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Geotechnical Properties of Expansive Soil Treated with Silica Fume

Dr. Zeena Waleed S. Abbawi
Building and Construction Department, University of Technology/ Baghdad
Email:zinawaleed2004@yahoo.com

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ABSTRACT

Problematic soils such as expansive soil are those clay soils which exhibited significant volume changes as results of soil moisture variation, when a dry mass of clay is allowed to absorb water, the effective size of particles increases and therefore the clay mass swells. This type of soil, upon wetting and drying, causes sever damage to structures built on such soil.

A treatment of swelling/shrinkage using silica fume was studied in this work. The soil selected for the present investigation classified as (CH) according to unified soil classification system with liquid limit = 51% and plastic limit = 27%. Soil specimens were mixed with various percentages of silica fume contents (10%, 20%, 25%, 30% and 50%) to determine their effects on geotechnical properties such as Atterberge's limits, compaction, unconfined compression and swelling properties.

The results show that the silica fume played an important role in improving the problem of swelling behavior in expansive soil. The silica fume decrease liquid limit and changed compaction parameters of expansive soils the moisture content values increased and the maximum dry unit weight values decrease. Also the silica fume increased unconfined compressive strength, decreased the compressibility and the vertical swelling percentages of clayey soil-silica fume mixtures.

Keywords: Expansive Soil, Silica Fume, Vertical Swelling Percentages.

الخواص الجيوتكنيكية للترب الأنتفاخية المعالجة بمادة السيليكا فوم

الخلاصة

تعرف الترب ذات المشاكل مثل الترب الأنتفاخية بانها الترب الطينية التي تعاني من تغيرات في الحجم كنتيجة للتغير في المحتوى الرطوبي فعندما تكون جافة و يسمح لها بامتصاص الماء فالحجم الفعال للحبيبات يزداد وهذا يؤدي الى ان كتلة الطين ستنتفخ و تؤدي مثل هذه الترب نتيجة لعمليات التجفيف و الترطيب الى ان تتسبب باضرار كبيرة للمنشات المقامة عليها. في هذا البحث تم دراسة معالجة الترب الأنتفاخية باستعمال مادة السيليكا فيوم. صنفت التربة المستعملة تبعا للتصنيف الموحد بانها تربة طينية غيرعضوية عالية اللدونة بمحتوى سيولة قدره ٥١% ومحتوى لدونة قدره ٢٧%. نماذج التربة تم خلطها بنسب مختلفة من مادة السليكا فيوم (١٠%,٢٠%,٢٥%,٣٠%,٥٠%). تم

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2412-0758/University of Technology-Iraq, Baghdad, Iraq

دراسة تأثيرها على حدود أتربرك وعلى الرص و مقاومة التربة وتأثيرها على خصائص الأنتفاخ للتربة. و أظهرت النتائج بأن مادة السليكا فيوم تلعب دور كبير في تحسين مشكلة الأنتفاخ التي تعاني منها الترب الأنتفاخية حيث وجد بأنها تقلل من حدود السيولة للتربة وتغير عوامل الرص بحيث انها تزيد من محتوى الرطوبة المثلى وتقلل من قيمة الكثافة الجافة العظمى كما انها تعمل على زيادة مقاومة التربة للأنضغاط غير المحصور وتقلل من انضغاطية التربة ومن نسبة الأنتفاخ العمودي للتربة المضاف اليها مادة السليكا فوم .

INTRODUCTION

Soil stabilization is a virtual task not only for weak soils but also for expansive types as well. Expansive potential of highly plastic clay is a source of great damages and economical dispense.

The construction on subgrades requires sometimes altering the engineering properties of the upper soil layers, using one of the available stabilizing methods. Theses include the use of chemical additives, rewetting, soil replacement compaction control, surcharge loading and thermal methods. [(Chen, (6), (Nelson and Miller, (16) and (Young and Ouhadi, (21)]. The experimental investigations of the behavior of swelling soils using chemical additives are numerous. [(Fattah et al., (8)] studied treatment of expansive soil using four types of additives: cement, steel fibers, gasoline fuel and injection by cement grout. The results shows the treatment of the expansive soils with 5% of cement or steel fibers or the injection with cement grout revealed a better improvement while 4% of gasoline oil is sufficient to reveal the optimum treatment by this material and the angle of friction is not affected by the treatment while the cohesion between particles is slightly affected by the additives due to a change in the adhesion between the additives and soil particles. [(Ali and Koranne, (1)] investigated the effect of stone dust and flyash combine at different percentage on the expansive soil. The test results such as index properties, Procter compaction, swelling pressure and unconfined compressive strength obtained on expansive clays mixed at different proportions of stone dust and flyash. From the results, it is observed that at optimum percentages 20% to 30% of admixture, it is found that the swelling of expansive clays is almost controlled and there is a marked improvement in the other properties of soil. The conclusion drawn from this investigation is that the combination of equal portion stone dust and flyash is more effective than the addition of stone dust/flyash alone to the expansive soil in controlling the swelling nature. [(Ramadas et al., (20)] performed laboratory tests carried out on three expansive soil treated with lime and flyash to determine their effects on geotechnical characteristics such as Atterberge limits, the compaction, unconfined compression and swelling properties. The experimental results noticed a better improvement in the properties of expansive soil. [(Abdullah and Alsharqi, (2)] studied rehabilitation of medium expansive soil using cement treatment with various contents (1%, 2%, 3% and 4%). It was found that 2% cement content cured for 28 days was sufficient to reduce the free swell percentage for medium expansive soil from as high as 7.4% to merely 0.4%. The potential swell pressure was reduced from a damagingly high value (333kPa) for the untreated soil to a tolerable value (20kPa) for the same enhancement conditions.

New methods continue to be researched to increase the strength properties and to reduce the swell behaviour of expansive soils. [(Puppala and Musenda, (19) and (Mo and Yasrobi, (15)]. Many investigations have studied natural fabricated and by product materials and their use as stabilizers for the modification of clayey soils.

[(Prabakar et al., (18), (kalkan and Akbulut,(11), (Cetien et al.,(5), (kalkan,(10), (Akbulut et al.,(3)]. In pervious studies, the effect of silica fume on the hydraulic conductivity and swelling pressure of clayey soils were investigated. It was seen that clayey soil-silica fume mixtures were shown to have low hydraulic conductivity and swelling pressure values. (kalkan,(9), examined the suitability of using silica fume as a stabilization material to reduce development of desiccation cracks in compacted clayey linear and cover systems. The results show that the silica fume waste material can be successfully used to reduced development of desiccation cracks in compacted clayey linear and cover systems.

MATERIALS USED

Soil Used

The soil used brought from north of Iraq. It is in general light brown colored clay. The soil is classified as (CH) according to unified soil classification system and described as "Inorganic clay with high plasticity".
The grain size distribution of this soil is shown in Figure (1). It is properties are summarized in Table (1).

Silica Fume

Densified silica fume from Elkem Materials Company in Dubai has been used as a mineral admixture added to the mixture of the research. The used percentages are (10%, 20%, 25%, 30% and 50%) of soil weight. Silica fume is highly active pozzolanic material and is by product from the manufacture of silicon or ferro silicon metal. It is collected from the flue gases from electric arc furnaces. Silica fume is an extremely fine powder, with particles about 100 times smaller. The chemical composition of silica fume used in this investigation in Table 2. The silica fume used in this work conforms to chemical and physical requirements of ASTM C 1240-03 as shown in Table (3 and 4).

PREPARATION OF SAMPLES

Preparation of Clayey Soil-Silica Fumes Mixtures.

The clay soil samples were dried in the oven at 100º C before gridding. Then the clay soil and silica fume were blended under dry condition to prepare mixtures. The amount of silica fume was selected to (10%, 20%, 25%, 30% and 50%) of the total dry weight of the clay soil-silica fume mixture. The dry mixtures were mixed with the required amount of water to give the optimum moisture content.

Preparation of Samples for the Index Properties Tests.

The following tests were conducted on the soil samples mixed at different percentages of silica fume admixtures. The liquid Limit and plastic Limit tests were conducted according to (ASTM D 4318). Compaction test was carried out according to (ASTM D 698) to determine compaction parameters (optimum moisture content and maximum dry density).Clay soil-silica fume mixtures were blended with various amount of water. Each material was evaluated at six different water concentrations in three steps. Unconfined compressive strength (UCS) tests were conducted at optimum moisture content and maximum dry density as per ASTM D2166.

Preparation of Samples for the Consolidation Tests

The samples were prepared at the natural moisture content and the wet unit weight of the soil. For the treated samples, the amount of additive by weight is added to the dry weight of the soil to get the same unit weight while water (weighted by the total weight of dry soil) is then added. [Fattah et al., (8)]. For the sample treated by silica fume, the amount of silica fume by weight is mixed with the dry soil. Then, the water is added, the mixed soil with the additive is placed in the odeometer ring to carry out the test. When a soil is subjected to an increase of the effective stress through an increase of the overburden stress, the soil undergoes a long term reduction in void ratio, e, which is accompanied by a settlement of the soil layer [Fattah et al., (8)]. This test is conducted according to ASTM D 2435.

Preparation of Samples for the Vertical Swelling Tests.

After placing the soil in the odeometer ring, the porous stones and load pad are placed on the sample, and then the dial gauge is seated. Then a weight of 135 gm which is required to cause a pressure of (6.9 kN/m^2) is placed on the load ram. Water is added, until the sample is covered completely. At that time the dial gauge is reading the swelling due to the soil expansion. The final swelling reading is recorded after (24) hours of adding water. [Fattah et al., (8)]. This test is conducted according to ASTM D 4546.

The amount of vertical swelling percentage is determined using the following equation:

$$SVP = H_2\text{-}H_1/H_1 \qquad \ldots(1)$$

Where:

SVP = Swelling vertical percentage, %.

H_1 = The first height of sample before adding water.

H_2 = The final height of sample after it had been allowed to swell for 24 hr.

RESULTS AND DISCUSSIONS

Atterberg's limits, compaction tests, unconfined compressive strength, swell pressure and swell potential tests were conducted with different percentages of silica fume as admixtures in expansive soil for finding the optimum percentage of additives.

The Effect of Silica Fume on the Liquid Limit and Plastic Limit:

Results of liquid Limit and plastic Limit tests on expansive soil treated with silica fume are shown in Figure (2). It is observed that as the percentage of silica fume increases, there is a marked reduction in liquid Limit and plasticity index of clay tested. From this, it can be deduced that the flow characteristics and plastic characteristics of the soil samples are gradually decreasing with increase in the percentage of silica fume. This reduced plasticity of clay is very much required to avoid the failure pattern in the road construction over the expansive subgrade soils.

The Effect of Silica Fume on the Optimum Moisture Content and Maximum Dry Density

Optimum moisture content and maximum dry density for expansive clay varies when treated with silica fume are presented in Figure (3). From the figure, it can be seen that there is a decrease in maximum dry density value and increase in optimum moisture content with increases in percentage of silica fume. As also observed by [Pera et al. (17)] silica fume changed the particle size distribution and the surface area of the composite samples. Increasing in optimum moisture content are due to change in surface area of composite samples in the same way the reason for the decrease in the maximum dry density is the addition of higher amount of silica fume which filled with the voids of composite samples. Figure 4 represents effects of silica fume content on the compaction parameters (maximum dry unit weight and optimum moisture content) the values were normalized to that of natural soil, and expressed in term "Variables" represents the ratio of ($\gamma_{dry\ t}$ / $\gamma_{dry\ unt}$) which is defined as the ratio of maximum dry unit weight for treated samples to maximum dry unit weight for untreated samples and ratio of optimum moisture content for treated samples to optimum moisture content for untreated samples ($M_{opt\ t}$/ $M_{opt\ unt}$).

The Effect of Silica Fume on the Unconfined Compressive Strength (UCS)

For the compression study of (UCS), three samples for each percentage of the added silica fume were prepared using compaction test. The variations of unconfined compressive strength for all samples are presented in Figure 5. It can be observed that there is a good improvement in unconfined compressive strength of clay as increasing the percentages of silica fume. The unconfined compressive strength value at 50% addition of silica fume to the clay is (144.6 kPa). As compared to untreated soil, the percentage increase in (UCS) at 50% addition of silica fume is (72.4%). Through the increase in strength is marginal with addition of silica fume, there is a good control over the plasticity characteristics of clay. Table (5) shows results of unconfined compressive strength and the ratio of increase in strength (q_t/q_{unt}), which is defined as the ratio of unconfined compressive strength for treated samples to the unconfined compressive strength for untreated

The Effect of Silica Fume on the Void Ratio-Effective Stress Relationship:

The void ratio-effective stress relations for the natural clayey soil and clayey soil-silica fume mixtures are shown in Figure (6). It can be seen that silica fume decreased the compressibility of the composite samples, when an effective stress between 10 kPa and 800 kPa was applied. It was observed that the void ratio and compressibility gradually decreased with increasing silica fume contents. Table (6) summarized the results.

This behavior is due to the addition of low plastic material and the interaction between clay minerals and silica fume particles. The active silica reacts with calcium and hydroxide and forms calcium silicate hydrate gels. This chemical modification reduces clay mineral contents of composite samples. [(Attom and Al-sharif, (4) and (kalkan and Akbulut, (11)]. There are a number of studies on the effect of mineral composition on the compressibility and swelling behaviour of clayey soils. [(Mersi and Olson, (13), (Lamb and Whitman, (12), (Mitchell, (14) and (Di Maio et al., (7)]. The silica fume contents decreased the cation exchange capacity and specific surface area values of composite samples which caused low water holding capacity and swelling.

The Effect of Silica Fume on the Swelling Percentage:

The amount of swelling of natural clayey soil and composite samples is shown in Figure (7) and the results are summarized in Table (7). It can be seen that silica fume decreased the vertical swelling of clayey soil-silica fume mixtures. The vertical swelling percentages of clayey soil-silica fume mixture samples decreased from 18.7% to 2.7% for clayey soil-silica fume mixture containing 0%, 30% and 50% respectively.

CONCLUSIONS

1- The reduction of the index properties towards less plastic nature indicates that there will be pronounced reduction in the swelling potential.

2- The silica fume changed compaction parameters of clayey soil. The optimum moisture content values increased and the maximum dry unit weight values decreased with increased silica fume content.
3- The maximum unconfined compressive strength was gained by 50% silica fume addition. It was (144.6 kPa) as compared with (83.9 kPa) for untreated soils.
4- The additive mixtures played an important role in improving the problem of swelling behavior of clayey soil. Silica fume decreased the compressibility and swelling behavior of clayey soil- silica fume mixtures samples. Optimum silica fume addition is 20%.
5- The compression index (Cc) and swelling (expansive) index (Cr) for treated soils decreased compared with those for untreated soils.
6- Silica fume decreased the vertical swelling percentages of clayey soil- silica fume mixtures.

The following points are concluded based on the results obtained and discussion made in this study

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Table (1) Physical properties of Soil used.

Oxide Composition	**Oxide Content %**	**Oxide Composition**	**Oxide Content %**
SiO_2	95.95	CaO	1.21
Al_2O_3	0.02	MgO	0.01
Fe_2O_3	0.01	SO_3	0.22
Na_2O	0.01	L.O.L	2.5
K_2O	0.07		

Test No.	Index Property	Index Value
1-	Max.dry unit weight, γ_{dry}, (kN/m^3)	16.6
2-	Optimum Moisture Content ($M_{opt.}$)	19.7%
3-	Liquid Limit % (LL)	51%
4-	Plastic Limit % (PL)	27 %
5-	Plasticity Index % (PI)	24 %
6-	Linear Shrinkage Limit % (LS)	13.4
7-	Specific Gravity, Gs	2.72
8-	% of Clay	50%
9-	% of Silt	43%
10-	% of Sand	7%
11-	According to unified soil classification system(USCS)	CH

Table (2) Physical properties of Silica Fume used*

*Test was carried out at National Center of Geological Survey & Mining.

Table (3) Chemical Requirements of Silica Fume (SF) ASTM C 1240-03.

Oxide Composition	S.F	Limit of Requirements ASTM C 1240-03
SiO_2, Min. percent	90.0	>85
Moisture Content, Max. percent	0.68	<3.0
Loss on Ignition, Max. percent	2.86	<6.0

Table (4) Physical Requirements of Silica Fume (SF) ASTM C 1240-03.

Oxide Composition	S.F	Limit of Requirements ASTM C 1240-03
Percent Retained on 45Mm (No.325) sieve, Max.	7	<10
Accelerated Pozzolanic strength the Activity Index with Portland cement at 7 days, Min. percent of	128.6	>105

control		
Specific Surface, Min. percent, m^2/g	21	>15

Table (5). Results of unconfined compressive strength and increase in strength at different addition percentages of silica fume.

% silica fume	0%	10%	20%	25%	30%	50%
unconfined compressive strength(U.C.S.),q,(kPa)	83.9	115.9	128.9	137.7	139.8	144.6
increase in strength (q_t/q_{unt})	1.0	1.381	1.536	1.641	1.666	1.0

Table (6) Effect of silica fume on the compressibility characterizes.

% silica fume	0%	10%	20%	30%	50%
void ratio, (e)	1.186-1.007	1.107-0.999	1.057-0.982	1.000-0.925	0.925-0.864
Compression index,(Cc)	0.7143	0.32	0.28	0.25	0.231
Swelling index, (Cr)	0.1029	0.075	0.026	0.0256	0.0238

Table (7) Results of vertical swelling of clayey soil-silica fume mixtures.

% silica fume	0%	10%	20%	30%	50%
Swelling height, (mm)	10.2	5.5	2.5	1.5	1.5
Swelling percentage, (%)	18.7	10	4.5	2.7	2.7

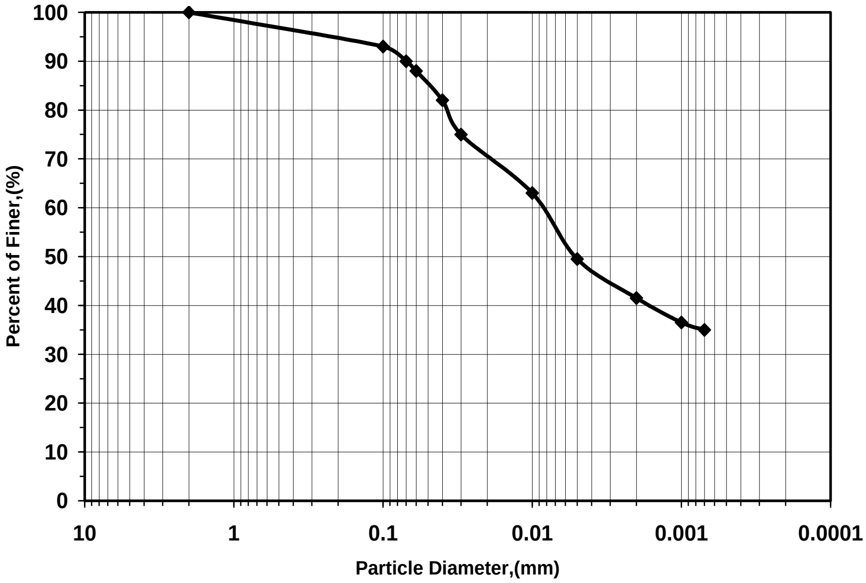

Figure (1). Grain Size Distribution of Soil Used

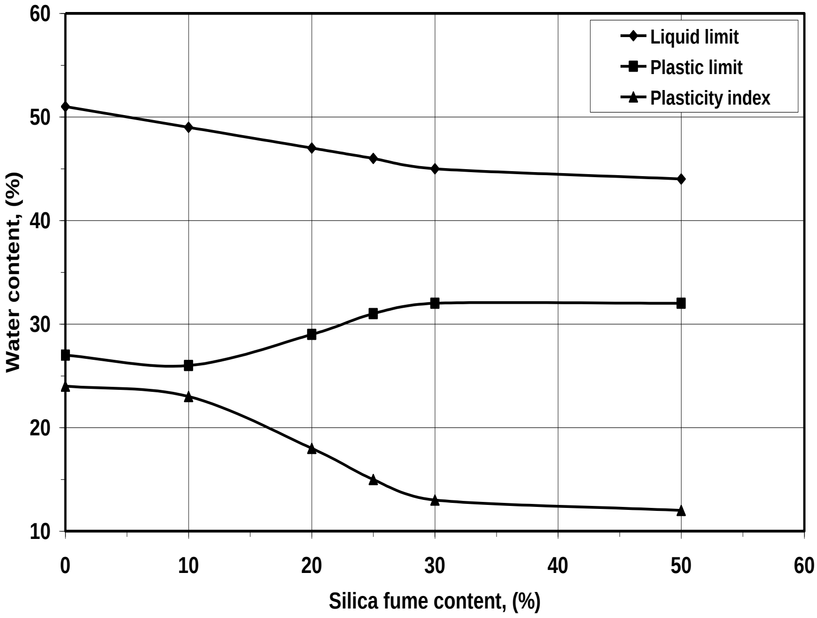

Figure (2). Effects of silica fume on the consistency limits

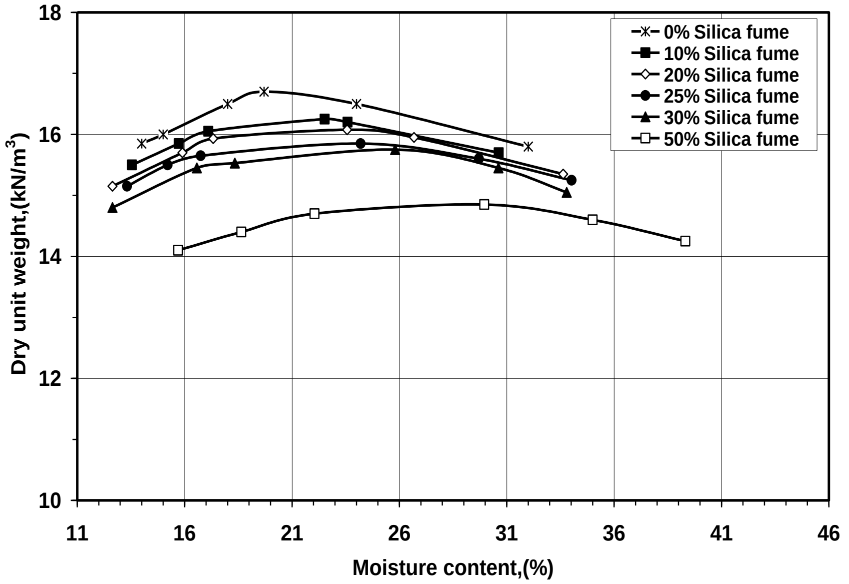

Figure (3). Relationship between dry unit weight and moisture content at different silica fume content

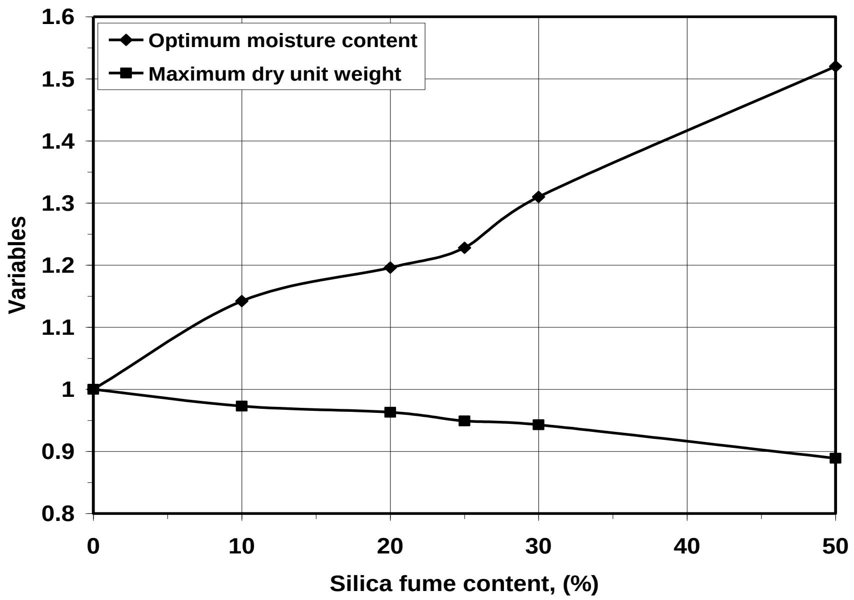

Figure (4). Effects of silica fume on the compaction parameters.

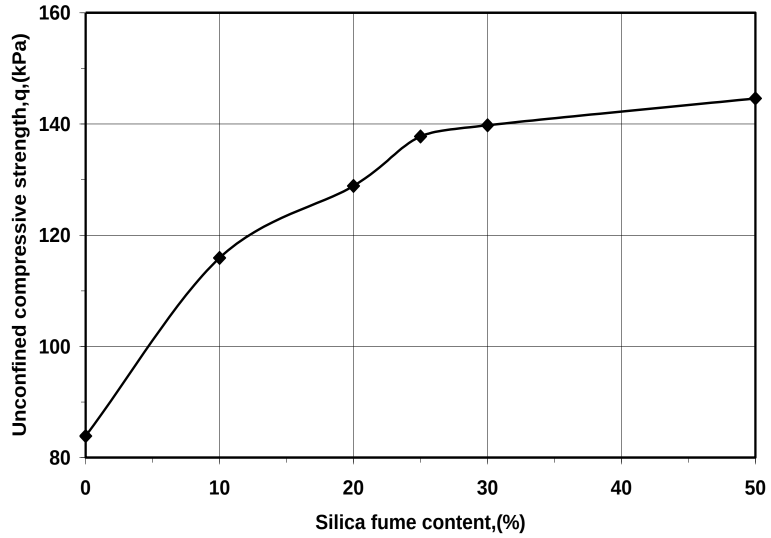

Figure (5). Effects of silica fume on the unconfined compressive strength.

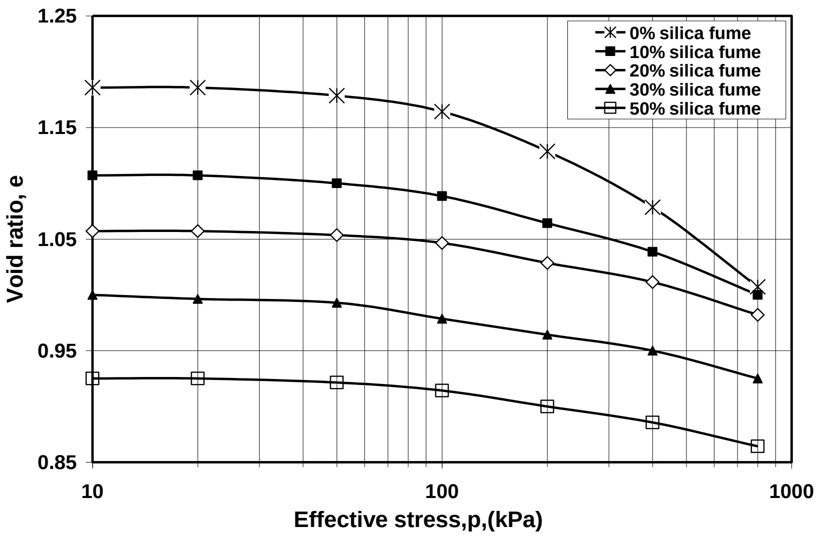

Figure (6). Effect of silica fume on the void ratio.

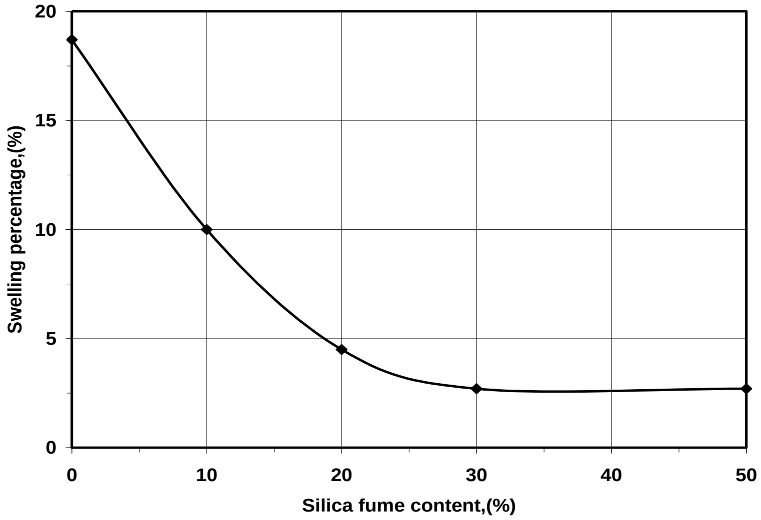

Figure. (7). Effect of silica fume on the swelling percentages.