Improvement of Expansive Soil by Using Micro Silica Fume

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***Abstract* - Expansive soil shows frequent volume changes with the changes in the moisture content, causing severe problems to the civil engineering structures. Consequently, the measurements of swelling properties including free swell index and swelling pressure are extremely important. Several attempts are being made all over the world to control the swell-shrink behavior of expansive soils. Many researches have investigated how to overcome the problems of such soils by means of using different additives such as cement, lime, steel fibers, stone dust and fly ash. This study is directed towards the improvement of expansive soil with a new, inexpensive and environmentally friendly additive. In this study, the effect of using micro silica fume to stabilize the soil was investigated through a laboratory study. Test results showed that, the micro silica fume can considerably decrease the free swell index value by 69% at 25% micro silica fume content. Also, the swelling pressure is reduced from 410 kN/m^2 to nearly 330 kN/m^2 and 302 kN/m^2 at micro silica fume content of 5% and 25%, respectively. This demonstrates the effectiveness of the proposed addition in the expansive soils improvement. This improvement technique can be used in different civil engineering construction projects including slope stabilization and road embankments.**

Keywords: Micro silica fume, improvement, expansive soil, swelling pressure and free swell index.

I. INTRODUCTION

Swelling soils is the generic description of all soils containing montmorillonite mineral. Swelling soil deposits are mainly found near the arid areas of Egypt including the regions extending around the Nile valley in Upper Egypt [1]. Swelling soils, also known as expansive soils or reactive soils, composed predominantly of high percentage of fine-grained clay particles. Also, high plastic clays are defined as fine-grained clays with a plasticity index greater than 35%. This soil type is prone to remarkable volumetric changes due to changes in the moisture content. The main cause of volume change behavior is the increase and decrease in soil moisture content which results in the swelling and the shrinkage phenomena, respectively. Several classifications based on parameters such as moisture content, dry unit weight, Atterberg limits and clay content have been proposed in the Egyptian Code of practice as indicators of the soil swelling behavior. Direct measurements of the swelling potential using laboratory and/or field tests, are essential once a soil shows indications of swelling behavior. Improvement methods such as soil replacement, compaction control and chemical stabilization showed significant reduction in the swelling potential. The choice of the appropriate method depends on the depth of the soil, type of structure to be constructed, and the cost and practicality of the method. Kate, 2008 [2] studied the engineering properties of expansive soil when it is mixed with fly ash. Gupta and Sharma, 2014 [3] investigated the effect of adding micro silica fume on the shear strength of expansive soil to be used as a sub grade material for construction of flexible pavements in rural roads with low traffic volume. An experimental investigation was performed to quantify the effect of mixing bentonite as a swelling soil with chemical additives such as sodium chloride, lime, sodium carbonate and ammonium chloride by Elmashad, 2017 [1]. Sakr et al., 2020 investigated the effect of using nanoclay [4] and micro metakaolin [5] on reducing the swelling potential of expansive soils. Also, several researchers proposed different techniques to improve the geotechnical properties of expansive soils by adding dust shield polymer [6], waste tire rubber [7], nanoclay [8] and egg shell powder mixed with plastic wastes [9] and with corn cob ash [10].

In this study the effect of using micro silica fume to stabilize the swelling soils is investigated through a laboratory testing program. The conducted tests include XRD analysis, free swell index, swelling pressure and compaction on expansive soil stabilized with different percentages of micro silica fume.

II. MATERIALS AND EXPERIMENTAL PROCEDURES

A. Tested soil

The soil used in this study is obtained from the Bentonite and Derivatives Company in Borg Al-Arab, Alexandria, Egypt. The bentonite presents the expansive soil in a homogeneous phase. The chemical and physical properties of the tested soil are illustrated in Table I, the mechanical properties of the bentonite are listed in Table II and the bentonite sample is shown in Fig. 1a. The obtained results of the hydrometer analysis performed on the bentonite material indicated that the tested samples contains 64% clay and 36% silt.

B. Micro silica fume

The used additive for treating the expansive soil is a commercial material known as micro silica fume (SF). SF is obtained from Cementrac for cement and contentious materials company (S.A.E) in Cairo, Egypt. The main properties of the used micro silica fume are illustrated in Table III, its mechanical properties are listed in Table IV and the silica fume additive is shown in Fig. 1b.

Silica fume is a very fine solid material generated during silicon metal production and is considered as a waste product. It is a by-product of production of silicon metal or ferrosilicon alloys. Although the silica fume is a waste industrial material, it has become one of the most valuable by-product pozzolanic materials due to its very active and high pozzolanic property [11]. Silica fume is used to improve the physical and chemical properties of the expansive soil because of its high ability to adsorb water according to the manufacturer’s data sheet.

TABLE I
CHEMICAL & PHYSICAL PROPERTIES OF THE USED BENTONITE (ACCORDING TO THE MANUFACTURER’S DATA SHEET)

Property		Value
Physical properties	Specific gravity, Gs	2.6
	Initial water content, Wc (%)	10
	Quartz (%)	35 - 50
	Smectite (%)	35 - 50
	Kaolinite (%)	10 - 16
	Others (%)	0 - 10
Chemical properties	SiO_2 (%)	٦١
	Al_2O_3 (%)	١٤,٥٩
	Fe_2O_3 (%)	٢,٠٩
	TiO_2, SO_2, Cl, BaO (%)	< 0.5
	CaO, K_2O (%)	0.77
	MgO (%)	٢,٢٢
	Na_2O (%)	٢,٠٤
	Loss on ignition, LOI (%)	١٣,٢

TABLE II
MECHANICAL PROPERTIES OF THE USED EXPANSIVE SOIL

Property	Value
Free swell index, SI (%)	501.98
Density, γ (kN/m^3)	10.69
Liquid limit, L.L. (%)	331
Plastic limit, P.L. (%)	36
Plasticity index, P.I. (%)	295

C. X-Ray Diffraction analysis

X-Ray Diffraction (XRD) analysis was conducted on the expansive soil samples in the central laboratory at Tanta University. 2Theta chart for the expansive soil is shown in Fig. 2. X-Ray Diffraction (XRD) test was also conducted on the micro silica fume sample in the central laboratory at Tanta University. 2Theta chart for the micro silica fume is shown in Fig. 3.

TABLE III
THE MAIN PROPERTIES OF THE USED MICRO SILICA FUME (ACCORDING TO THE S.A.E. DATA SHEET)

SiO_2 (%)	92 - 96
Free Si (%)	٠,١٤
Free CaO (%)	< 0.1
SO_3 (%)	٠,٢٥
Na_2O (%)	٠,٥
Cl^- (%)	< 0.1
Loss on ignition, LOI (%)	2.0
Specific Surface (BET, m^2/g)	< 25
Pozzolanic activity index curing (28d)	110
Pozzolanic activity accelerated curing (7d)	120
H_2O (%)	0.5
> 45 µm (%)	< 2
pH	٨
Brightness	4٥ - 6٥

TABLE IV
MECHANICAL PROPERTIES OF THE USED MICRO SILICA FUME

Property	Value
Free swell index, SI (%)	0.0
Density, γ (kN/m^3)	8.17
Liquid limit, L.L. (%)	N/A
Plastic limit, P.L. (%)	N/A
Plasticity index, P.I. (%)	N/A

Kaolinite component peaks mainly exist at 2Theta equals 12.3° and 24.9°. While, quartz component peak exists at 2Theta equals 27° and smectite (montmorillonite) component peak exists at 2Theta equals 5.9°. As a result, a tangent line was drawn to calculate the areas under those peaks. According to the calculated areas, each component percentage can be obtained. The soil mineralogy is shown in Table V. As can be seen from this table, the expansive soil consists of 40% quartz, 40% smectite and 16% kaolinite.

III. TESTING METHODOLOGY

The bentonite presents the expansive soil in a homogenous phase. The preparation of test samples is an important step, to form a homogenous sample mix for testing. The main principle is to prepare a reconstituted soil with a certain additive content and then compact it to a certain dry unit weight (80% of maximum γdry) [12] in the cell of Oedometer. The tool of sample compaction is presented in Fig. 4. This compaction tool is prepared in our laboratory as described by [12 and 13]. It is composed of a disc fixed to a rod with a load of 136 gm slides alongside of the rod, falls from 150 mm height and comes to strike the disc to compact the mixture. Therefore, to prepare the expansive soil-additive mixture samples for testing, these samples were oven dried at 105ºc [1], then weighted according to the maximum dry unit weight of the soil and the chosen percentage of additive and physical mixing for 10 minutes to each portion was adopted. Finally, the weighted amount of the mixture is compacted using the tool described previously in two layers with the same compaction energy. The tested sample is levelled inside the ring of Oedometer cell taking into consideration keeping the upper surface as a levelled surface.

IV. TESTING PROGRAM

Though the focus of this study was to investigate the swell potential mitigation of the expansive soil, other geotechnical characteristics of tested soil should be studied. In this study, the effect of adding micro silica fume on the X-Ray Diffraction analysis was conducted to determine the change in the mineralogical structure of the mixture after micro silica fume addition. The compaction curves were determined according to the ASTM, D 1557 [14]. Also, the free swell index and the swelling pressure of soil were obtained according to the ASTM, D 4546 [15]. The amounts of micro silica fume added to the expansive soil samples as a percentage of the dry soil mass were (5%, 10%, 15%, 20% and 25%).

(a) Expansive soil sample (b) Micro silica fume additive

Figure 1. Tested soil and the micro silica fume additive

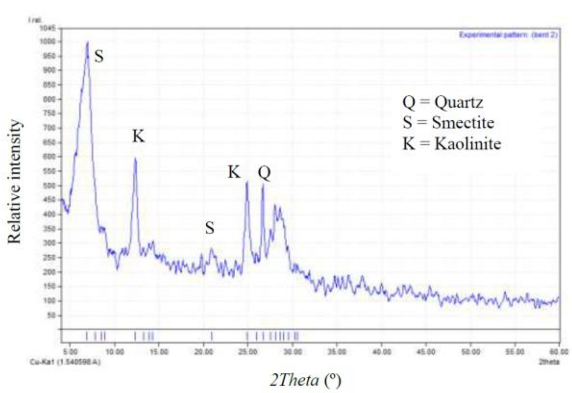

Figure 2. *2Theta* chart of the expansive soil sample

TABLE V
EXPANSIVE SOIL MINERALOGY

Kaolinite	Quartz	Smectite	Others
16%	40%	40%	4%

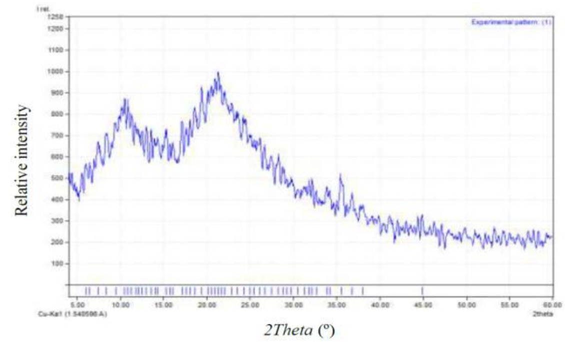

Figure 3. *2Theta* chart of the used micro silica fume

V. TEST RESULTS

A. Influence of SF content on X-Ray Diffraction analysis

Fig. 5 shows the *2Theta* chart of the expansive soil after micro silica fume addition. As can be seen from this figure, the percentage of smectite (montmorillonite) present inside the expansive soil remains the same with increasing the micro silica fume content till 25%. This indicates that there is no changes in the mineralogical characteristics of the treated soil due to the fact that adding micro silica fume is only physical mixing without any effect on the crystalline structure of the expansive soil. This result is in conformity with the results observed by Taha and Taha, 2012 [16].

B. Influence of micro silica fume content on the free swell index

The obtained values of the free swell index (SI) for the tested soil mixed with different percentages of micro silica fume (SF) are presented in Fig. 6 and tabulated in Table VI. As shown in this figure, the addition of micro silica fume (SF) gradually to the expansive soil samples decreases the swelling behavior of soil. Hence, the free swell index (SI) decreases with the increase in micro silica fume content till 25%. For 5% and 25% SF content, the free swell index was reduced by about 46% and 69%, respectively as compared to the untreated sample. The optimum content for SF is 5% as for SF content exceeding this value, there is no much change in the free swell index of soil. This is also confirmed by other investigators [17 and 18]. The reduction in the free swell index values of the improved soils is explained by the fact that micro silica fume fills the voids between soil particles. Silica fume reduces porosity and improves water resistance making the expansive soil less capable of swelling.

Influence of micro silica fume content on the swelling pressure

The obtained values of swelling pressure (Sp) for the tested soil mixtures at different micro silica fume contents are shown in Fig. 7 and tabulated in Table VII. As can be seen from this figure, it is clearly observed that the addition of micro silica fume (SF) gradually to the expansive soil samples decreases the swelling pressure (Sp) till micro silica fume content of 25%. The series of Oedometer tests used to evaluate the swelling pressure of expansive soil confirmed that SF enhanced the expansive soil properties and formed a new improved mixture. For 5% and 25% SF content, the swelling pressure was reduced by 20% and 26%, respectively as compared to the untreated sample. The optimum content for SF can be considered as 5% as mentioned previously as there is no much change in the swelling pressure after this content. Swelling pressure reduction is due to adding a non-expansive particles to the expansive soil. Also, this can be attributed to the interaction of the expansive soil with micro silica fume particles. These results are in conformity with the results obtained by [17 and 18].

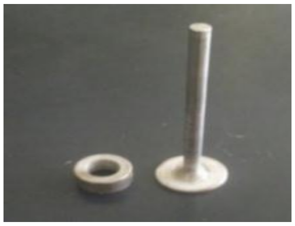

Figure 4. Compaction tool

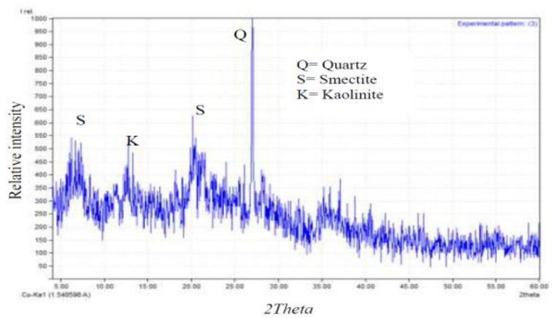

Figure 5. *2Theta* chart of the expansive soil mixed with 5% micro silica fume by dry weight

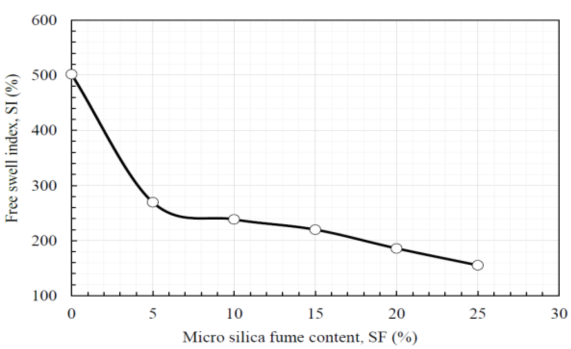

Figure 6. Relationship between SF content and the free swell index

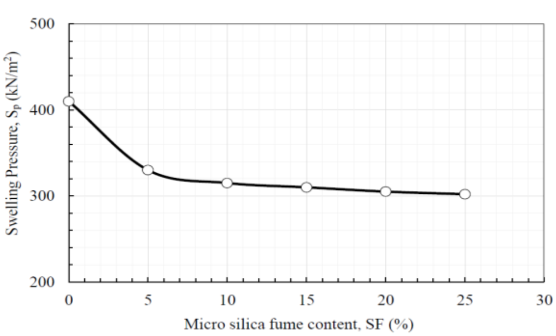

Figure 7. Relationship between SF content and the swelling pressure

TABLE VI
% (SF) CONTENT AND CORRESPONDING (SI)

SF content (%)	SI (%)
0	501.98
5	269.76
10	238.63
15	220.06
20	186.09
25	155.47

SF: Micro silica fume; SI: free swell index

TABLE VII
% (SF) CONTENT AND CORRESPONDING (S_P)

SF content (%)	Sp (kPa)
0	410
5	330
10	315
15	310
20	305
25	302

SF: Micro silica fume; S_p: swelling pressure

D. Influence of micro silica fume content on the compaction parameters

The compaction curves for the soil mixed with different micro silica fume contents are shown in Fig.8 and tabulated in Table VIII. Fig. (9 and 10) show the Influence of SF on the maximum dry unit weight and the optimum moisture content, respectively.

As can be seen from these figures, mixing the expansive soil with micro silica fume decrease the maximum dry unit weight and increases the optimum moisture content. This could be backed to the fact that the weight of SF is much lesser than the weight of the expansive soil leading to the decrease in the weight of the mixture.

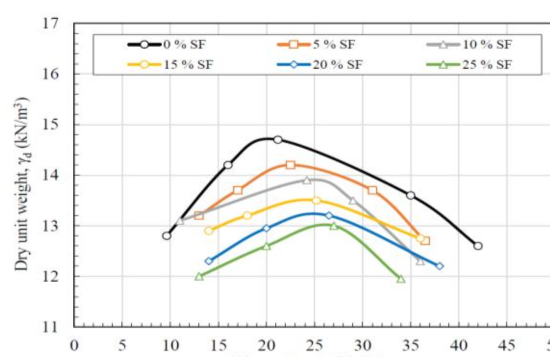

Figure. 8. The relation between dry unit weight and water content for different micro silica fume (SF) contents

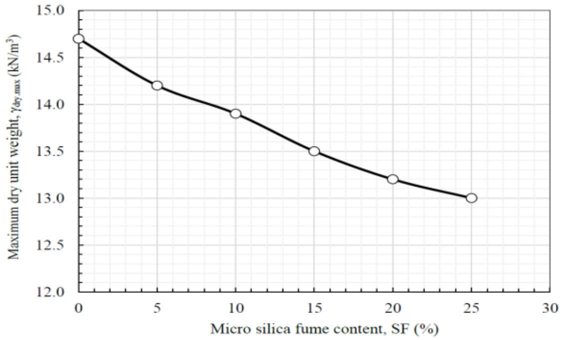

Figure. 9 Influence of SF on the γ_{dmax} of expansive soil

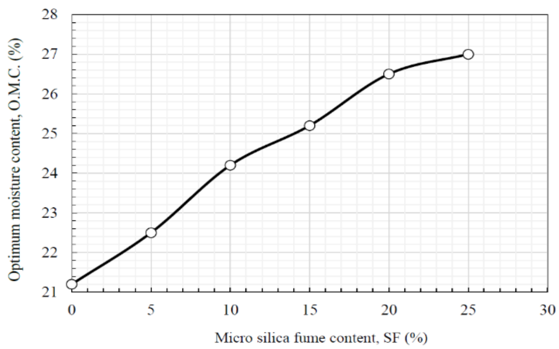

Figure 10. Influence of SF on the O.M.C. of expansive soil

VI. CONCLUSION

A laboratory testing program was performed to study the effect of using micro silica fume on the characteristics of expansive soil. The obtained results can be summarized as follows:

• Improvement of expansive soil with micro silica fume showed significantly lower free swell index in comparison with untreated soil. Adding 5% and 25% micro silica fume to the expansive soil, the free swell index of tested soil was reduced by 46% and 69%, respectively.

• Using micro silica fume reduced the swelling pressure of the untreated soil from 410 kN/m^2 to 330 kN/m^2 and 302 kN/m^2 for the treated soil at 5% and 25% micro silica fume content, respectively.

• Adding micro silica fume decreased the resulted maximum dry unit weight and increased the optimum moisture content. Meanwhile, no change was noticed on the X-Ray Diffraction analysis of the expansive soil due to adding micro silica fume.

• • • Based on the test results, it can be recommended to use micro silica fume as a cheap, environmentally friendly stabilizer for the improvement of the expansive soil at 5% micro silica fume content.

VII. REFERENCES

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