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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