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Remediation of Clayey Soil Using Silica Fume

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Abstract. This paper evaluates the use of silica fumes as modification of fine-grained soil in order to alter undesirable properties of the native soil and create new useful soils. Silica fume as well as clay material, are used in changing the engineering properties to be compatible and satisfying this is due to their pozzolanic reactivity. The study aims to investigate the uses of these materials in geotechnical engineering and to improve the properties of soils. Four percentages of silica fumes were used in the present study, which is 0, 3, 5 and 7%. Classification, specific gravity, compaction characteristics, swell and swell pressure, CBR and compressive strength tests had been conducted on the prepared and modified soils. Results clarified that the silica fume increasing leads to decrease the plasticity index and liquid limit. Increasing in silica fume causes an increasing in plastic limit and optimum water contents while the maximum dry unit weight values decrease. The compressive shear strength, California Bearing Ratio (CBR), swell and swell pressure is improved by using silica fume so that silica fume can be considered as a successful material in improving the soil properties.

1 Introduction

A great challenge faces civil engineering especially when the subgrade soil is found to be clayey soils, these soils usually have a tendency to change in volume if there is any change in moisture content [1]. The changes in moisture content may be due to floods, rains, leaking sewer lines or water evaporation this due to the fact that soils is covered by a pavement or a building. Remarkably, these cases causes the cracking and breaking up of pavements, highway, railways and embankments, foundations and reservoir linings or channe [2, 3].

Construction of this type of soils needs to be improved by using additives. Improvement of subgrade soils has traditionally depended on treating the soils with cement, lime, or waste material such as slag, Silica fume [4, 5, 6]. The silica fume found to be abundant material, and it is about 40% cheaper than other material such as Portland cement [4] but there is insufficient data on the effect of this material on the compressive strength of clayey soil.

There is little data available to define the relationship of shear strength of clay with different percent of silica fume. [7] used silica fume-clay for liners and the main conclusion that using silica fume-clay causes a reduction" in permeability and swelling pressure with high shear strength for landfills, "found that a higher attaching strength between clay and silica fume particles resulted in higher internal shear strength in the clay silica fume mixture. There are very complex engineering problems in the clay soil, especially when accompanied by environmental changes in moisture content and undergoes large settlement under long term of loads. Failure of different structures constructed on clay soils in various locations in Iraq were recorded such as Ammara, Nasiriya and Basra that are characterized by their low undrained shear strength (<40 kPa) and compression index as high as 0.3 were reported [8, 9]. Thus, it is necessary to improve large areas covered by weak clay soil that has created problems to roads and airports built on clay soils because of their low bearing capacity.

This research concentrates on investigating experimentally the feasibility of stabilizing and improving the geotechnical properties of soft clay soil using a silica fume material in different proportions and to study the silica fume effect on the engineering characteristics of the stabilized clay.

2 Materials used

2.1 Soil

The soil used was taken from a site east of Baghdad. The soil has low plasticity classified (CL) according to Unified Soil Classification System (USCS). The physical and chemical properties are listed in Table 1, the grain size distribution is shown in Figure 1.

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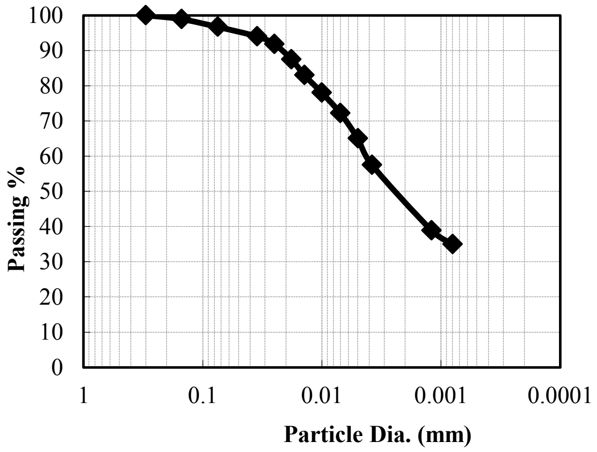

Fig. 1. Grain size distribution of soil used.

Table 1. Engineering properties of the used soil.

Index property	Value	Specification	Bentonite
Liquid limit %(LL)	45	ASTM D 4318	512
Plastic limit %(PL)	18	ASTM D 4318	38
Shrinkage limit %(SL)	27	ASTM D 427	-
Plasticity index %(PI)	16.5	ASTM D 4318	474
Activity (A_t)	0.45	Skempton formula*	-
Specific gravity (Gs)	2.69	ASTM D 854 – 02	2.26
Gravel (larger than 2mm)%	0	ASTM D 422 – 63	-
Sand (0.06 to 2mm)%	3.3	ASTM D 422 – 63	-
silt (0.005 to 0.06mm)%	31.7	ASTM D 422 – 63	-
Clay (less than 0.005mm)%	65	ASTM D 422 – 63	-
Gypsum content %	2.92	Chemical Analysis	-
SO_3 content %	1.36	Chemical Analysis	-
Organic matter O.M %	0.43	ASTM D 2974	-
PH value	8.7	ASTM D 4972	-
Soil symbols (USCS)	CL	ASTM D 2487	-

2.2 Silica fume material

During the manufacture of silicon and ferrosilicon alloys, Silica fume (SF) which is also known as micro-silica, is produced as a secondary product from reduction of high-purity quartz with coal in electric oven. It could be made from other silicon alloys such as ferrochromium, ferromanganese, ferromagnesium, and calcium silicon [10]. Silica fume is composed of very fine hyaline particles, about 100 times smaller than the average of cement particles with approximated surface area of 20,000 m2/kg (215,280 ft2/lb) depending on techniques nitrogen absorption measurement. Because of a high silica content and its extreme fineness it is considered a very effective pozzolanic material [10, 11]. One of its main uses is to improve concrete properties by increasing concrete bond strength, compressive strength, abrasion resistancein addition to reducing its permeability; therefore,

It helps in protection of the reinforcing steel from abrasion. In the present work, the chemical composition of the used silica is given Table 2, which is applicable according to the [10] requirements.

Table 2. Chemical composition of silica fume used in the tests

Composition	Silica fume
Sio_2	98.87 %
Al_2O_3	0.01%
Fe_2O_3	0.01 %
CaO	0.23 %
MgO	0.01 %
K2O	0.08 %
Na2O	0.00 %

3 Results and discussion

3.1 Atterberg limits

Concerning the effect of silica fume content on Atterbergs limits shown in Figure (2), (3) and (4). It was noticed that with increasing SF content there was a decrease in liquid limit and plasticity index. This could be because SF coats and binds all clay particles, which possesses large particles with little cementitious value. This effect is called a pozzolanic reaction between SF and aluminous material as stated by [6].

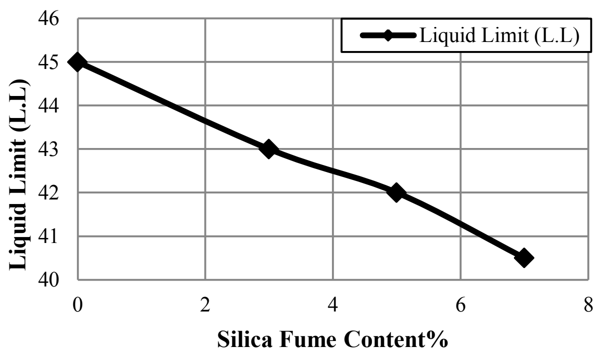

Fig. 2. Liquid limits behavior of clayey soil with increasing silica fume.

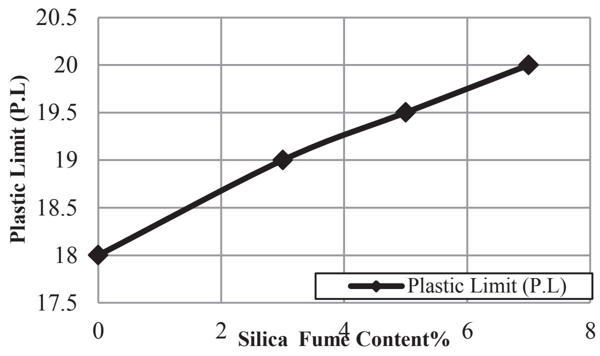

Fig. 3. Plastic limits behavior of clayey soil with increasing silica fume.

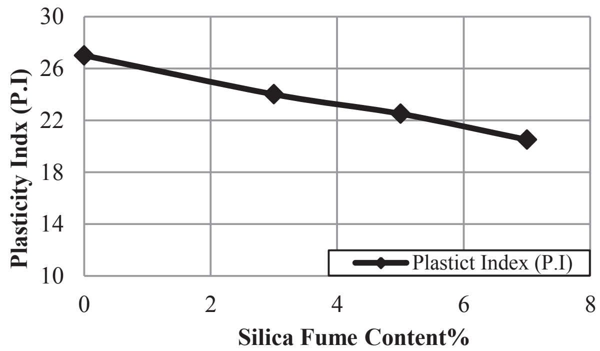

Fig. 4. Plasticity behavior of clayey soil with increasing silica fume.

3.2 Specific gravity

The addition of SF content affects soil's specific gravity. It is obvious from Figure 5 that with increasing SF content, the specific gravity of treated soil sharply drops from 2.69 for untreated natural clayey soil to 2.62 after 7 % SF addition. That is due to the very low specific gravity of the SF (2.2) compared with that of natural clay soil.

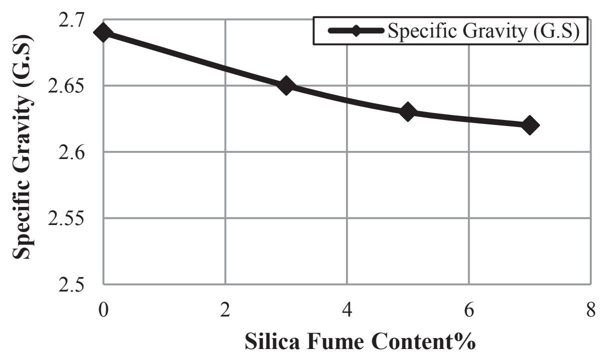

Fig. 5. Specific gravity of clayey soil with increasing silica fume.

3.3 Compaction test

The dry unit weight relationship with water content for different SF values, is shown in Figure (6). It is clearly shown that due to reduction in the parallel orientation to the clay particles at 7% SF there is a decrease in compaction effect. The optimum moisture content (OMC) is increased with increasing the amount of SF content as shown in Figure (7). While Figure (8) illustrates the effect of SF on the maximum dry unit weight.

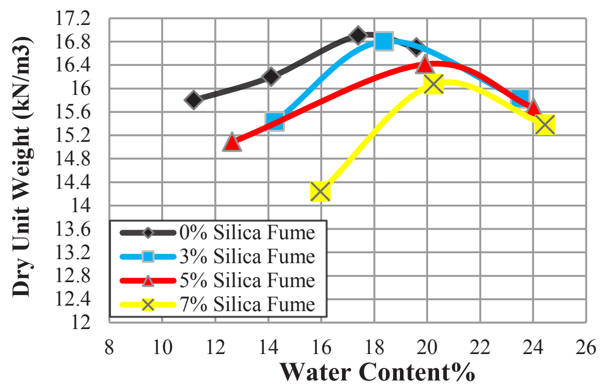

Fig. 6 Variation of the dry unit weight with moisture content for different SF percents.

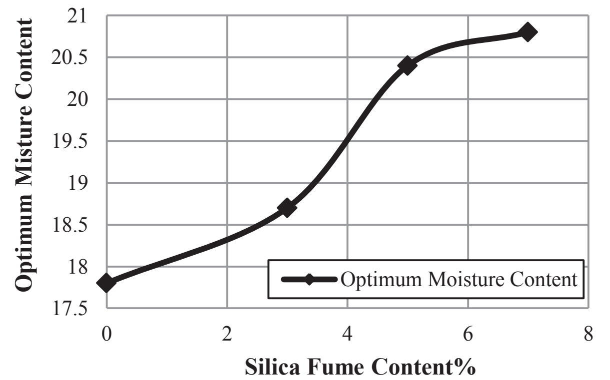

Fig. 7. Optimum moisture content variation with different SF contents.

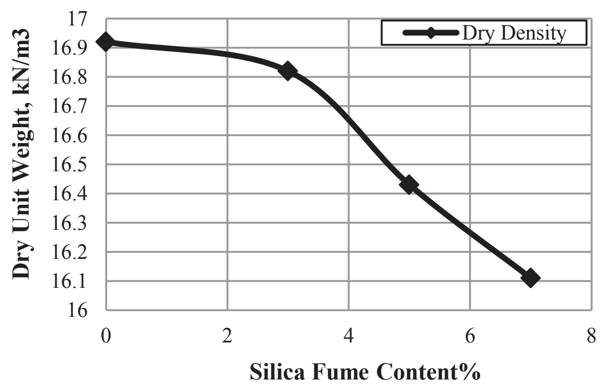

Fig. 8. Variation of the maximum dry unit weight with SF percent.

Generally, the optimum moisture content is increased with the increasing of SF percent from 17.8% to 20.8% at SF 7% as could be seen in Figure (7). 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 hinted that the compacting of soil-SF mixtures needs more water as mentioned in [12]. In the same way, can be as result of replacement of soil by silica fume in the blend, which has a lower specific gravity (2.2) in comparison to soil (2.69) the decrease in the maximum dry unit from 16.92 to 16.11 kN/m3, as shown in Figure (8).

3.4 Shear strength tests

This test is performed according to ASTM D 2435-02 [23] The most common and adaptable method to evaluate the strength of stabilized soil is the Unconfined Compressive Strength (UCS) test for the compacted soil. It is recommended to perform this test to define the required additive amount to use in operation of soil stabilization [13]. UCS tests were performed on natural soil with (3%, 5% and 7% SF). All the unconfined compressive tests were carried out for specimens with 24% moisture content and 15.5 kN/m3 dry unit weights by static compaction.
UCS testing for soil-SF mixtures was carried out after curing time at 20° C for 2 days and 100% relative humidity. The specimens remain in molds as suggested by ref. [14].

Figure (9) and (10) shows the relationship between the unconfined compressive strength and SF percents while Table (3) shows the relationship between the undrained angle of internal friction and SF percents.

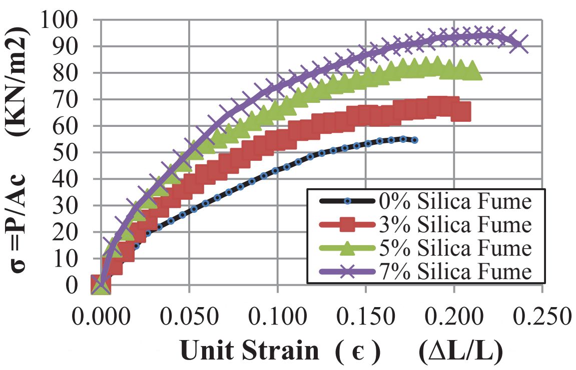

Fig. 9. Stress-Strain relationship from unconfined compression test for samples treated by SF.

Table 3. Shear strength parameters for soil stabilized with SF.

SF %	0%	3%	5%	7%
cu, kPa	27.5	33.7	41.3	47
ϕ_u,	4	17	20	22

ϕu, * These values are calculate from angle of failure plane, θ = 45 + ϕu/2

It can be noticed that UCS and the undrained angle of internal friction increases with increase of SF percents. The reason for these results of development strength is due to the pozzalanic reaction acceleration. The stages of preparation samples are illustrated in Figures (11), (12) and (13).

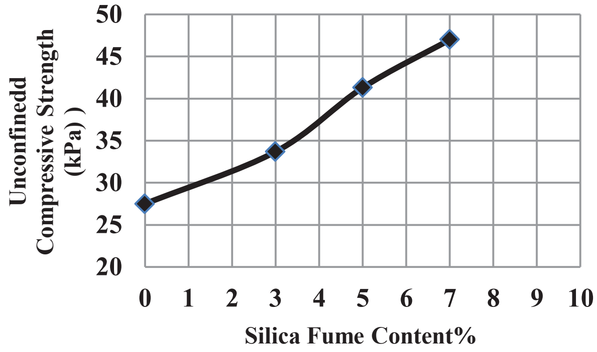

Fig. 10. Effect of silica fume on the unconfined compressive strength of soils.

Fig. 11. Preparation of Samples.

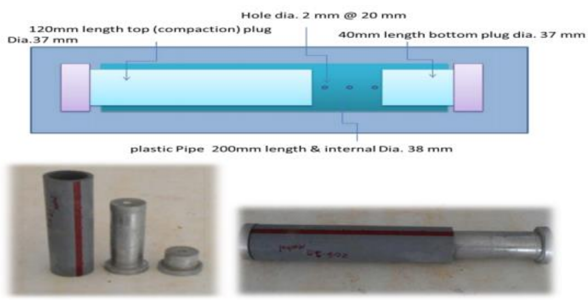

Fig. 12. The details of the plastic pipe and the metal plugs.

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Fig. 13. Sample under shearing in unconfined compression apparatus.

3.5 California bearing ratio (CBR)

The adding effect of silica fume on California Bearing Ratio (CBR) values of clayey soil, shown in figures (14), (15). This simple, fast and reliable test had been used to verify the stabilization of weak soils by adding physical and chemical additives [15, 16]. The CBR test is described in ASTM Standards D1883-05 (for laboratory prepared samples) and D4429 (for soils in place in field) which this research depends on it, AASHTO T193. In general it could be seen that the addition of SF increase the CBR value of the soil. The optimum percent of SF mixtures was carried out after curing time at 20° C for 2 days, which gives a higher improvement of CBR value was found when adding 5% and 7%. Thus, there is an enhancement in CBR values with addition SF and finally a good relationship between the values of UCS and CBR shown in Figure (16).

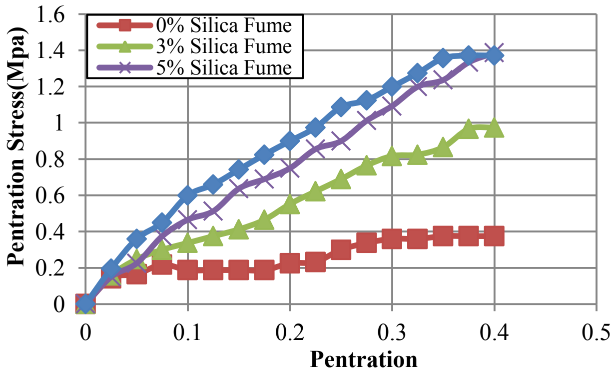

Fig. 14. Effect of addition of different percentages of SF on CBR.

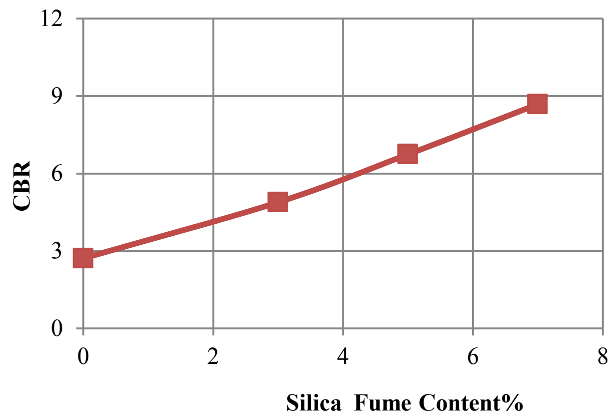

Fig. 15. Effect of addition of different percentages of SF on CBR.

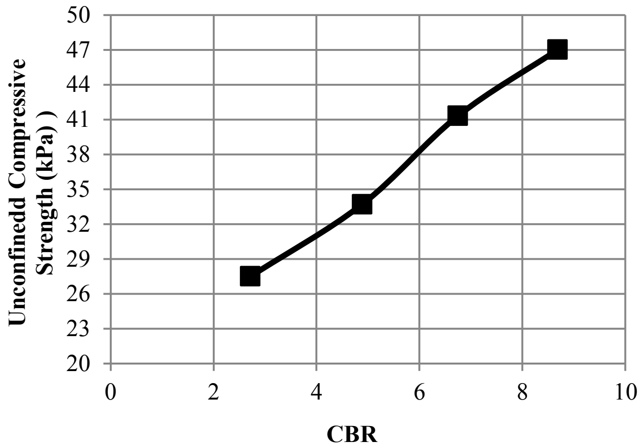

Fig. 16. Relationship between CBR and UCS.

3.6 Silica fume content effect on swelling

The soil samples used in this test were prepared in the laboratory by mixing natural soil with 50% of bentonite. Static Compaction Method was followed for the preparation of soil samples using a special mold and a compression testing machine. Load was applied statically to the soil sample at a compression rate of 0.04mm/sec. until the depth of penetration approached the required height (1.5cm), the samples were prepared at a dry unit weight of (16.92 kN/m^3) and moisture content of (17.8%). The load was maintained on the specimen for about five minutes after reaching the required height to prevent the occurrence of rebound after static load removale. Figure (17), (18) and (19) Show the silica fume effect in different percentages on the free swell and swell pressure of the prepared soil .From these figure it can be observed that the free swell and swell pressure decrease fast with increasing percentage of silica fume. The reduction in the swelling and swelling pressure values of the improved soils may be due to the addition of non-expansive silt-size particles to the expansive soil and the interaction of soil with silica fume particles. In this experiential study the silica fume consists mainly of spherical non-crystal silicate, aluminum, and iron oxides compounded with some microcrystal material and unburned carbon. Consequently, this decreased the specific surface area. This affinity of the inspected soil samples. This refers to the reduction in the swell-shrinkage values such as swelling pressure and free swell. And obtained that 5% silica fume was the perfect percentage to decrease the swell and swell pressure.

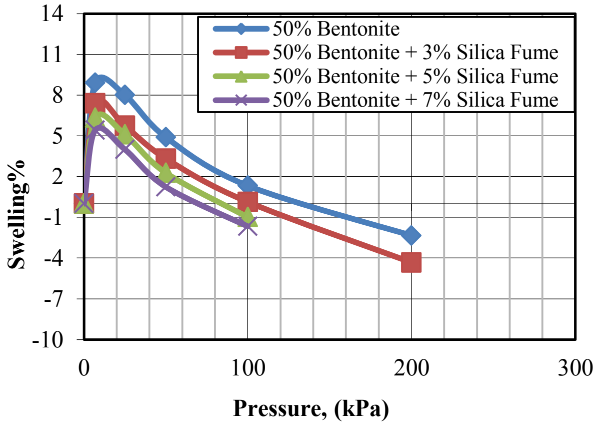

Fig. 17. Relationship between swelling and pressure for prepared soil with 3, 5 and 7% silica fume.

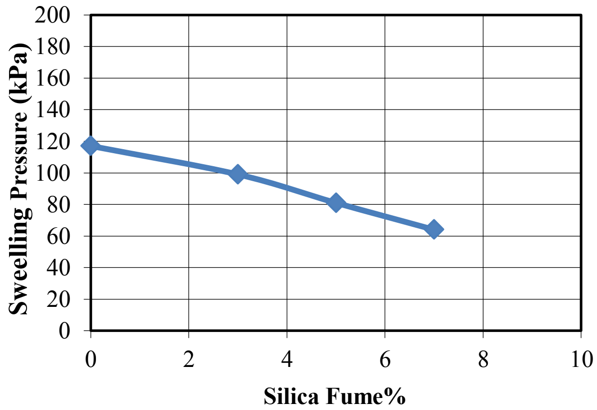

Fig. 18. Relationship between swelling pressure and silica fume content for soil with 3, 5 and 7 % silica fume.

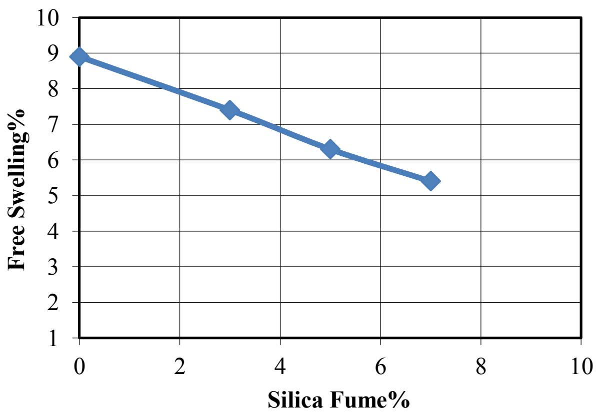

Fig. 19. Relationship between free swelling and silica fume content for soil with 3, 5 and 7 % silica fume.

4 Conclusions

Based on the results obtained, it can be concluded as follows:

1. For Atterbergs limits, decreasing in both liquid limit and plasticity index, increasing in plastic limit were observed with increasing SF content.
2. The specific gravity decreases with increasing of SF percentage.
3. The silica fume changes compaction parameters of clayey soil. The maximum dry unit weight decreases with the increase of the SF content, while optimum moisture content increases with increasing SF content.
4. Increasing SF improves the Unconfined Compression Strength (UCS).Silica Fume percentages at 5% & 7% gave UCS 41.3% and 47% respectively, after 2 days of curing compared to UCS of untreated soil 27.5%.
5. CBR increases with increasing SF content.
6. Free swell and Swell pressure decrease with increasing of SF percentage. And 5% was the perfect percentage to decrease free swell and swell pressure.

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