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ORIGINAL ARTICLE

Stabilization of indigenous Saudi Arabian soils using fuel oil flyash

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Abstract Fuel oil flyash (FFA) produced in power and water desalination plants firing crude oils in the Kingdom of Saudi Arabia is being disposed in landfills, which increases the burden on the environment, therefore, FFA utilization must be encouraged. In the current research, the effect of adding FFA on the engineering properties of two indigenous soils, namely sand and marl, was investigated. FFA was added at concentrations of 5%, 10% and 15% to both soils with and without the addition of Portland cement. Mixtures of the stabilized soils were thoroughly evaluated using compaction, California Bearing Ratio (CBR), unconfined compressive strength (USC) and durability tests. Results of these tests indicated that stabilized sand mixtures could not attain the ACI strength requirements. However, marl was found to satisfy the ACI strength requirement when only 5% of FFA was added together with 5% of cement. When the FFA was increased to 10% and 15%, the mixture's strength was found to decrease to values below the ACI requirements. Results of the Toxicity Characteristics Leaching Procedure (TCLP), which was performed on samples that passed the ACI requirements, indicated that FFA must be cautiously used in soil stabilization.

1. Introduction

Rapid population growth and expansion of the infrastructure and industrial facilities in Saudi Arabia are increasing the demand on electric and water desalination utilities. However, it is known that the bigger power plants in Saudi Arabia are fueled by oil, which is not widely used in other parts of the world, partly because of fluctuation in oil prices (Dincer and Al-Rashed, 2002). Since most of the studies have addressed the usage of flyash generated from burning coals, specific research programs should be initiated to identify possible uses of fuel oil flyash (FFA), particularly in civil engineering applications.

FFA is totally different in many of its characteristics from the coal flyash, therefore, its impact on the environment and its

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uses and ways of disposal are also different. The quantity and characteristics of FFA depend primarily on the fuel characteristics and the burning process (NCASI, 2003). In addition to carbon, major elements in fuel oil flyash include magnesium, vanadium, nickel and sulfur. Bacci et al. (1983) reported substantial enrichment of both Ni and V in the submicron particle size fraction of samples collected at a large oil-fired power plant. The high carbon content and presence of toxic heavy metals (vanadium and nickel) suggested that this FFA be considered as a hazardous respirable dust that demands careful handling and safe disposal (Al-Malack et al., 2010).

The use of coal flyash in stabilization of different types of soils is very well documented in the literature. Recently, Gaciarz (2012) investigated the efficacy of class C flyash to stabilize silty soils. It has been observed that the addition of flyash did not alter significantly the plasticity characteristics of the soil. Standard Proctor and Harvard Miniature Compaction Tests revealed that maximum dry density increases with increasing flyash content and optimum moisture contents decreased with increasing in ash contents. Results also showed that the unconfined compressive strength (q_u) and consequently the un-drained shear strength (SuO) increased moderately with increasing flyash content for all samples. However, the stress–strain modulus decreased with increasing flyash content. From the analysis of results of this study, it appears that flyash is not an effective stabilizer to stabilize silty soils. This may be due to the fact that both silt particles and flyash particles have approximately the same size, which may result in poor gradation that is deficient in particle interlocking in silt-flyash mixtures. Ansary et al. (2006) investigated the use of flyash to study the strength properties of stabilized soils. In their study, UCS (q_u), compaction properties and flexural properties were studied. The admixture was flyash with lime; the amount of lime was fixed at 3%, while amounts of flyash were 0%, 6%, 12% and 18%. Results showed that by increasing the amount of flyash the strength properties of lime–flyash stabilized soils improved. For samples of both soils, when compared with the untreated samples, the UCS of flyash and lime treated was found to increase significantly, depending on the additive content and curing time. Compared with the untreated sample, the flexural strength and flexural modulus of flyash treated samples were reported to increase by about 4.6 and 4.7 times and 3 and 4.3 times, respectively for both soils. Recently, and as example, low-calcium flyash was used to stabilize granitic soil (Cristelo et al., 2012a,b), sandy soil (Yang and Tang, 2012; Lopes et al., 2012), lime (Rao and Asha, 2012), soft soil (Cristelo et al., 2012a,b), silty clay (Horpibulsuk et al., 2012), granular soil (Hossain and Mol, 2011), expansive soil (Rao and Subbarao, 2012), kaolin (Firat and Coemert, 2011), tropical beach soil (Kolay et al., 2011), organic soil (Tastan et al., 2011; Filipiak, 2011), biosolid (Laor et al., 2011), soil (Pinilla et al., 2011), problem soil (Brooks et al., 2011), and clayey soil (Mishra and Rath, 2011). Moreover, rice husk flyash was reported to be used to stabilize clayey soil (Hossain, 2011) and expansive soil (Seco et al., 2011 and Brooks, 2009). CFBC flyash was used to stabilize lake sludge (Hua et al., 2012). Furthermore, volcanic ash was used to stabilize clayey soil (Kalkan, 2011). More work on the use of flyash can be cited in Tastan et al. (2011), Bhuvaneshwari et al. (2005), Kumpiene et al. (2008), Dermatas and Meng (2003), Kumpiene et al. (2007). With the exception of the work published by Koroljova and Pototski (2012), the literature lacks published work in the field of utilization of FFA in the stabilization of soils.

Based on the above, the main objective of the current research is to investigate the potentiality of utilizing fuel oil flyash for the stabilization of two indigenous soils of the Kingdom of Saudi Arabia, namely, sand and marl. The assessment will be entirely based on determining the engineering properties such as strength, durability and CBR. TCLP will be performed on samples passing requirements of engineering properties.

2. Materials and methods

2.1. *Sand, marl and fuel flyash (FFA)*

The sand used in this study was collected from the Dhahran dunes in the Eastern Province of Saudi Arabia, while marl was collected from an area along Dhahran–Abqaiq highway. On the other hand, the FFA was obtained from Shuaiba Water Desalination Plant, Western Region of Saudi Arabia. The elemental composition of FFA used in this study is shown in Table 1 (Abdullah, 2009).

2.2. *Experimental program*

2.2.1. *Compaction tests*

Compaction tests were performed according to the modified Proctor test (ASTM D 1557) to determine the maximum dry unit weights ($\gamma_{d(max)}$) and the optimum moisture contents (w_{opt}). Dosages of FFA used were 5%, 10% and 15%.

2.2.2. *California Bearing Ratio (CBR) tests*

Un-soaked CBR tests were conducted in compliance with the ASTM D 1883. After sample preparation, samples were sealed by plastic sheets and left to cure in laboratory conditions (23 ± 3 °C) for 7 days before testing.

2.2.3. *Unconfined Compressive Strength (UCS) tests*

After compaction, the specimens were stored in the laboratory (23 ± 3 °C) and kept to cure for different curing periods (3, 7, 14 and 28 days) before testing. All specimens were subjected to the UCS test in accordance with the ASTM D 2166.

Table 1 Elemental composition of FFA (Abdullah, 2009).

Element	FFA	
	Weight (%)	Atomic (%)
Oxygen (O)	29.68	31.66
Carbon (C)	32.52	46.20
Magnesium (Mg)	19.20	13.48
Aluminum (Al)	0.44	0.28
Silicon (Si)	0.33	0.20
Sulfur (S)	11.42	6.08
Calcium (Ca)	0.31	0.13
Iron (Fe)	0.50	0.15
Vanadium (V)	4.11	1.38
Chromium (Cr)	0.08	0.03
Manganese (Mn)	0.41	0.13
Nickel (Ni)	1.01	0.29

2.2.4. Durability tests

The durability tests were conducted on samples of FFA–marl mixtures in compliance with the ASTM D 559 and the modified slake durability apparatus. It is worth mentioning that all FFA–sand mixtures were excluded from the durability tests because they produced in low strength and failed to satisfy the 7-day strength requirements (ACI, 1990).

2.2.5. Toxicity characteristic leaching procedure (TCLP)

TCLP measures the concentrations of possibly leaching toxic metals into the environment. These metals are: arsenic, barium, cadmium, chromium, lead, mercury, selenium and silver. Nickel and vanadium were also monitored due to their expected presence in the FFA. The TCLP method is approved and registered under method number EPA 1311. It is worth mentioning that the TCLP was conducted using stabilized soil samples that passed the mechanical properties.

3. Results and discussion

3.1. Characterization of sand and marl soil

Characterization tests that were conducted according to the ASTM and AASHTO standards included specific gravity of the solid grains, grain size distribution and plasticity tests.

3.1.1. Specific gravity of both soils

Two representative samples of each soil (sand and marl) were subjected to the specific gravity test. Specific gravity of sand was found to be between 2.663 and 2.661 with an average value of 2.662, while for marl it was between 2.7 and 2.68 with an average value of 2.69. The obtained values are within the ranges reported by Al-Gunaiyan (1998) and Ahmed (1995).

3.1.2. Plasticity of marl

Liquid and plastic limits were conducted according to the ASTM D 423 and ASTM D 424, respectively. For marl, it was not possible to get the number of blows for the liquid limit test, so it was reported as nil. The soil also could not be rolled to a thread of 1/8 in (3.18 mm), therefore, it was classified as non-plastic marl.

3.1.3. Grain–size distribution of both soils

The grain–size distribution curves for sand and marl are shown in Fig. 1. The figure clearly shows that the percent passing Sieve No. 200 is 10.6 and 29 when the dry and wet marl samples were sieved, respectively. The figure indicates that the grain–size curve obtained when using the wet sieving method was consistently above the one when the dry sieving method was used. This is attributed to the fact that water tends to dissolve the bonds and salts between particles of the soil, thus, the percent passing of the soil is higher than that for dry sieving. For sand, the figure shows that there is no significant variation between grain size distributions for both the dry and washed sieved samples. This can be attributed to the fact that sand is made up of quartz which is not affected so much by washing. The marl was classified as SM and A-3 according to the USCS and AASHTO, respectively, while the sand was classified as SP and A-3 according to the same classification systems.

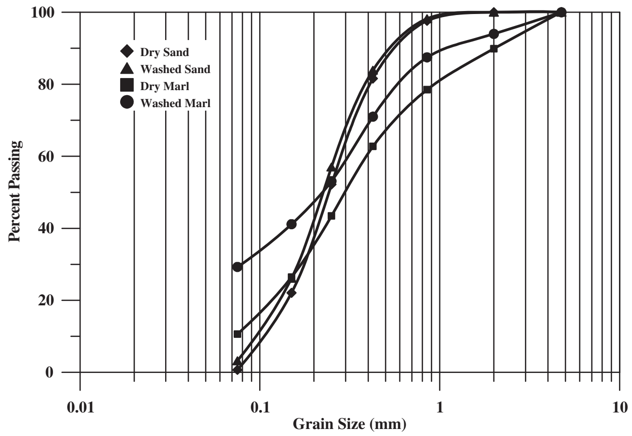

Figure 1 Grain-size distribution of marl and sand soils.

3.2. Chemical stabilization of both soils

3.2.1. Compaction of marl

Results on dry density versus water content for marl, marl mixed with cement, marl with cement and FFA and marl mixed with FFA are shown in Figs. 2 and 3. For untreated non-plastic marl soil (no additives), Fig. 2 shows that the maximum dry density [$\gamma_{d(max)}$] was 18.5 kN/m^3 at an optimum moisture content of 13%. When 5% of Portland cement was added to the marl, the maximum dry density of the marl-cement mixture was found to decrease to 17.5 kN/m^3 at an optimum moisture content of 14.2%. When the marl–cement mixture was further treated using 5%, 10% and 15% of FFA, the maximum dry density was found to be 17.75, 16.74 and 16.67 kN/m^3, respectively, with corresponding optimum moisture contents of 16.5%, 16.6% and 19.1%. When marl was treated using FFA only (no cement was added), Fig. 3 shows that for FFA values of 5%, 10% and 15%, the maximum attained dry density values were 17.95, 17.60 and 16.64 kN/m^3, respectively, with corresponding optimum water contents of 15.4%, 14.6% and 16.4%. Results of the two figures clearly indicate that the maximum dry density values were slightly decreasing with increasing the FFA content. On the other hand, water content was found to increase with increasing the FFA content. This can be attributed to the fact that

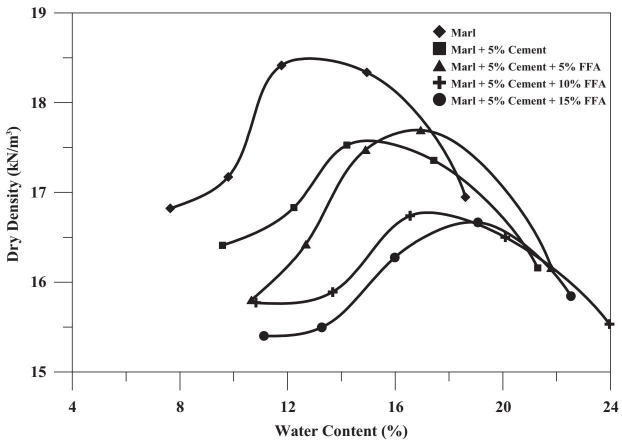

Figure 2 Effect of FFA addition with 5% of cement on moisture–density relationship for non-plastic marl.

FFA is a very fine material and, therefore, has a high surface area which could result in absorbing more volumes of water. Moreover, FFA has a lower specific gravity (1.3) than marl (2.7) which results in reducing the maximum dry unit weight when added at higher percentages.

3.2.2. *Compaction of sand*

Maximum dry density values of sand mixed with cement, sand mixed with cement and FFA and sand mixed with FFA are shown in Figs. 4 and 5. When sand was mixed with 5% of Portland cement, a maximum dry density of 17.87 kN/m^3 was obtained at an optimum of water content of 11% (Fig. 4). The figure shows that when 5%, 10% and 15% of FFA was added to the sand-cement mixture, the maximum dry density values obtained were 17.63, 17.30 and 16.96 kN/m^3, respectively, at corresponding optimum water contents of 12%, 13.7% and 14.3%. When FFA was mixed with sand (without cement), Fig. 5 shows that the maximum dry density values obtained were 16.99, 17.42 and 17.78 for FFA contents of 5%, 10% and 15%, respectively, at corresponding optimum water contents of 12.7%, 12.2% and 12.1%. The two figures clearly indicate that the addition of FFA resulted in reducing the maximum dry density of the sand–cement mixture, however, increasing the FFA content added to sand (no cement) was found to increase the maximum dry density. This can be attributed to the reasons given above. However, increasing the FFA content in sand (without cement) was found to increase the maximum dry unit weight because the FFA acted as a filler.

3.2.3. *CBR of marl*

Results of CBR versus water content for marl, marl with cement and marl with cement and FFA are shown in Fig. 6. For untreated marl, a maximum CBR of 47% was obtained at a moisture content of 11.8%. Results clearly indicate that the moisture content for maximum CBR (11.8%) is less than that for maximum dry density (13%). This is in agreement with the findings reported by Al-Amoudi et al. (1992) and Aiban et al. (1995). When 5% of Portland cement was added to the marl, the maximum CBR was found to increase to 119 at an optimum water content of 14.2%. When the marl–cement mixture was treated using 5%, 10% and 15% of FFA, the maximum CBR values were 164.5, 158 and 154%, respectively, at corresponding optimum water contents of 14.9%, 16.6% and 18%. When marl was mixed with FFA only (no added cement), results of CBR values versus water content are presented in Fig. 7. The figure clearly shows that for FFA contents of 5%, 10% and 15%, the maximum CBR values were 116%, 105% and 91%, respectively, for water contents of 13.4%, 13% and 16.4%.

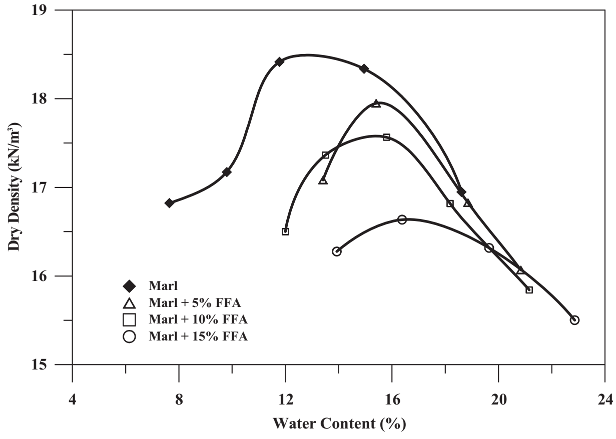

Figure 3 Effect of FFA addition on moisture–density relationship for non-plastic marl.

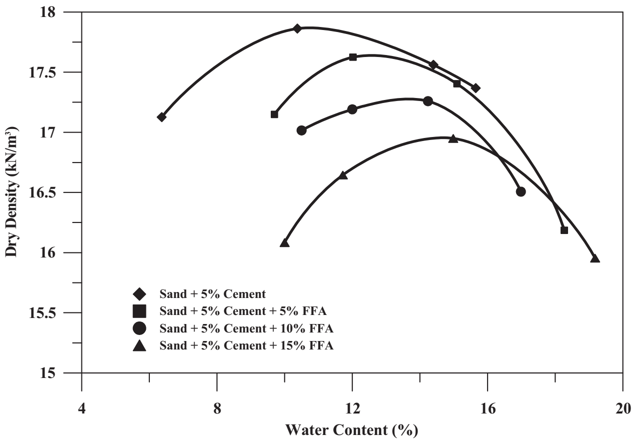

Figure 4 Effect of FFA addition with 5% of cement on moisture–density relationship for sand.

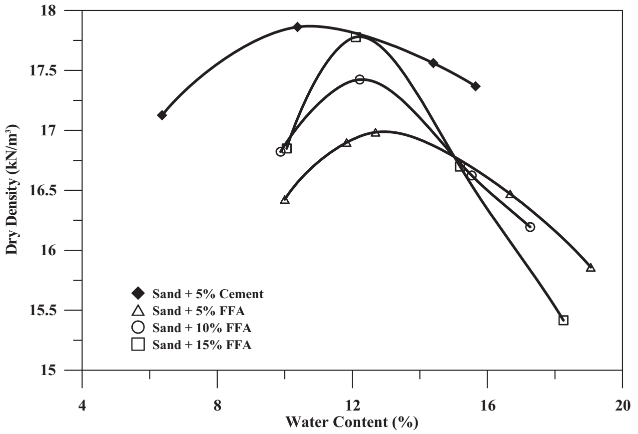

Figure 5 Effect of FFA addition on moisture–density relationship for sand.

Results of the two figures clearly indicate that the maximum CBR values were decreasing with increasing the FFA content. On the other hand, water contents were found to increase with increasing the FFA content. The reduction in the CBR value can be attributed to the fact that FFA is not considered as a cementitious material, therefore, further increase in the FFA content will result in disrupting the granular structure of the non-plastic marl and cause the particles to float in the FFA. Consequently, the dry density and the strength of the treated marl are reduced. On the other hand, the increase in water content can be attributed to the fact that FFA is a light material and has a large surface area which results in absorbing more volumes of water needed to make the mix. It can be seen that the reduction in the CBR value was marginal and that the CBR value was still higher than that of the untreated soil.

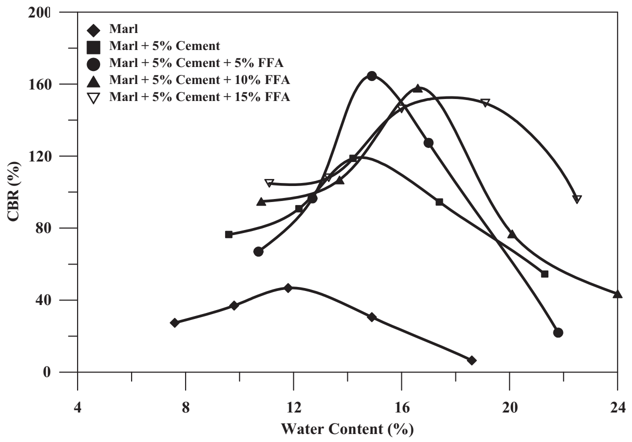

Figure 6 Effects of moisture and 5% cement with FFA contents on CBR of non-plastic marl.

3.2.4. *CBR of sand*

Fig. 8 shows the CBR values versus water content of the sand–cement mixture with and without the addition of FFA. The figure shows that the maximum CBR value for the sand–cement mixture (no FFA) was found to be 273% at an optimum moisture content of 8.8%. When 5% of FFA was added to the sand–cement mixture, the maximum CBR value was found to sharply decrease to 120% at the same optimum moisture content. The figure clearly shows that addition of FFA to the sand-cement mixture resulted in reducing the positive effect of cement substantially. When FFA was further increased to 10% and 15%, the maximum CBR values were noticed to start to increase and reached 133% and 151%, respectively, at corresponding optimum water contents of 11.8% and 11.7%. Although there was an increase in the maximum CBR value with the increase in the FFA content, the values were still much lower than that when FFA was not added to the sand–cement (273%).

When cement was not used, Fig. 9 shows that the addition of 5% of FFA to sand resulted in producing a maximum CBR value of 36% at an optimum water content of 11.8%. When FFA content was further increased to 10% and 15%, the maximum CBR values were found to increase to 40% and 68%, respectively, at corresponding optimum water contents of 12% and 12.1%. Results clearly indicate that the addition of FFA to the sand–cement mixture had a detrimental effect on the engineering properties of the mixture. Results also indicate that the increase in the maximum CBR values when FFA was added to the sand was negligible. Consequently, it can be concluded that the FFA addition does not work with sand soil and, therefore, it is not beneficial in sand stabilization.

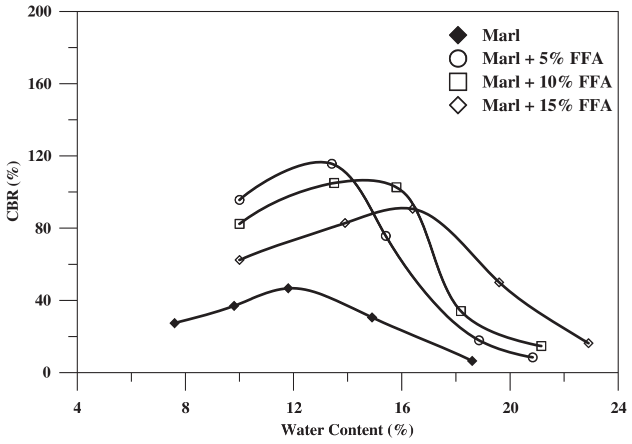

Figure 7 Effects of moisture and FFA contents on CBR of non-plastic marl.

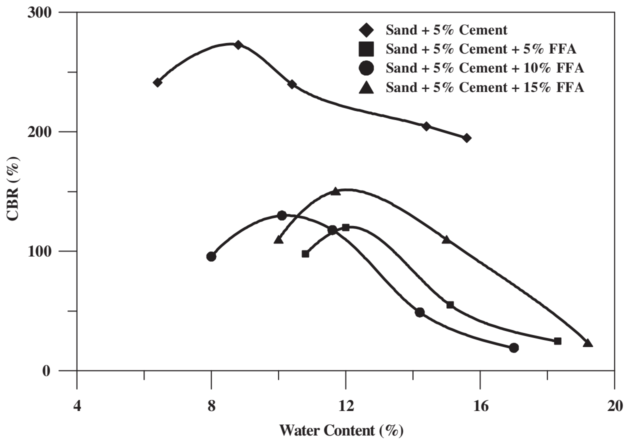

Figure 8 Effects of moisture and 5% cement with different FFA dosages on CBR of sand.

3.2.5. *Unconfined compressive strength (UCS) of marl*

Figs. 10 and 11 demonstrate the relationship between the unconfined compressive strength (q_u) and curing period for the different mixtures. Results clearly indicate that the strength of treated marl with 5% cement and various percentages of FFA increased with the extended period of curing. This can be attributed to the availability of sufficient moisture content for the hydration process to proceed. Fig. 11 shows the same trend when marl was treated with FFA only (no cement). From the two figures, it can be deduced that the unconfined compressive strength was much higher when 5% of cement was used with FFA. As an example, when 5% of FFA was added to the marl–cement mixture, the UCS was found to be 963, 1386, 1595 and 2151 kPa after 3, 7, 14 and 28 days of curing period, respectively. When only 5% of FFA was used with

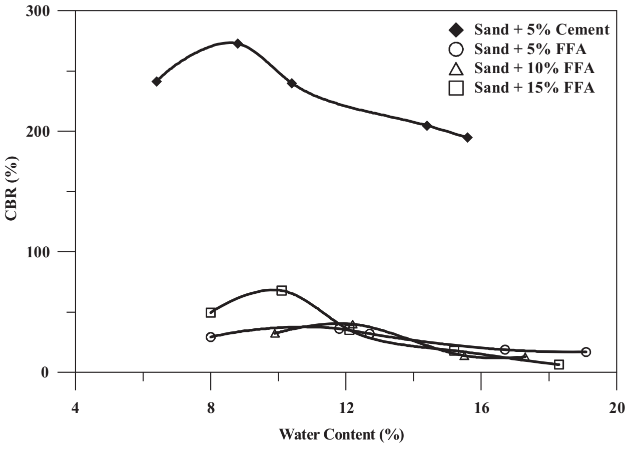

Figure 9 Effect of moisture and different FFA dosages on CBR of sand.

marl (no cement), the corresponding values dropped to 600, 708, 836 and 1041 kPa which represent a strength reduction by 37.7%, 48.9%, 47.6% and 51.6%, respectively.

The relationship between the unconfined compressive strength (UCS) and additive content for the FFA–cement–marl mixtures and FFA–marl is presented in Figs. 12 and 13, respectively. The figures clearly show that there was a sharp increase in the strength when 5% of FFA and 5% of cement were added to the marl, thereafter a further increase in the FFA content was found to result in decreasing the strength of the marl–cement mixture and marl. The sharp increase in the unconfined compressive strength when 5% of FFA was added to the marl–cement mixture indicates that the additives (cement and FFA) filled the voids of the marl and, therefore, made it much denser. Similarly, when the FFA alone was added to the marl (no cement), the q_u increased sharply due to the addition 5% of FFA. Further increase in the FFA content was found to result in decreasing the strength. Additionally, the figures indicate that the addition of 5% of cement produced higher UCS values compared to those when cement was not used in mixes. Results clearly indicate that only marl stabilized with 5% cement and 5% FFA satisfied the 7-day strength requirements according to the ACI Committee 230 Report (ACI, 1990). However, the other mixes (cement with FFA) gave q_u close to the 7-day strength ACI requirements. Consequently, marl–cement mixture stabilized with 10% and 15% of FFA can be used in many other engineering applications such as improving the bearing capacity.

3.2.6. Unconfined compressive strength (UCS) of sand

The relationship between the unconfined compressive strength (q_u) and the curing period is depicted in Figs. 14 and 15. The figures clearly indicate that the strength was found to increase with increasing the curing period. This can be attributed to the above-given reasons. The figures also indicate that when cement was not used in mixtures (only FFA), the rate of strength increase was marginal due to the absence of cement. Results clearly indicate that FFA is not of cementitious nature and, therefore, its presence in the mixture will result in decreasing the strength. As an example, when 15% of FFA was added to the sand–cement mixture, the UCS values were 188, 297, 488 and 643 kPa after 3, 7, 14 and 28 days of curing period (Fig. 14). When 15% of FFA was mixed with sand (without cement), the corresponding UCS values were 34, 48 56 and 63 for the same curing periods (Fig. 15). This indicates that by removing the cement from the mixtures, the strength was reduced by 82%, 84%, 89% and 90% for the curing periods of 3, 7, 14 and 28 days, respectively. The figures also show that the rate of strength gain was higher in the initial days of curing and, subsequently, began to decrease.

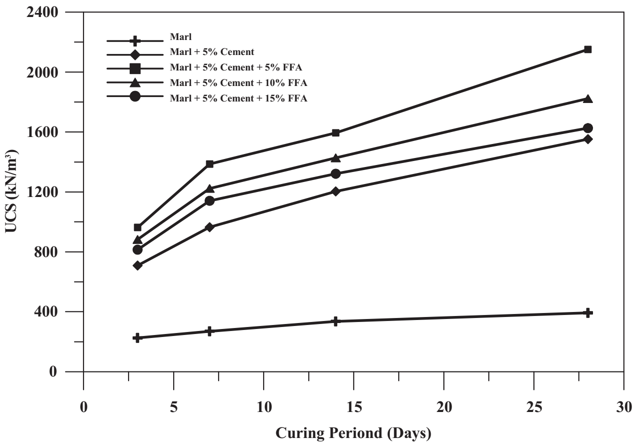

Figure 10 Variation of the q_u with curing period for FFA–cement–non-plastic marl mixtures.

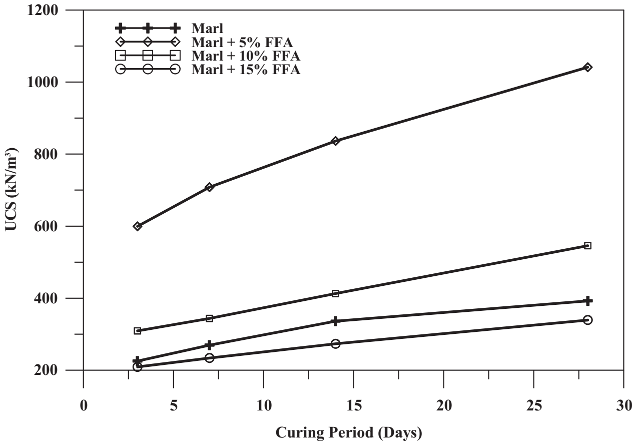

Figure 11 Variation of the q_u with curing period for FFA–non-plastic marl mixtures.

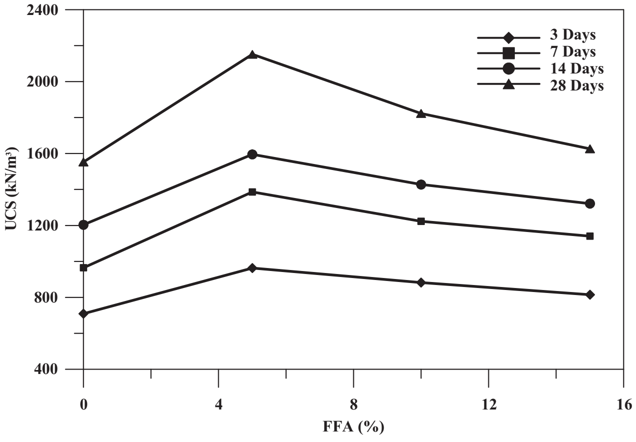

Figure 12 Effect of FFA addition on the q_u for different curing periods.

With respect to the effect of FFA, Figs. 16 and 17 demonstrate the relationship between the unconfined compressive strength (q_u) and the FFA content for the FFA–cement–sand and FFA–sand mixtures. The figures clearly indicate that the addition of FFA to the cement stabilized sand reduced the q_u. As an example, the q_u after 7 days for 5% cement stabilized sand was reduced from 343 kPa to 135 kPa when 5% of FFA was added. The figures also show that as the FFA content was increased the UCS was found to increase. When 5%, 10% and 15% of FFA was added to the sand–cement mixture, the UCS values were found to be 135, 252 and 297 kPa after 7 days of curing periods. On the other hand, when cement was not used, the corresponding UCS values were 17, 34 and 48 kPa for the same curing period. This clearly indicates that the UCS was

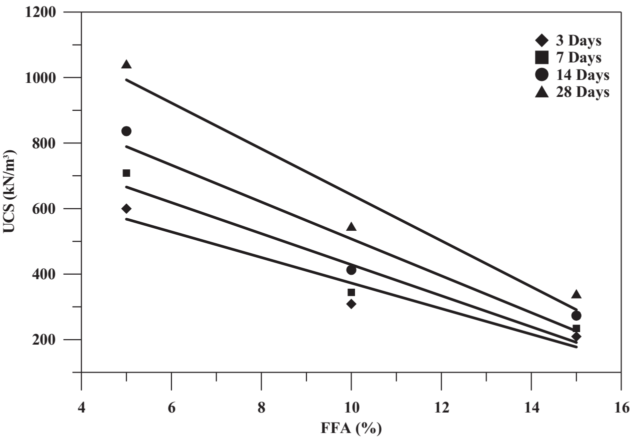

Figure 13 Effect of adding more than 5% of FFA on the q_u of marl for different curing periods.

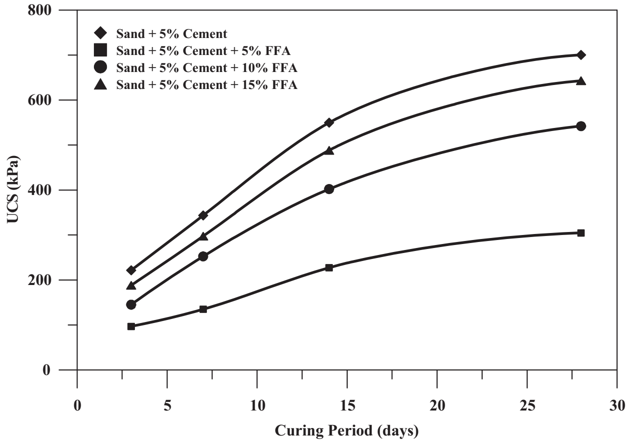

Figure 14 Variation of q_u with curing period for FFA–cement (5%)–sand mixtures.

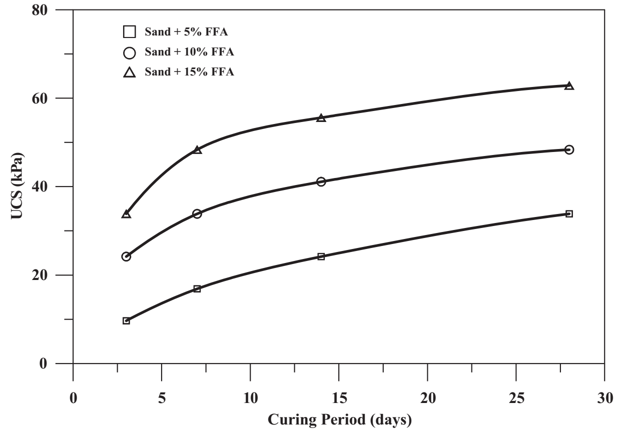

Figure 15 Variation of q_u with curing period for FFA–sand mixtures.

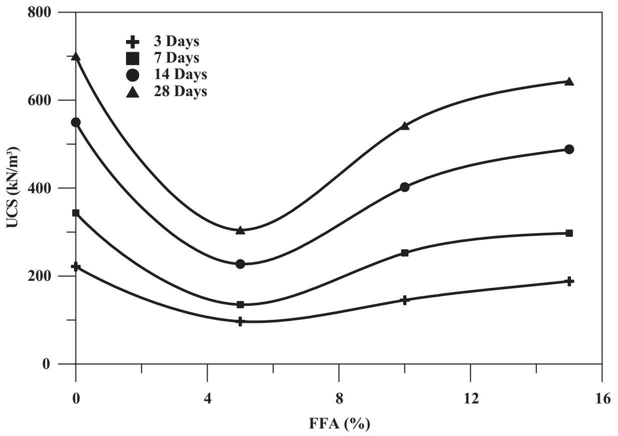

Figure 16 Variation of q_u with FFA content for FFA–cement (5%)–sand mixtures.

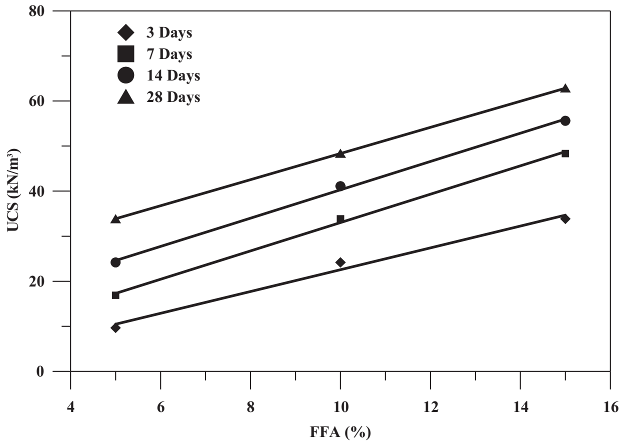

Figure 17 Effect of adding more than 5% of FFA on the q_u of sand for different curing periods.

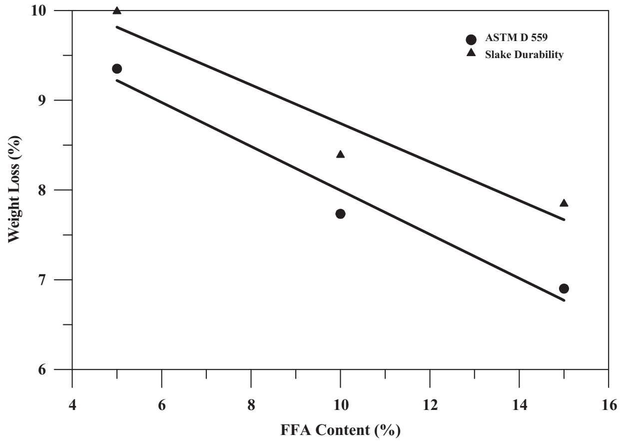

Figure 18 Variation of the weight loss with FFA content and 5% cement for stabilized non-plastic marl.

reduced by 87%, 87% and 84% for additions of 5%, 10% and 15% of FFA, respectively. Such reduction indicates that the addition of FFA had a detrimental effect on the sand stabilized with cement. Results clearly indicate that none of FFA–cement–sand or FFA–sand mixtures satisfied the 7-day strength requirements set by the ACI Committee 230 Report (ACI, 1990). Consequently, it can be concluded that FFA is not a suitable stabilizer for sand soil.

Table 2 Weight loss of FFA–marl after 12 Cycles.

FFA (%)	Cement (%)	Weight loss (%)					
		ASTM D 559			Slake durability		
		Sample 1	Sample 2	Average	Sample 1	Sample 2	Average
5	5	9.2	9.5	9.4	10.7	9.3	10
10	5	7.2	8.2	7.7	8.7	8.0	8.4
15	5	7.1	6.7	6.9	7.4	8.3	7.8

Table 3 TCLP for marl soil stabilized with 5% cement and 5% FFA.

Metal	EPA (mg/l)	Stabilized marl soil (5% cement + 5% FFA)	
		Sample 1 (mg/l)	Sample 2 (mg/l)
Ag	5	3.96	4.08
As	5	<0.015	<0.015
Ba	100	0.136	0.141
Cd	1	<0.002	<0.002
Cr	5	0.029	0.071
Hg	0.2	<0.002	<0.002
Pb	5	<0.01	<0.01
Se	1	<0.02	<0.02
Ni	NR	8.78	9.05
V	NR	16.2	16.2

NR: Not Regulated by EPA.

3.2.7. Durability of marl and sand

All FFA–marl soil mixtures collapsed during the first cycle and, therefore, they were considered as "failed" in the durability test. The weight loss of the FFA–marl soil mixtures with the addition of 5% cement is depicted in Fig. 18. The figure clearly shows that as the FFA content was increased, the weight loss decreased. The average weight losses of all mixtures at the end of the 12 cycles are summarized in Table 2. It can be noticed that the average weight loss after 12 cycles for the all mixtures did not exceed the maximum allowable weight loss of 14% set by PCA (Portland Cement Association). With respect to FFA–sand mixtures, the mixtures were excluded from the durability tests because they were produced in low strength and failed to satisfy the 7-day strength requirements set by the ACI Committee 230 Report (ACI, 1990).

3.3. Toxicity characteristic leaching procedure (TCLP)

The TCLP set by the United States Environmental Protection Agency (USEPA) was performed on two specimens of marl stabilized with 5% cement plus 5% FFA which satisfied the strength requirements and durability assessment. The concentrations of the regulated metals that leached from the stabilized soil samples are shown in Table 3 and compared with the maximum concentrations set by the USEPA for toxicity characteristics of the regulated metals. The table clearly shows that all concentrations of the leached metals are below the USEPA maximum concentration for toxicity characteristics. However, the concentrations of vanadium and nickel in the TCLP test were found to be relatively high. It is worth to mention that nickel and vanadium are not regulated by the USEPA. The TCLP is used in order to identify hazardous wastes and it mimics what will happen to a given material when exposed to normal climatic conditions in a landfill over time. Consequently, it can be concluded that the usage of 5% FFA plus 5% cement in marl stabilization may not be suitable from the environmental point of view.

4. Conclusions

The utilization of oil fuel flyash (FFA) produced in power plants firing fuel oil in soil stabilization was investigated using two indigenous soils, namely, sand and marl. The FFA was added to the selected soils at 5%, 10% and 15% with and without the addition of cement. The stabilization process was evaluated by determining engineering properties such as CBR, compaction, UCS and durability of the stabilized soils. Results clearly indicated that FFA was found to be a suitable chemical addition to treat marl. On the other hand, FFA did not bring about a significant improvement to sand in terms of strength. A flyash content of 5% plus 5% cement was found to be adequate for the effective stabilization of marl. The marl–FFA mixtures were found to meet the strength and durability requirements. FFA is considered a waste material and is very cheap when compared to cement. However, FFA may have hazardous ingredients that are deleterious to the groundwater and the surrounding environment. Therefore, caution has to be practiced to prevent or at least minimize the negative effects of soils stabilized with FFA on the environment and human health.

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