

Silica Fume Influence on Behavior of Expansive Soil

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Abstract. In this investigation, silica fume (SF) was used as an additive material to study its influence on the characteristics of expansive soil. The soil used in this research was prepared in a lab by mingling bentonite (50 percent by soil dry weight) with natural soil. According to (USCS), the prepared soil was classified as (CH) with a liquid limit of 67.5 percent and a plastic limit of 29.3%. Expansive soil was mixed with different percentages of (SF), (8, 9, 10, 11, 12, and 13%), and experiments were conducted for treated and untreated soil to examine the impact of (SF) on Atterberg's limits, compressibility, swelling, and shear strength parameters. The outcome of this test shows that the use of silica fume raised Atterberg's limits (L.L, P.L, and P.I) and lowered compressibility and swelling percentage, as well as shear strength parameters (c,φ), were altered by increasing the angle of internal friction (φ), and decreased the cohesion (c). From these results, it is concluded that (SF) has a positive effect as an additive material to enhance the geotechnical properties of expansive soil.

Keywords: Silica fume, expansive soil, swelling percentage, compressibility, shear strength parameters.

1. INTRODUCTION

The expansive soil is distinguished by its capacity to expand when wet. The presence of clay minerals like montmorillonite is mostly to blame for the expansion of soil [1]. Desert and semi-desert sections of the globe are affected by soil swelling. For these countries, evaporation levels are higher than the average annual precipitation. Adding water can stimulate the soil with the potential for swell. Semi-arid regions are characterized by short periods of precipitation accompanied by long periods of clouds, resulting in periodic swelling and deflation [2]. The soil heave resulting from soil swelling potential is a multi-factorial phenomenon involving a mixture of a type of matter, clay minerals' shape and quantity, microfabric, initial water content, and dry density [3]. Swollen soil issues can include the cracking and collapsing of sidewalks and building foundations, roads, and canals. As well as that, it harms irrigation systems' water pipelines, tank liners, and sewage lines [4].

When a soil material is improved and stabilized, its bearing capacity is boosted, and its strength and durability are enhanced [5]. Some techniques of treatment may be necessary to make expansive soils appropriate for building purposes. Stabilizing these soils has been the subject of several studies. One of these methods is using pozzolanic materials [6], such as lime, cement, waste materials (fly ash, rice husk ash, etc.), and metakaolin [7-11]. Additionally, a new technology known as the precipitation of calcite induced through microorganisms (MICP), which employs ureolytic bacteria to stabilize soil, has been developed [12]. Many researchers studied the effectiveness of silica fume as a stabilizer to modify expansive soils. This additive material (SF) may be used alone [13 - 19] or mixed with other materials to enhance the properties of expansive soil, such as (scrap tire rubber fiber, rice husk ash, cement, lime, etc.) [20-26]. This study aims to investigate silica fume's influence on the behavior of expansive soil.

2. MATERIALS

2.1 Soil Used

The natural soil was blended with 50% bentonite in order to create the expansive soil in the lab. The natural soil was brought from a region east of Baghdad. The physical and chemical parameters of the soil were specified via a series of experiments on both natural and prepared soil. Table 1 contains the test results. (USCS) defines prepared soil as (CH). The grain size distribution and outcomes of compaction are shown in Figures 1 and 2.

Table 1: Physical and chemical properties of soil used.

Property	Natural soil	Prepared soil	Property	Natural soil	Prepared soil
Liquid limit, L.L (%)	25	68	Maximum dry density (kN/m ³)	19.4	14.68
Plastic limit, P.L (%)	19	29	Optimum moisture content (%)	13.3	19.5
Plasticity Index, P.I (%)	6	39	Soil symbols (USCS)	CL-ML	CH
Specific gravity, G _s	2.68	2.81	Gypsum content	0.8	-
Gravel (%)	0	0	Total dissolved salt, TSD (%)	1.3	-
Sand (%)	38	35	SO ₃ content (%)	0.41	-
Silt (%)	28	17	pH value	8.73	-
Clay (%)	34	48	CaCO ₄ content (%)	30.7	-

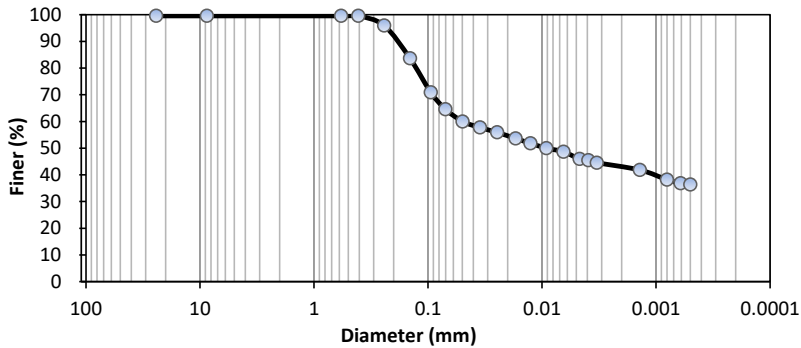


Figure 1: Grain size distribution of prepared soil.

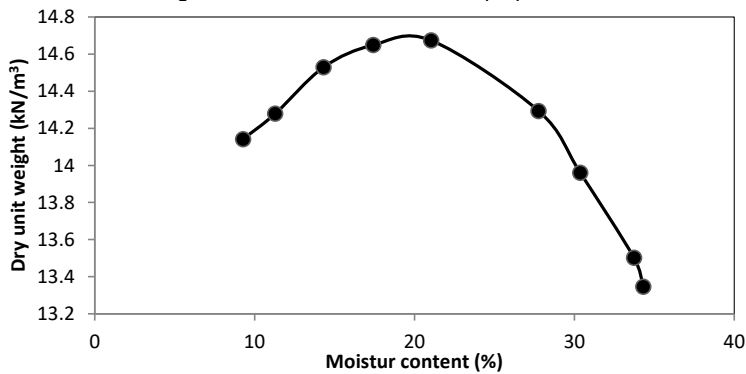


Figure 2: Relationship between dry unit weight and moisture content of prepared soil.

2.2 Silica Fume (SF)

Silicon and ferrosilicon alloys may produce (SF) as a byproduct of the process. Every year, the globe produces almost 100,000 tons of (SF). Due to the high surface area and silica content, silica fume is Pozzolanic and finer than fly ash. (SF) were emitted into the atmosphere until the mid-1970s [23].

3. PREPARATION OF MIXTURES

For 24 hours, the natural soil was dehydrated at 105 degrees Celsius to remove moisture. The natural soil was first blended with 50% bentonite to create expansive soil. Then, the required percentage of silica fume (8, 9, 10, 11, 12, and 13) % was added as a percentage (total dry weight of the prepared expansive soil) to the prepared soil and mixed manually. Also, the appropriate quantity of water (for optimum water content) at room temperature in a slow stream was mixed by hand until the water dispersed throughout the mixture.

4. RESULTS AND DISCUSSIONS

4.1 Silica Fume's Effect on Atterberg's Limits

The outcome of the Atterberg limits tests for treated and untreated prepared expansive soil are displayed in Figure 3, from which it can be noticed that L.L., P.L., and P.I increased with increasing silica fume percentage (8, 9, 10, 11, 12, and 13) %, depending on the soil condition. This is attributed to the soil type, the silicate clay mineral's relative concentration, and its associated exchangeable cat ions in the samples [27,28]. In addition, Atterberg's limit was raised due to the excess of (SF) without aluminous materials [24].

4.2 Silica Fume's Effect on Compressibility

The consolidation test was done for treated and untreated prepared expansive soil to explain the impact of (SF) on compressibility characterizes. Figure 4 shows the relationship between silica fume content (8, 9, 10, 11, 12, and 13) % and compressibility characterized (swelling (expansive) index (Cr) and compression index (Cc)). It can be seen that (Cc) and (Cr) decrease as the amount of silica fume added rises. An explanation for this action may be found in clay minerals' relationship with silica fume particles and the addition of low plastic content. Calcium silicate gels are produced by the reaction of activated silica with calcium and hydroxide, the clay mineral content of the composite samples has decreased as a consequence of this chemical reaction [16,29-31].

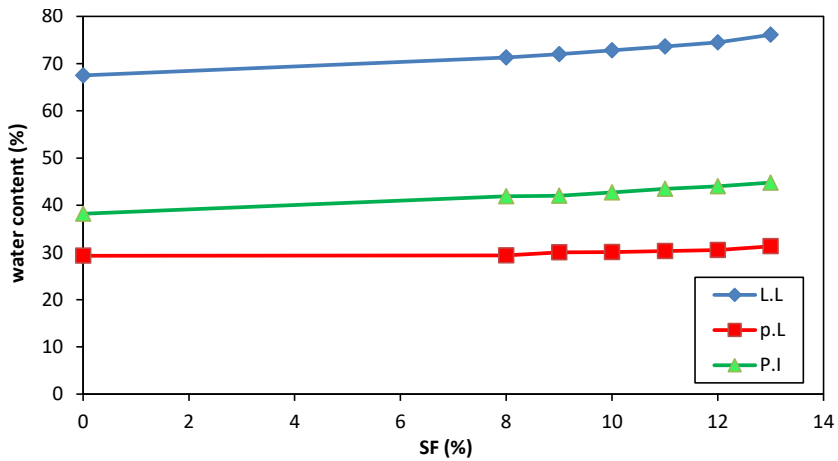


Figure 3: Influence of (SF) % on Atterberg's Limits.

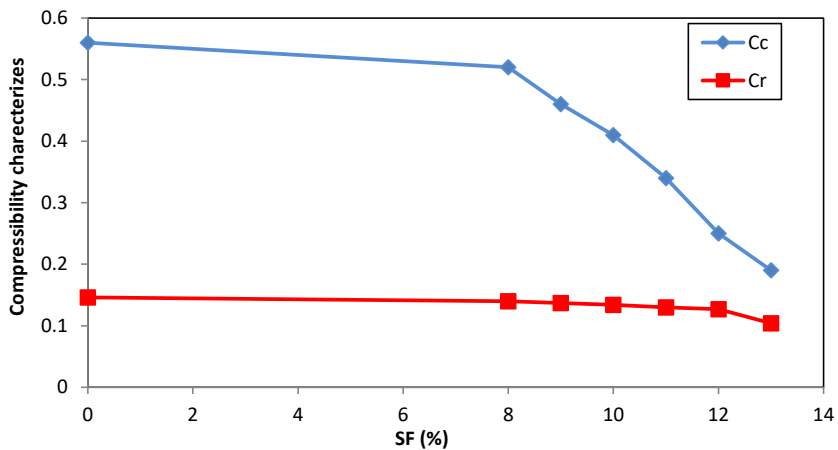


Figure 4: Influence of (SF) % on compressibility characterizes.

4.3 Silica Fume's Effect on Shear Strength Parameters

The direct shear test was carried out on untreated and treated prepared expansive soil in order to study the impact of (SF) on shear strength parameters (c and ϕ). The outcome of these tests is presented in Table 2 and Figure 5. From this, it is noticed that the cohesion (c) decreased as the percentage of silica fume increased. While (ϕ) was increased as the percentage of (SF) increased. This behavior results from a chemical reaction between soils and (SF) and internal friction of silica fume particles.

Table 2: Shear strength parameters for untreated and treated soil.

SF%	Cohesion (kPa)	The angle of internal friction (ϕ°)
0	26	9.46
8	22	11.3
9	19	12.72
10	18	14.47
11	17	15.44
12	15	15.47
13	15	16.85

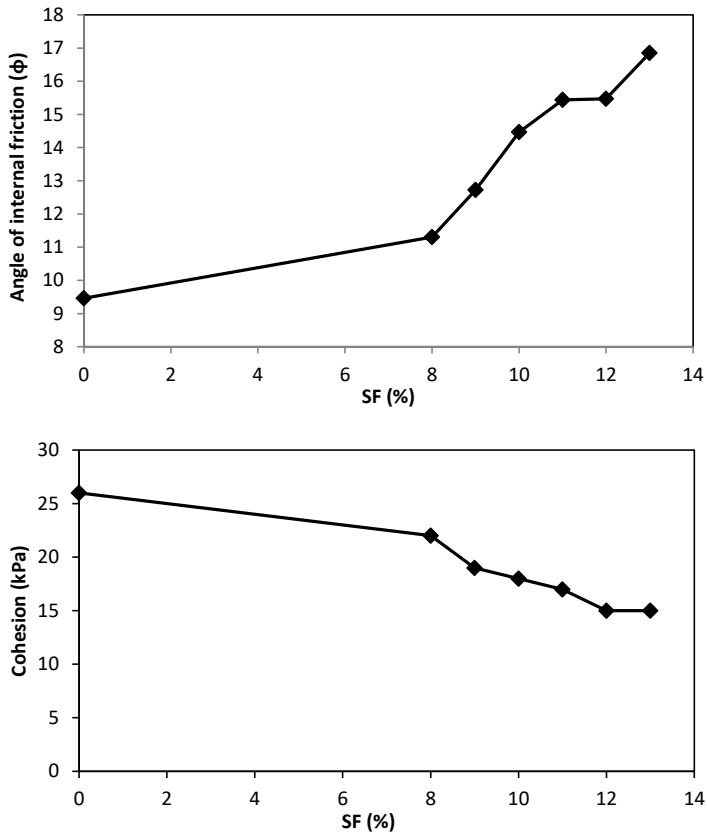


Figure 5: Influence of (SF) % on shear strength parameters.

4.4 Silica Fume's Effect on Swelling

A swelling test was done for treated and untreated prepared expansive soil using consolidation cells to determine the impact of (SF) addition on soil swelling. The influence of (SF) addition on swelling percentage is shown in Figure 6, from which it can be noticed that the swelling percentage decreases by increasing the percentage of (SF). This is due to the interaction between (SF) particles and the soil minerals.

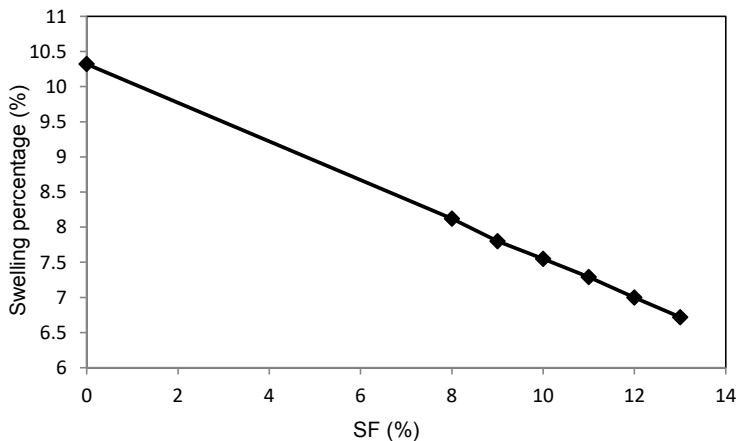


Figure 6: Influence of (SF) % on swelling percentage.

5. CONCLUSIONS

Depending on the outcomes achieved and the discussion, it is important to draw the following conclusions:

- As (SF) % increases, the L.L, P.L., and P.I. increase.
- The compression index (Cc) and swelling (expansive) index (Cr) decreased with increasing (SF) %.
- By adding (SF), the cohesion (c) decreased while the angle of internal friction (ϕ) increased.
- The swelling percentage % decreased with the increase in (SF) %.
- From this work, we concluded that (SF) can modify the geotechnical properties of expansive soil.

REFERENCES

- [1] AL-Ani SM, Karkush MO, Zhussupbekov A, Al-Hity AA. Influence of magnetized water on the geotechnical properties of expansive soil. In *Modern Applications of Geotechnical Engineering and Construction: Geotechnical Engineering and Construction*. Springer Singapore. 2021.
- [2] Chen FH. *Foundations on expansive soils*. Elsevier. 2012 Dec 2.
- [3] STAVRIDAKIS, Evangelos I.; AL-RAWAS, A. A.; GOOSEN, Z. F. A. Assessment of anisotropic behavior of swelling soils on ground and construction work. In: *Expansive soils: recent advances in characterization and treatment*. London: Taylor and Francis. 2006; 371-384.
- [4] Cokca E. Use of class c fly ashes for the stabilization of an expansive soil. *Journal of Geotechnical and Geoenvironmental Engineering*. 2001 Jul; 127(7):568-73.
- [5] Joel M, Agbede IO. Mechanical-cement stabilization of laterite for use as flexible pavement material. *Journal of Materials in Civil Engineering*. 2011 Feb; 23(2):146-52.
- [6] Al-Kalili A, Ali AS, Al-Taie AJ. A review on expansive soils stabilized with different pozzolanic materials. *Journal of Engineering*. 2022 Jan 1; 28(1):1-8.
- [7] Abdalla TA, Salih NB. Hydrated lime effects on geotechnical properties of clayey soil. *Journal of Engineering*. 2020 Nov 1; 26(11):150-69.
- [8] Kumar BS, Preethi TV. Behavior of clayey soil stabilized with rice husk ash & lime. *Int J Eng Trends Technol*. 2014 May; 11(1):44-8.
- [9] Radhakrishnan G, Kumar MA, Raju GV. Swelling properties of expansive soils treated with chemicals and fly ash. *Am J Eng Res*. 2014; 3(4):245-50.
- [10] Sorsa A. Engineering Properties of Cement Stabilized Expansive Clay Soil. *Civil and Environmental Engineering*. 2022 Jun; 18(1):332-9.
- [11] Ahmed MD, Hamza NA. Effect of metakaolin on the geotechnical properties of expansive soil *Journal of Engineering*. 2015 Dec 1; 21(12):29-45.
- [12] Ali NA, Karkush MO. Improvement of unconfined compressive strength of soft clay using microbial calcite precipitates. *Journal of Engineering*. 2021 Feb 27; 27(3):67-75.
- [13] Bharadwaj S, Trivedi MK. Impact of micro silica fumes on engineering properties of expansive soil. *Int J Sci Technol Eng*. 2016 Jun; 2(12):43540.
- [14] Goodarzi AR, Goodarzi SH, Akbari HR. Assessing geo-mechanical and micro-structural performance of modified expansive clayey soil by silica fume as industrial waste. *Iranian Journal of Science and Technology Transactions of Civil Engineering*. 2015 Aug 1; 39(C2):333-50.
- [15] Gupta C, Sharma RK. Influence of micro silica fume on sub grade characteristics of expansive soil. *International Journal of Civil Engineering Research*. 2014; 5(1):77-82.
- [16] Kalkan E, Akbulut S. The positive effects of silica fume on the permeability, swelling pressure and compressive strength of natural clay liners. *Engineering geology*. 2004 May 1; 73(1-2):145-56.
- [17] Kalkan E. Influence of silica fume on the desiccation cracks of compacted clayey soils. *Applied clay science*. 2009 Mar 1; 43(3-4):296-302.
- [18] Kalkan E. Effects of silica fume on the geotechnical properties of fine-grained soils exposed to freeze and thaw. *Cold Regions Science and Technology*. 2009 Sep 1; 58(3):130-5.
- [19] Negi C, Yadav RK, Singhai AK. Effect of silica fume on index properties of black cotton soil. *Int J Sci Eng Res*. 2013 Aug; 4(8):828-33.
- [20] Kalkan E. Preparation of scrap tire rubber fiber-silica fume mixtures for modification of clayey soils. *Applied Clay Science*. 2013 Aug 1; 80:117-25.
- [21] Mohamed MH. Evaluation the Swelling Properties of Expansive Soil mixed with Rice Husk Ash (RHA) and Silica Fume (SF). *Journal Of Engineering and Computer Sciences*. 2015; 8(2):95-108.
- [22] Karkush MO, Ali HA, Ahmed BA. Improvement of unconfined compressive strength of soft clay by grouting gel and silica fume. In *Proceedings of China-Europe Conference on Geotechnical Engineering*. Springer International Publishing. 2018; 1(1): 546-550.
- [23] Fattah MY, Al-Saidi A, Jaber MM. Improvement of bearing capacity of footing on soft clay grouted with lime-silica fume mix. *Geomechanics and Engineering*. 2015 Jan 1; 8(1):113-32.
- [24] Fattah MY, Al-Saidi AA, Jaber MM. Characteristics of clays stabilized with lime-silica fume mix. *Italian Journal of Geosciences*. 2015 Feb 1; 134(1):104-13.

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- [25] Fattah MY, Al-Saidi AA, Jaber MM. Consolidation properties of compacted soft soil stabilized with lime-silica fume mix. *International Journal of Scientific & Engineering Research*. 2014 Jul; 5(7):1675-82.
- [26] REZAEI, Azadeh. Effect of silica fume and curing time on volume change characteristics of rice husk ash stabilized expansive soil. PhD Thesis. Eastern Mediterranean University (EMU)-Doğu Akdeniz Üniversitesi (DAÜ). 2014.
- [27] Bell F. *Engineering treatment of soils*. CRC Press; 1993 May 6.
- [28] Sivapullaiah PV, Sridharan A, Bhaskar Raju KV. Role of amount and type of clay in the lime stabilization of soils. *Proceedings of the Institution of Civil Engineers-Ground Improvement*. 2000; 4(1):37-45.
- [29] Attom MF, Al-Sharif MM. Soil stabilization with burned olive waste. *Applied clay science*. 1998 Sep 1; 13(3):219-30.
- [30] AL-Ani SM, Karkush MO, Zhussupbekov A, Al-Hity AA. Influence of magnetized water on the geotechnical properties of expansive soil. In *Modern Applications of Geotechnical Engineering and Construction: Geotechnical Engineering and Construction 2021* (pp. 39-50). Springer Singapore.
- [31] Karkush MO, Yassin S. Improvement of geotechnical properties of cohesive soil using crushed concrete. *Civil Engineering Journal*. 2019 Oct 7;5(10):2110-9.