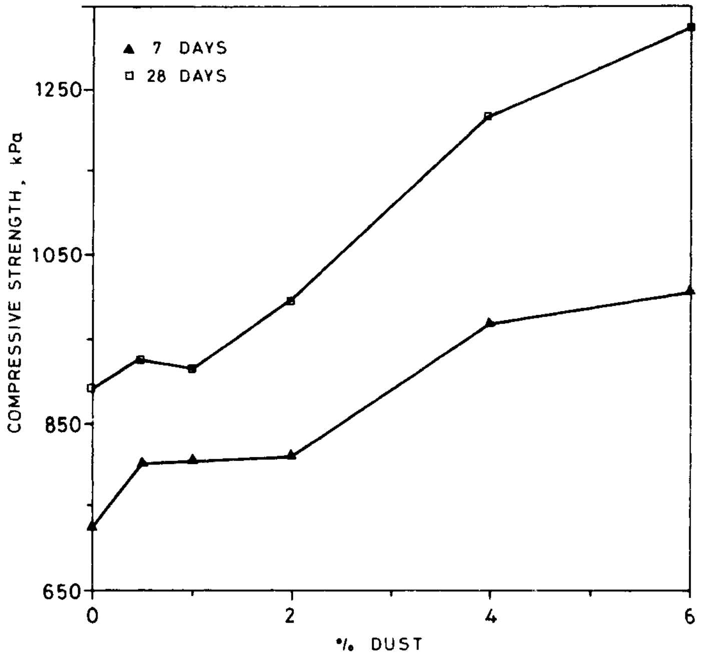

FIG. 8. Compressive strength of kaolinite mixed with 3% lime and kiln dust, Series C.

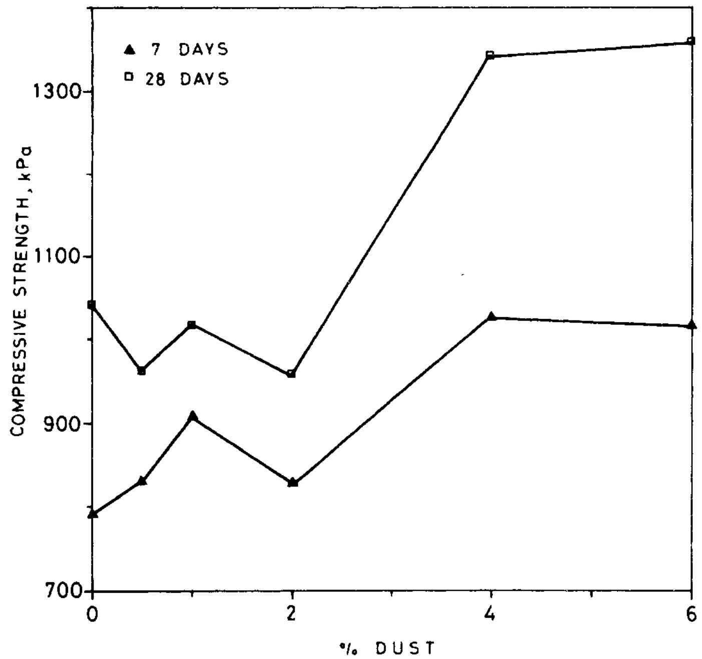

FIG. 9. Compressive strength of kaolinite mixed with 6% lime and kiln dust, Series D.

3. Compressive strength of kaolinite clay was substantially improved due to addition of kiln dust. The strength increased as the amount of dust was increased. Pure kiln dust gave significantly higher compressive strengths than those of soil-kiln dust mixtures.

4. There was no or little effect as a result of addition of low amounts of kiln dust to cement or lime stabilized kaolinite, but higher amounts of kiln dust resulted in higher strengths.

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استخـــــدام الغبـــــار التنـــوري في تثبيت الطَّفـــــل

زكي عبد الله بغدادي
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تنتج مادة غبـار التنـور ، وهى من النفـايات ، بكميات كبـيرة أثنـاء تصنيع الأسمنت البورتلاندي . تقدم هذه الورقة نتائج تجارب لاستكشاف تأثير غبار التنور على اللدونة ، الدمك وخواص مقاومة الانضغاط لترب طينية .

تدل نتائج الاختبارات على نقص كبير في اللدونة وزيادة ملحوظة في مقاومة الانضغاط نتيجة لإضافة غبار التنور .

كذلك يعزز غبار التنور المقاومات الانضغاطية لمخلوطات الأسمنت أو الجير مع التربة .