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RESEARCH ARTICLE

Impact of Silica Fume on the Strength Characterizes of Contaminated Soil

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ABSTRACT

In this paper a silica fume (SF) utilized as an admixture for improving the strength characterizes of contaminated soil and create new useful soils. Compaction test and direct shear test are used to evaluate the strength properties of clean and contaminated soil. Mixing SF with contaminated soil by crude oil is a rare study carried out. The strength characterizes of clean and polluted soil with crude oil was investigated. Three amount of light crude oil is combined with soils artificially in the percentage of 3%, 6%, and 9% by dry weight. However, three portions of SFs are used in the experimental work, which are 0%, 12%, and 18%. In the compaction test, results show that optimum moisture content (OMC) decreases with increasing degree of contamination, inversely while adding SF, OMC is increased. Maximum dry density dramatically decreased with an increasing amount of SF and crude oil. The shear strength properties enhance by utilizing SF where observed that the cohesion in clean soil is increased from 25.3 to 40.3 kPa and in contaminated soil by 9% crude oil is raised from 12.3 to 18.6 kPa so that SF can be rate as a successful material to enhance the soil properties.

Keywords: Silica fume; Contaminated soil; Compaction; Strength; ANOVA

INTRODUCTION

By pipeline broke, refineries, tanker accidental, and oil tanks, the contamination soil naturally caused. Accidental oil spillage or leaking has produced severe pollution to the environment. Oil pollution can sceptically influence the soil microbes and plant as well as pollute groundwater resources for drinking or agriculture (Hill, 2010).

Stabilization is needful for runway and highway construction; stabilization indicates enhancing in both shear strength and stability, which are related to the performance of soil. The emphasis is placed on the effective utilization of wastes byproducts like silica fume (SF), to decrease the construction cost and enhance the soil durability. Soils can be stabilized by combining with the correct proportion of stabilizers to improve the strength and cohesion. Many authorities and investigators are lately working to reusing the wastes in environmentally and economically sustainable ways (Mermerdaş and Arbili, 2015; Arbili, Mermerdaş and Ghaffoori, 2016a; Arbili, Ghaffoori and Mermerdaş, 2016b; Ghaffoori and Arbili, 2019).

Several researchers studied the negative characteristics of soil by adding it with additives such as lime, clay, cement, SF, and steel slag. There has been recent interest globally in use of SF in various civil engineering applications, due to economic advantages and environmental protection. This new procedure of soil stabilization can be effectively utilized to meet the present challenges of society, to decrease the quantities of waste, producing serviceable material from no useful waste material. Globally, SF is considered as best byproducts that can be used for many utilizations.

Reactive pozzolan as a SF is interested in growing awareness due to its fine particles, big surface area, and the high silicon dioxide content (Rezaei, 2014). The SF was used as a partial replacement for Portland cement in concrete (Çakır and Sofyanlı, 2015). Besides, it has been argued that SF is a potential and viable bidder to enhance the geotechnical properties of soils as a stabilization instrument by increasing strength and reducing the permeability coefficient (Kalkan and Akbulut, 2004; Goodarzi et al., 2015). In this esteem, the effect of SF on the geotechnical properties of soil was examined and showed that this stabilizer could enhance the permeability, swelling pressure, and compressive strength of composite (Kalkan and Akbulut, 2004). Furthermore, Vakili et al., 2013, used pozzolanic additives to develop the characteristics of expansive soils. The outcomes show that these additives can considerably increase the compressive strength of the soils after the curing process.

MATERIALS AND SAMPLE PREPARATION

Materials

Soil

Table 1 demonstrates the basic characterizes of used soil. A clayey, silty soil comprising 43% clay, 50% silt, and 7% sand was used, as shown in Figure 1. To measure the gradation of the soil, the distribution of sieve analysis was used. The selection of sieves based on ASTM D-422 standard details. The utilized soil was brown color, low plasticity clay soil which was collected from a borrow pit of 1 m depth below the existing ground level (Arbili and Karpuzcu, 2018).

Crude oil

The crude oil used has its specific gravity at 25.0°C to be 0.851 and its American Petroleum Institute (API) gravity at 25.0°C to be 23.261° API. The properties of the crude oil are shown in Table 2.

SF

SF is the producer of the silicon and ferrosilicon alloy. It is developed through the manufacture of silicon metal. Its appearance is light gray, and the size is <2 μ. Throughout the production of silicon metal, ashes of silica rise as an oxidized vapor. These oxidized vapors are then cold, condenses and collected as SF. The appearance of SF is spherical, which is very fine having a surface area of about 20,000 m^2/kg, as shown in Figure 2.

SF for the present investigation was obtained from Turkey. The physical and chemical properties of SF are presented in Table 3.

Sample Preparation

The soil used in this study was obtained from Lajan area at Erbil Governorate, Iraq. It was collected from the site

Table 1: Properties of uncontaminated soil

Properties	Description
Sand (0.0075–4.75 mm)%	7
Silt and clay (<0.0075 mm)%	93
USC	Low plasticity clay – CL
Color	Brown
Organic content (%)	0.5
Liquid limit (%)	35
Plastic limit (%)	21
Specific gravity	2.663

Table 2: Properties of crude oil

Sample	Flash point °C	Density at 25°C (g/cm³)	API°	Viscosity (Cp)
Kar refinery	53	0.849	23.261	18.2

Table 3: Chemical composition of silica fume

Physical properties	
Specific gravity	2.2
Mean grain size (μm)	0.15
Color	Light to low gray
Chemical compositions (%)	
Silicon dioxide (SiO_2)	85
Aluminum oxide (Al_2O_3)	1.12
Iron oxide (Fe_2O_3)	1.46
Calcium oxide (CaO)	0.2–0.8
Magnesium oxide (MgO)	0.2–0.8
Sodium oxide (Na_2O)	0.5–1.2
Potassium oxide (K_2O)	
Loss on ignition	<60

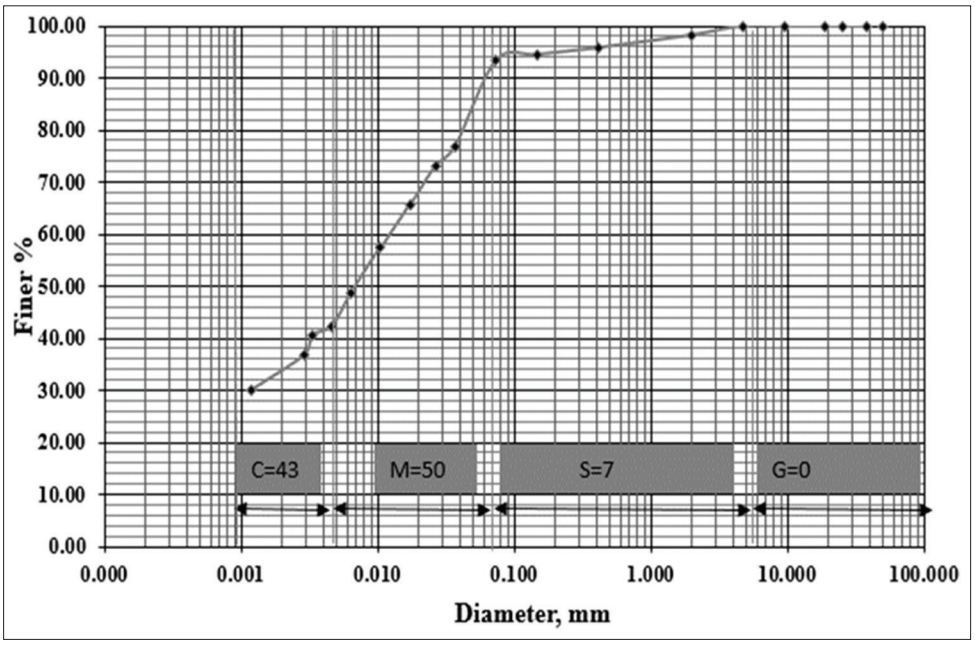

Figure 1: Sieve size analysis for soil sample (Arbili and Karpuzcu, 2018)

of the soil profile at about 50 cm depth below the ground surface to prevent upper organic soil layers from entering the sample soils. Before the commencement of laboratory tests on the soil samples collected in sacks and transported to the laboratory, they were passed through a 4.75 mm sieve and oven-dried. The polluted artificially of soil for this examination was set up by blending the dry soil test with the light crude oil in the measure of 0%, 3%, 6%, and 9%, estimated by the weight of the dry soil test to exemplify to the different levels of raw petroleum defilement

The mixed samples were put into closed containers for 2 weeks foraging and equilibrium, allowing possible reactions between soil and crude oil. The contamination of the soil with varying percentage of crude oil did in the laboratory. SF was used in proportions of 0%, 12%, and 18% by weight of soil sample for various experiments. Table 4 demonstrates the ratio of addition waste materials in four groups depending on the ratio of oil contaminated, for each group.

Figure 2: Silica fume sample

RESULTS

Compaction

Compaction test results showed optimum moisture content (OMC) and maximum dry density (MDD). The results show the effect of crude oil contamination and mineral admixture (SF) on both compaction parameters of soil.

Table 4: Mix description for addition waste materials

#	Mix ID	Oil (%)	Silica fume (%)	Soil (%)
Group I				
Mix 1	O_0SF_0	0	0	100
Mix 2	O_0SF_{12}	0	12	88
Mix 3	O_0SF_{18}	0	18	82
Group II				
Mix 1	O_3SF_0	3	0	97
Mix 2	O_3SF_{12}	3	12	85
Mix 3	O_3SF_{18}	3	18	79
Group III				
Mix 1	O_6SF_0	6	0	94
Mix 2	O_6SF_{12}	6	12	82
Mix 3	O_6SF_{18}	6	18	76
Group IV				
Mix 1	O_9SF_0	9	0	91
Mix 2	O_9SF_{12}	9	12	79
Mix 3	O_9SF_{18}	9	18	73

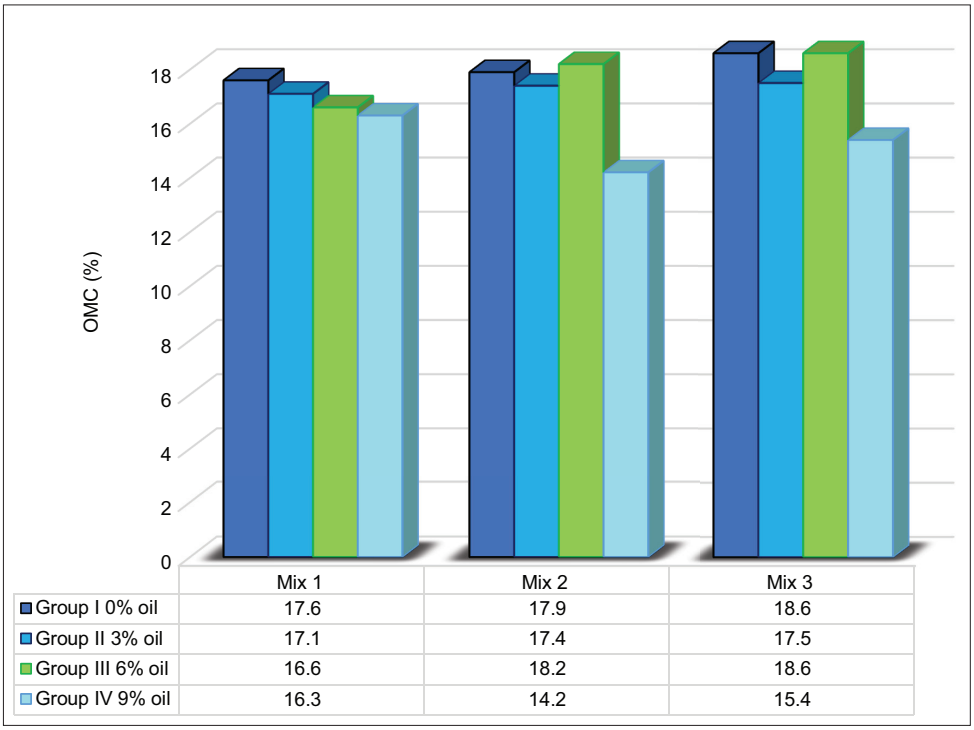

Figure 3: Variation of optimum moisture content values with different waste materials content in clean and contaminated soil

Soil samples prepared in one group for uncontaminated soil and three groups for contaminated soil samples with crude oil, each group consists of three mixtures with various percentages (0%, 12%, and 18%) from SF. Figure 3 illustrates the effect of OMC in all groups and each mixture, OMC decreased with added crude oil to the soil sample; it is due to the capillary effect. Usually, the spaces between soil particles could be considered as a capillary tube, which causes the rise of the water in it. While the compaction weight is falling on the soil, these spaces became thinner and thinner, which increases the capillary tension. When increased SF in Group I, OMC increased in mixes 1, 2, and 3 that significant effect on OMC, the highest value recorded in mix 3 in clean soil which contains 18% of SF.

In general, the OMC is increased with the increasing of SF percent from 17.6% to 18.6% at the Group I, as shown in Figure 3. This may be the effect of SF, which decreases the free silt clay fraction amount, and coarser material with forming of a large surface area, the water is needed here to make these operations take place. This also suggested that the compacting of soil-SF mixtures requires more water as discussed in Harichane et al., 2011, except for Group IV the OMC upset because of the presence of crude oil higher than the other groups.

The impact of crude oil contamination and mineral admixtures on MDD of soil samples is demonstrated in Figure 4. While increased crude oil, MDD decreased in all group. SF decreased MDD and in binder mixes demonstrated the effect of the mineral admixtures the peak value of MDD is in mix 1 from clean soil, with contaminated by oil the value of MDD be close of each other. Results for OMC and MDD are supported by results of many researchers such as Mahvash et al., 2017; Okonta and Govender, 2011; and Sabbar et al., 2018. According to specific gravity of silica fume, which has lower than the soil used in the study, it was observed the effect of SF on the maximum dry unit was decreased from 17.44 to 16.40 kN/m^3 in Group I and for other groups, as shown in Figure 4.

Direct Shear Test

Shear strength parameters are cohesion and angle of internal friction (c and ϕ). Results obtained from this study are shown in Table 5. Cohesion increased with increase SF in mixes 1, 2, and 3 in contaminated and uncontaminated soil samples. Furthermore, the effect of SF significant

Table 5: Result of direct shear test

	Mix ID	Oil (%)	Silica fume (%)	Cohesion (kPa)	Angle of friction (ϕ°)
Group I					
Mix 1	O_0SF_0	0	0	25.3	25.7
Mix 2	O_0SF_{12}	0	12	33.9	34.3
Mix 3	O_0SF_{18}	0	18	40.3	36.2
Group II					
Mix 1	O_3SF_0	3	0	22.5	28.5
Mix 2	O_3SF_{12}	3	12	26.2	27.8
Mix 3	O_3SF_{18}	3	18	34.7	30.9
Group III					
Mix 1	O_6SF_0	6	0	14.9	35.1
Mix 2	O_6SF_{12}	6	12	15.6	34.1
Mix 3	O_6SF_{18}	6	18	17.8	40.7
Group IV					
Mix 1	O_9SF_0	9	0	12.3	29.7
Mix 2	O_9SF_{12}	9	12	15.3	35.8
Mix 3	O_9SF_{18}	9	18	18.6	36.3

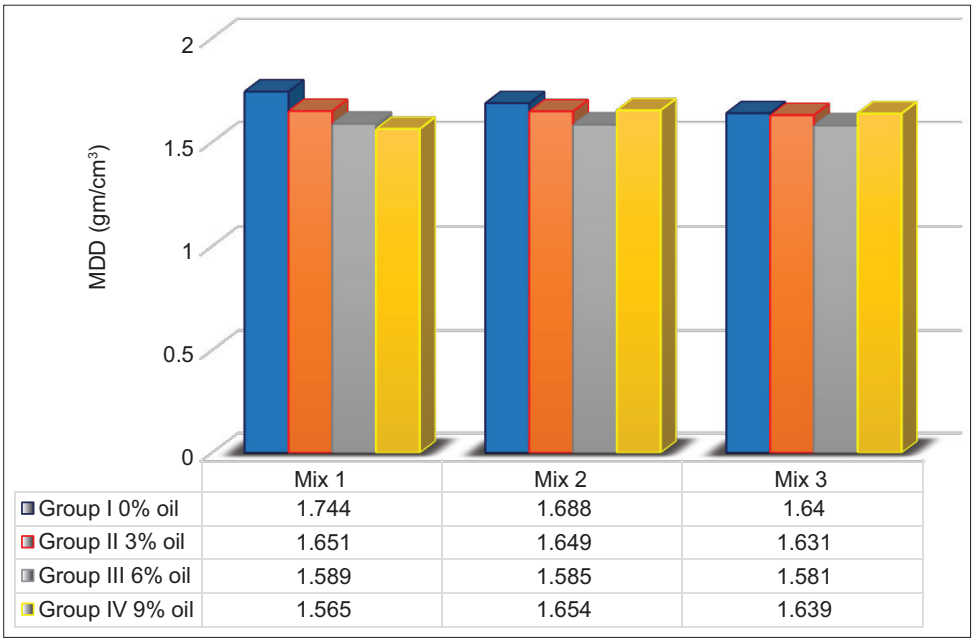

Figure 4: Variation of maximum dry density values with different waste materials content in clean and contaminated soil

Table 6: ANOVA results for the considered dependent variables

Dependent variables	Source of variation	Statistical parameters				
		DF	Adj. SS	Adj. MS	F-value	*P*-value
OMC	Oil (%)	3	13.963	4.6544	6.86	0.023
	Silica fume (%)	2	1.002	0.5008	0.74	0.517
	Error	6	4.072	0.6786		
	Total	11	19.037			
MDD	Oil (%)	3	0.017757	0.005919	3.82	0.076
	Silica fume (%)	2	0.000943	0.000472	0.30	0.748
	Error	6	0.009291	0.001548		
	Total	11	0.027991			
C	Oil (%)	3	695.15	231.717	28.04	0.001
	Silica fume (%)	2	166.43	83.213	10.07	0.012
	Error	6	49.58	8.263		
	Total	11	911.16			
	Oil (%)	3	91.18	30.392	4.40	0.058
ϕ	Silica fume (%)	2	78.78	39.392	5.71	0.041
	Error	6	41.42	6.904		
	Total	11	211.38			

impact on the result of cohesion, which was observed at mix 3 in contaminated soil sample with crude oil. Although, huge difference value for cohesion between Group 1 and Group 2 due to the effect of crude oil on soil particles. The increase in the cohesion is attributed to the internal friction of SF particles and chemical reaction between SF and soil. An increase in SF content in soil has made the stabilized soil samples more brittle than the natural soil samples. Angle of internal friction is increased with added crude oil for soil sample, regarding to increased (ϕ) with increased it. The Results were understandable with the change in the percentage of silica fume in all mixes. Table 5 demonstrated the result of the test of direct shear in all groups.

Statistical Analysis

All the data have been entered and processed using Minitab (Version 18). Analysis of variance (ANOVA) at 95% confidence level has been applied to find the statistical significance of the factors. In this study, the main parameters are crude oil and SF considered as the design factors, and the design responses defined as OMC, MDD, cohesion, and ϕ. In addition, ANOVA is performed to recognize the level of effectiveness of the independent variables on the design responses. p-values for results of the statistical analysis demonstrated in Table 6, which is higher than 0.05 the parameter rejected as an insignificant factor on the response at 95% confidence level, such as SF in OMC and MDD. Furthermore, the much effective results achieved in cohesion and ϕ response, as shown in Table 6.

CONCLUSION

The outcome of this study exhibit that the silica fume can be utilized as a waste material as a non-traditional stabilizer for contaminated soils. This article investigates the impact of adding SF on the strength properties of contaminated soils. Based on the results of laboratory experiments have been carried out on varieties of samples containing: 0%, 12%, and 18% of SF, it is found that the strength properties of contaminated soil have been improved 20% to 35% by adding SF. Therefore, contaminated soil stabilized with SF can be utilized as a subgrade material for the construction. On another hand, in highway, and embankment constructions reduce the cost of projects and environment friendly due to use disposal industrial waste materials.

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