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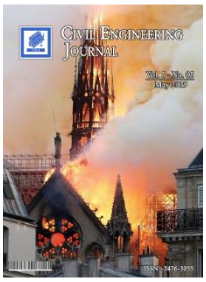

Effect of Soaking and Non-soaking Condition on Shear Strength Parameters of Sandy Soil Treated with Additives

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Abstract

The present paper aims to improve shear strength parameters: cohesion (c), and angle of internal friction (∅) for sandy soil treated by additives before and after soaking. The samples of sandy soil were obtained from Karbala city and then classified as poorly graded sand (SP) with relative density Dr (30%) according to the system of (USCS). The experiment has three stages. In the first stage ,the soil was treated with three different percentages of cement (3 ,5 and 7%) of dry weight for the soil with three different percentages of water content (2, 4 and 8%) in each above percentage of cement, while the second stage includes (2%) of lime from soil weight mixed with each different percentage of cement . In the third stage, (50%) of polymer of cement weight was mixed with each different percentage of cement. An analysis of behavior sandy soils treated by additives was carried out with the Direct Shear Tests. All the samples were cured (3) days before and after soaking. The results of the experiment showed that increase in shear strength parameters of sandy soil; especially the angle of internal friction with the rate value (16.6 %) of cement only, (21.88 %) of cement with lime , (20.3%) of cement with the polymer before soaked condition. After soaking condition, it was increased with the rate value (14.3%) with cement only, (23.57%) of cement with lime, and (15.38%) of cement with the polymer as compared with soil in the natural state.

Keywords: Additives Soil; Sandy Soils; Shear Strength Parameters; Cement; Lime; Polymer.

1. Introduction

Ground improvement is a process that aims to enhance the engineering properties of the soils and generate an improved constriction material by increasing soil strength, durability, stiffness, and decreasing permeability and compressibility of sandy soils. Additives materials are one of the most important methods to improve the engineering properties of soil that are used to improve the engineering performance. For example, Lime stabilization and cement stabilization are the two common additives of the material methods .These additives materials are categorized as traditional and non-traditional materials. The combination of traditional additives includes (cement, lime, fly ash, and bitumen materials, while non-traditional additives includes various combinations such as (enzymes, polymer, resins, acid, calcium chloride, sodium chloride, and fiber reinforcement). Many researchers relatively have studied the effect of the stabilization agent on shear strength parameters Mitchell [1] showed that stabilization agents increase the effect of cohesion. Other researchers such as Lo, SR, and S PR Wardani [2] found out that the soil treated by cement presented a significant increase in both internal friction angle and cohesion. While Balmer [3] concluded that the value of the internal friction angle varies from (36.1º to 43.8º) for fine and coarse-grained stabilized soils. While the shear strength parameters: cohesion(c), and angle of internal friction (∅) increase with increasing cement content according to Al-Aghbari et al. [4] and Shooshpasha, and Reza [5]. Ziaie-Moayed et al. [6] conducted research to improve the saline soils before and after soaking by using cement and polymer on shear strength and they concluded ;(1) the strength of soil

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specimens are increased by adding cement and resin epoxy and (2) saline materials have an effect on the strength of the soil specimens; in addition, the shear strength of the soil decreased after soaking.

Das et al. [7] conducted research in order to improve shear strength parameters of sandy soils by the use of hair fiber as reinforcing the material. Their results showed that almost (11.5%) of enhancement in shear strength parameter is obtained when hair fiber reinforcement is used. Ahmed et al. [8] investigated the behavior of soil-cement and soil-lime mixture in order to improve the engineering properties of the soil. The study was focused on three dimensions; (1) the effect of their mixture, (2) the effect of the mixture percentages, and (3) the effect of curing time; the results show that stabilizer with a higher percentage of mixture gives a higher increase in shear strength and the strength increases with more curing time. Yousuf [9] investigated the effect of cement grouting with different percentages of the water-cement ratio (W:C) and filler materials to improve shear strength parameters of sandy soil. He founded that when the water-cement ratio decrease, the shear strength parameters increases. A recent study was conducted by Pakbaz MS [10] in studying the effect of microbial –included calcite precipitation (MICP) treatment on the shear strength parameters of sandy soil. This researcher stated that the increase in the cohesion intercept was more significant than the increase in the angle of internal friction. While Avci, and Mollamahmutoğlu [11] investigated the effect of synthesis of sodium silicate manide and sodium silicate –glyoxal grouted sand on shear strength parameters under wet cured and air dried. The results showed that the shear strength parameters of wet cured sand decreased with time more than dried sand samples.

2. Methodology

2.1. Physical Properties of Sandy Soil

The samples of sandy soil were obtained from Karbala city. The physical properties of the sand included specific gravity, grain size distribution analysis as in the Figure 1, and then classified as poorly graded sand (SP) according to (USCS), Maximum dry unit weight ($\gamma_{max.}$) and minimum dry unit weight ($\gamma_{min.}$). The results are shown in the Table 1.

Table 1. The Physical Properties the Tested Sandy Soil

Property	Value	Standard of the test
Specific Gravity (Gs)	2.68	ASTM D854
D10 , mm	0.127	ASTM D422 and D2487
D30 , mm	0.210	
D60, mm	0.339	
Coefficient of uniformity (Cu)	2.67	
Coefficient of curvature (Cc)	1.02	
Type of soil	SP	
Maximum dry unit weight (kN/m³)	17.48	ASTM D4253
Minimum dry unit weight (kN/m³)	14.91	ASTM D4254
Maximum void ratio(e_{max})	0.8	
Minimum void ratio(e_{min})	0.53	
Relative density (%)	30	
Angle of internal friction (ϕ)	32°	ASTM D3080
Cohesion (c)	0	

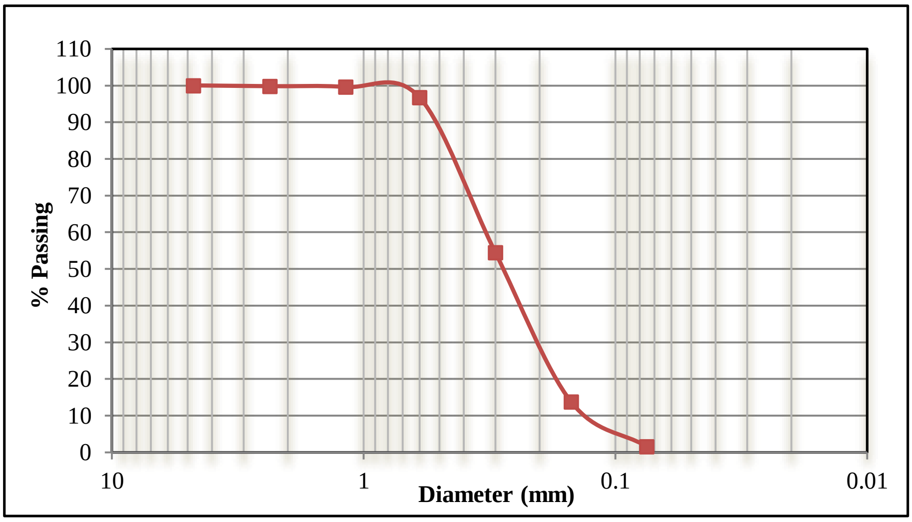

Figure 1. Grain size distribution curve of the sand

2.2. Chemical and Physical Properties of Additives Materials

Cement: The type of cement used in the research is sulfate resistant cement (Type II), this cement is produced by Tasluja cement factory. The chemical and physical properties of cement are listed in Table 2.

Table 2. Chemical and Physical Properties of the Cement

Property	Result
Compressive strength after 3days (Mpa)	27
Compressive strength after 7days (Mpa)	32.5
Time of initial setting (hour)	2.167
Time of final setting (hour)	4.167
SiO_3 (%)	19.37
CaO (%)	64.36
Al_2O_3 (%)	4.12
Fe_2O_3 (%)	4.99
MgO (%)	2.41
SO_3 (%)	2.44
C_3A (%)	2.47
LOI (%)	1.0

Lime: Hydrated lime was used in the experiment. The following Table 3 shows the chemical and physical properties of lime that it supplied by the manufactory.

Table 3. Chemical and Physical Properties of Lime

Properties	Result
Chemical formal	$Ca(OH)_2$
Appearance	White powder
L.O.I	26.74
SiO_2 %	5.62
Al_2O_3 %	0.46
CaO %	65.3
MgO %	0.10
SO_3 %	0.72
Density gm/cm^3	0.63

Polymer: The chemical and physical properties of polymer type (cebex 100) are listed in Table 4.

Table 4. Chemical and Physical Properties of Polymer

Properties	Result
Composition	Silica sands, plasticizers, aluminum powder (stabilized)
Appearance	Powder slivery
Odour	Slight/faint
Relative density at 20 C^o(g/cm^3) bulk	1.3
Water solubility	Insoluble
PH	7.3

2.3. Characteristics of the Direct Shear Test

The test of shear strength of the soil was carried out in the geotechnical laboratory/department of the Civil Engineering / University of Baghdad. The researcher used Standard Direct Shear which has a box with dimensions 6×6 cm. A vertical load was applied to the square specimen through a static weight hanger and the sample was sheared by applying the horizontal force that causes the two halves of the box to move relative to each other. The constant rate of strain 1.2

mm/min. The magnitude of proving ring with capacity 2 kN. The precision of dial gage for vertical and horizontal deformation was 0.002 and 0.01 mm respectively as shown in Figure 2. The test was performed with the normal stresses of 54.5, 109, and 218 kPa.

Figure 2. Direct shear test device

2.4. Sample Preparation

The study sample includes 26 of untreated and treated soil before and after soaking. In the beginning, the test was done on the untreated soil according to ASTM D3080 [17], and then the test was carried out with treated soil. The treated soil by additives contains; (3, 5 and 7%) of cement from dry weight of the soil in the first stage. 2% of lime from the dry weight of the soil mixed with each percentage of cement in the second stage, in the last stage, (50%) of polymer from weight cement mixed with each percentage of cement. During the test, three water content (W:C) (2, 4 and 8%) were used with each percentage of cement before soaking, and then the optimum water content with lime and polymer was used before and after soaking. Samples treated were covered with two layers (nylon and cellophane sheet) in order to maintain the moisture content during (3) days of the treatment period. In the case of the soaking condition, the samples were soaked for (1) day, and then the test was conducted, (see Figure 3).

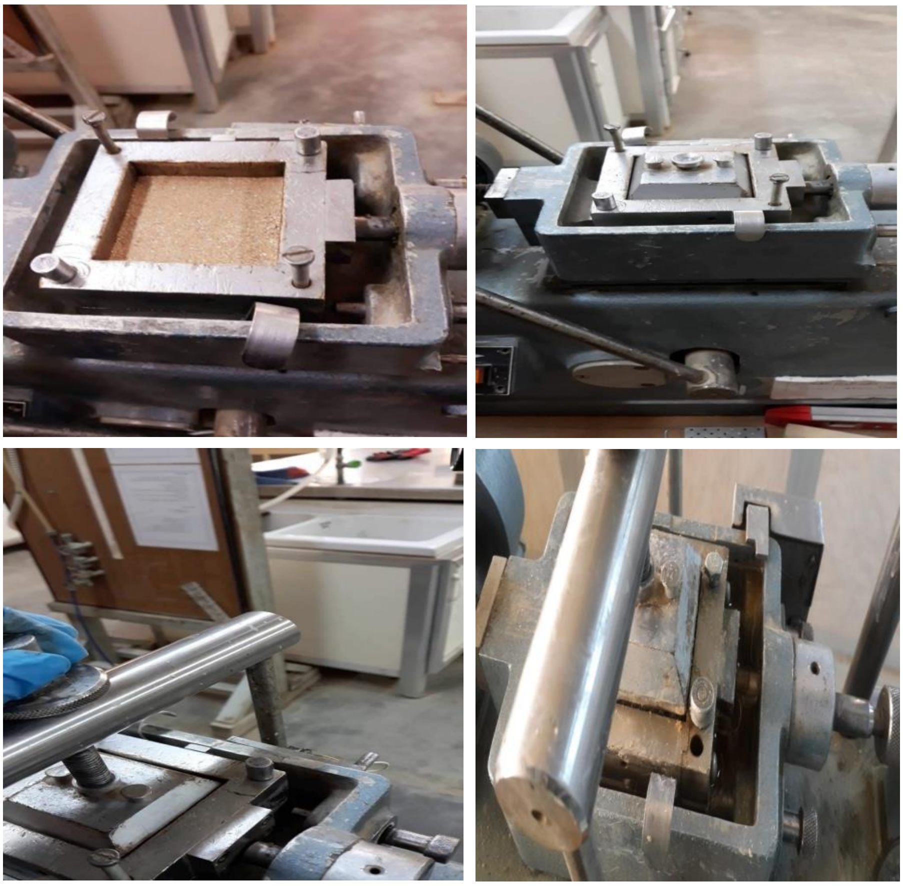

Figure 3. Shows preparing the sample in the Direct Shear Test

3. Direct Shear Test Results and Discussion

3.1. First Group Results

The first group included dry sand before soaking test condition with a relative density of (30%). The results showed that the cohesion (c) is equal to zero, while the angle of internal friction (Ø) is equal to (32°). After soaking the soil for (1) day, the cohesion slightly increased to (2.5) kPa, while the angle of internal friction decreased to (28°). This is due to the solubility of salts in the soil with water causes decrease in angle of internal friction. Figure 4 shows the relationship between normal stress versus maximum shear stress.

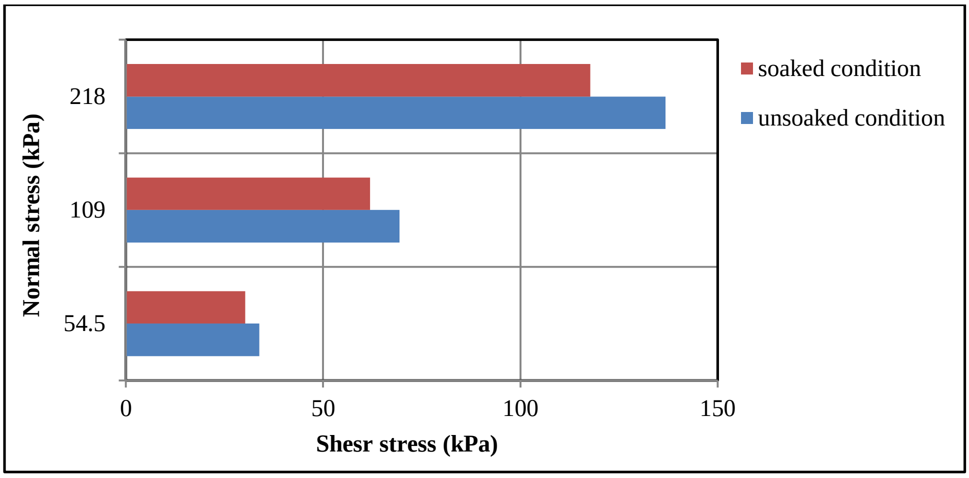

Figure 4. Shows shear stress versus normal stress for untreated samples of soil before and after soaking

3.2. Second Group Results

This group is included improved soil by cement with three percentages (3, 5 and 7%) of dry weight of soil before soaking condition, and then it was cured with three different percentages of water content (2, 4 and 8%) for (3) days. The relationship between normal stresses versus maximum shear stress is shown in Figures 5, 6 and 7. From the experimental work, the results of effect (W:C) with soil treated by cement on the shear strength parameter explained that the angle of internal friction increased when soil was treated by cement with 4% (W:C) of the rate value (between untreated soil and treated soil by cement) between (10-16.6%); therefore the optimum moisture content (OMC) is 4%. While the cohesion increased with 8% of (W:C) with a value range between (6.3-8.5) kPa as compared with the untreated sample. The results are illustrated in the Table 5.

Shear strength parameters: (c and Ø) increase with increasing cement content. Thus, the soil treated by 7% of cement with 4% OMC is the optimum value as a result of increasing the shear strength parameters (c and Ø) to (7 kPa , 16.6%) respectively, as they are shown in the Figures 8 and 9. This due to increase hydration of cement led to increase the bonding force between grains of soil cement. These findings are also introduced by [4-6], and [18-20]. Later, Laguros J.G [21] indicated that the cohesion as well as the angle of internal friction increase when the soils are treated with cement, the increase being higher for the granular soils than for the fine grained soils.

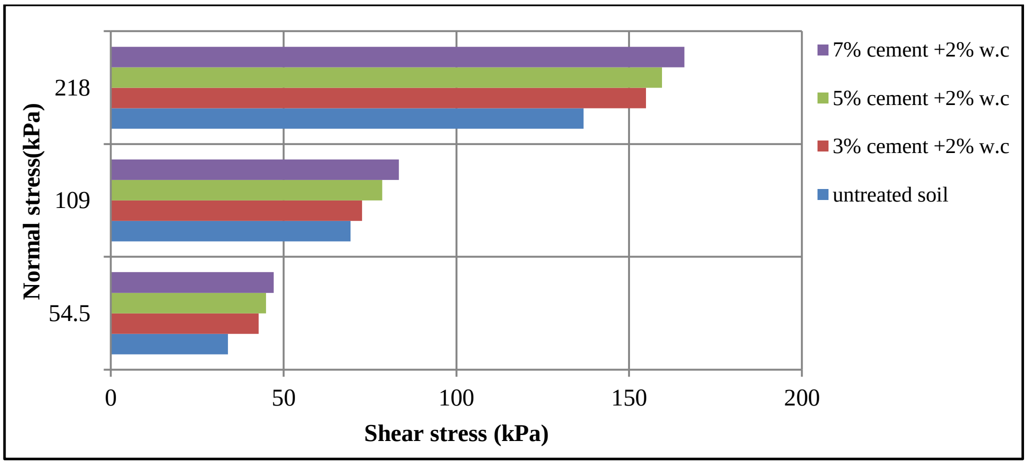

Figure 5. Shows shear stress versus normal stress for soil sample treated by cement at 2% W:C before soaking condition

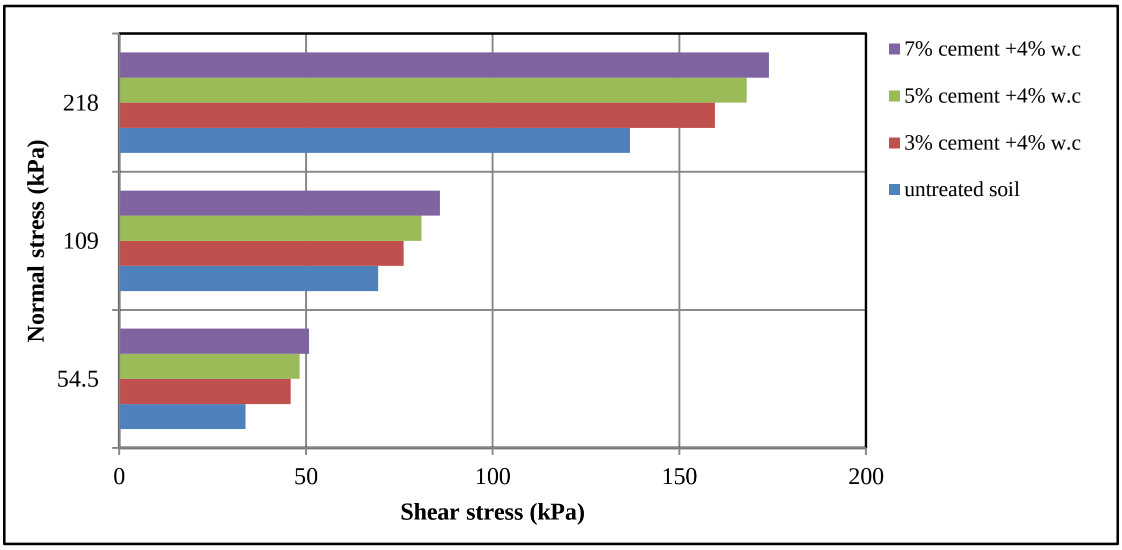

Figure 6. Shows shear stress versus normal stress for soil sample treated by cement at 4% W:C before soaking condition

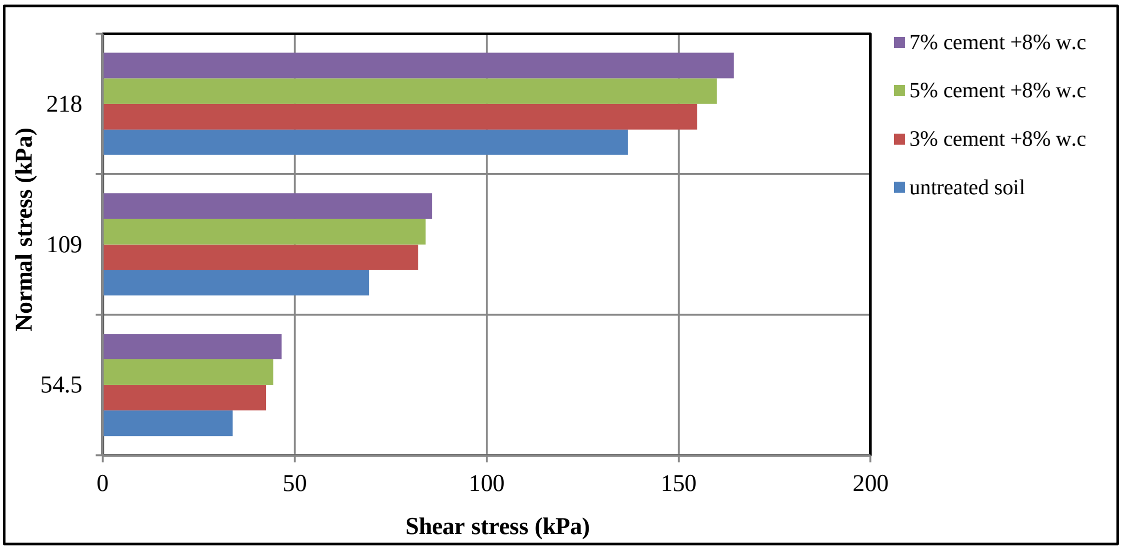

Figure 7. Shows Shear stress versus normal stress for soil sample treated by cement at 8% W:C before soaking condition

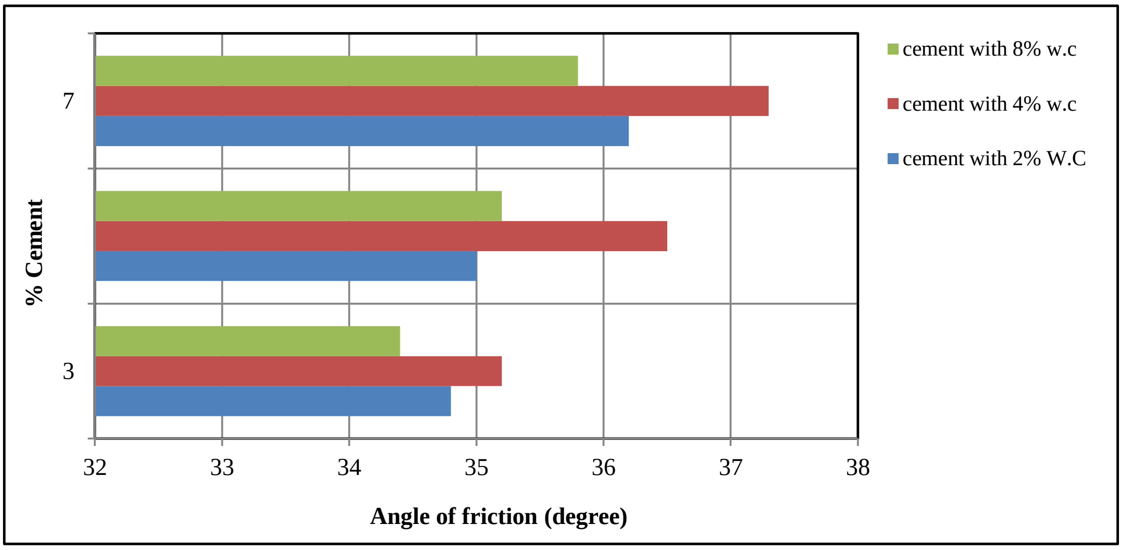

Figure 8. Shows the relationship between the percentages of cement with the angle of internal fiction before soaking condition

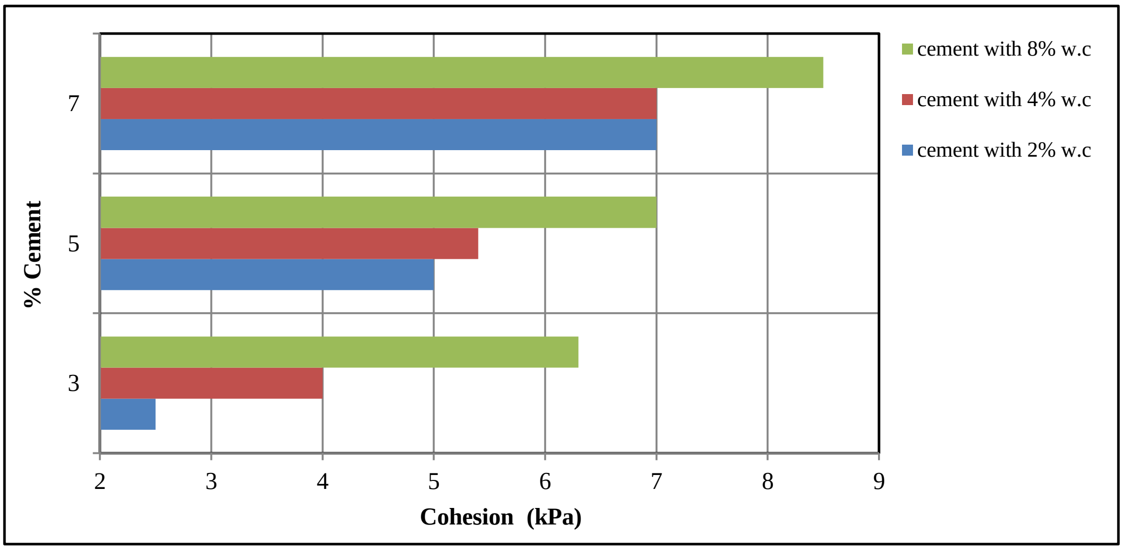

Figure 9. Shows the relationship between the percentages of cement with cohesion before soaking condition

Table 5. Shows the Results of Direct Shear Test on Sandy Soil treated by Cement with Different (W:C) Before Soaking Condition

W:C with the percent of cement		The result of the direct shear test		%Increasing of ∅ treated soil by cement before soaked
% W:C	% of Cement	c (kPa)	∅ degree	
Untreated soil	0	0	32	-
2	3	2.5	34.8	8.75
	5	5	35	9.38
	7	7	36.2	13.13
4	3	4	35.2	10
	5	5.4	36.5	14.1
	7	7	37.3	16.6
8	3	6.3	34.4	7.5
	5	7	35.2	10
	7	8.5	35.8	11.88

3.3. Third Group Results

The third group of samples contained soil treated by cement with three percentages (3, 5 and 7%) of dry weight of soil, and treated with (OMC) after soaking condition. The relationship between normal stresses versus maximum shear stress is shown in Figure 10. The experimental work showed the effect of soil treated by cement on the shear strength parameters after soaking; the cohesion has value range between (9.5-12 kPa), and the rate of increase in cohesion between (280-380%). While the angle of internal friction is increased with the rate value range between (7.14-14.3%), as compared with untreated soil after soaking (see Table 6). In the soaking condition, when cement content increased, shear strength parameters increased as compared with untreated soil sample; therefore the soil treated by 7% of cement is the optimum content as it is shown in the Figures 11 and 12. This is due to an increase in the reaction when cement is mixed with water led to increase hydration of cement to fill particles of soil with water. Thus, the shear strength parameters decreased as compared with the samples before soaking condition, and this was also observed by [5].

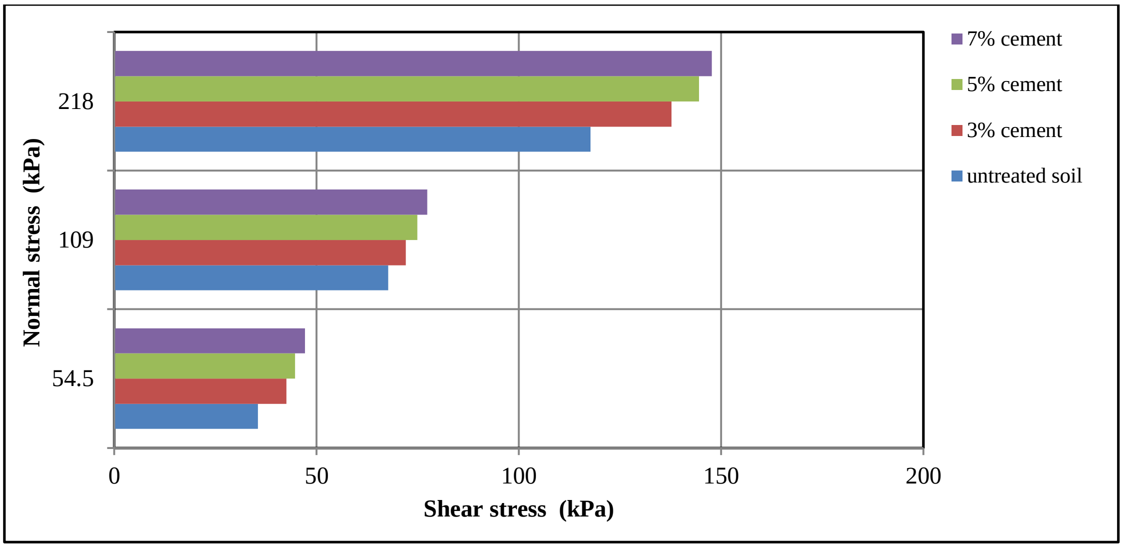

Figure 10. Shows shear stress versus normal stress for soil sample treated by cement at 4% OMC after the soaking condition

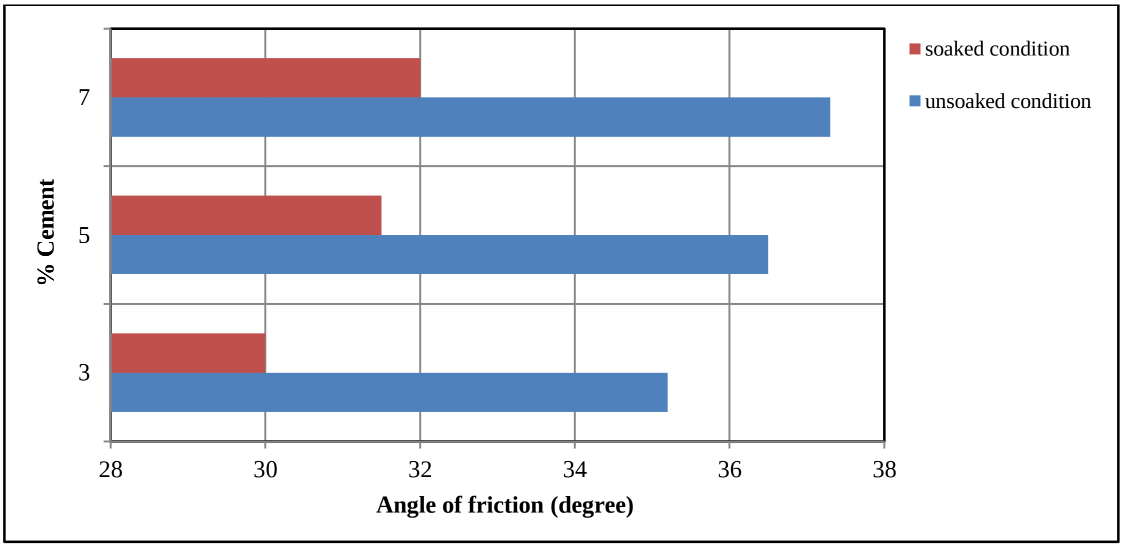

Figure 11. Shows the relationship between the percentages of cement with the angle of internal friction of soil treated at 4% OMC before and after the soaking condition

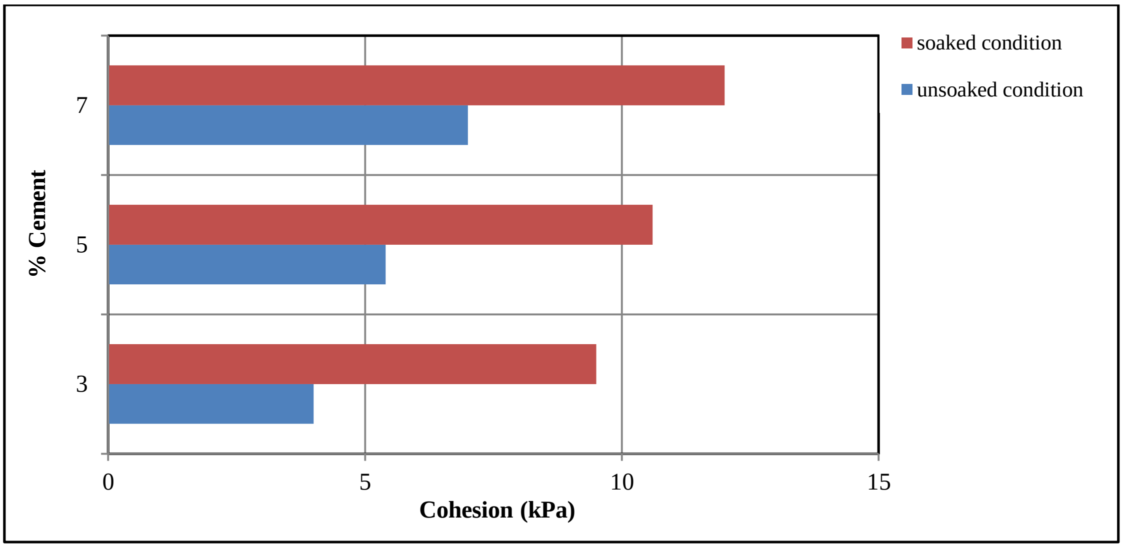

Figure 12. Shows the relationship between the percentages of cement with the cohesion of soil treated at 4% OMC before and after the soaking condition

Table 6. Shows the Results of Direct Shear Test on Sandy Soil Treated by Cement after Soaking Condition

% Cement content with OMC	The result of the direct shear test		%Increasing ∅ of treated soil by cement under the soaked condition	%Increasing *c* of treated soil by cement under the soaked condition
	c (kPa)	∅ (degree)		
Untreated soil	2.5	28	-	-
3	9.5	30	7.14	280
5	10.6	31.5	12.5	324
7	12	32	14.3	380

3.4. Fourth Group Results

The fourth group included improved sandy soil of mixture 2% of lime added with each percentage of cement, and then treated with 4% OMC before soaking condition. The relationship between normal stresses versus shear stress is illustrated in (Figure 13). The experimental results of shear strength parameter showed that the cohesion has value range between (3.6-11.5 kPa) and the rate value of the increase in the angle of internal friction (between untreated soil and treated soil by mixing cement with lime) between (18.75-21.88%) as it is explained in the Table 7. Shooshpasha, and Reza [5] observed that the shear strength parameters: cohesion and internal friction angle increase with increasing lime Portland cement content. The substantial increase in cohesion is evident than internal friction angle.

From the results, the comparison between shear strength treated by cement only and shear strength parameters treated by mixture cement with lime before soaking can be summarized as follows:

1. Shear strength of soil treated by mixing cement with lime was increased more than the soil treated by cement only. The shear strength parameters were increased due to the pozzolanic activity of lime from the reaction of the calcium in the lime and cement with soil particles this led to increase bonding between the additives and the particles of soil, this was also noted by [8], and [9]. While the soil treated by 5% of cement with 2% lime is the optimum value because of increasing the rate value of shear strength parameters; the cohesion was (20.4%), and the angle of friction is (5.75%). Thus, it was more than soil treated by cement only.

2. The similar results, in the case of the soil treated by 7% of cement with 2% of lime, showed an increase in shear strength parameter more than soil treated by cement only. In case of soil treated by 3% of cement with 2% of lime also showed an increase in the rate value of the angle of internal friction to (7.25%), while it decreased in the cohesion to (10%). The effect of lime with cement to improve the shear strength parameters are shown in Figures 15 and 16.

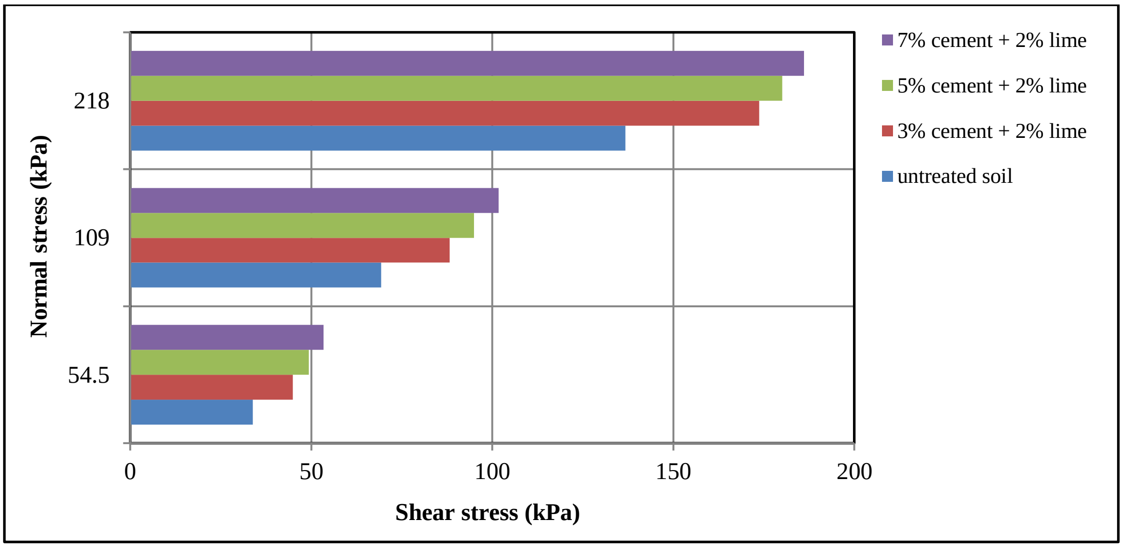

Figure 13. Shows shear stress versus normal stress for soil sample treated by mixing of cement with lime at 4% of OMC before soaking condition

Table 7. The Results of Direct Shear Test for Soil Treated by Mixture Cement with Lime at 4% OMC Before soaking Condition

Mixed type	Results of the direct shear test		%Increasing in Ø for treated soil	Different in %Ø for treated soil by cement and by cement with lime	%Rate of *c* for treated soil by cement and by cement with lime
	c (kPa)	Ø (degree)			
Untreated soil	0	32	-	-	-
3%Cement+2%Lime	3.6	38	18.75	7.95	-10
5%Cement+ 2%Lime	6.5	38.6	20.63	5.75	20.4
7%Cement+ 2%Lime	11.5	39	21.88	4.56	64.3

3.5. Fifth Group Results

This group included improved sandy soil by mixture 2% of lime added with each percentage of cement, and then treated with 4% of OMC after soaking condition. The relationship between normal stresses versus shear stress was shown in Figure 14. The experimental work showed the results of shear strength parameters were: the cohesion has a value range between (2.5-15.6 kPa) and the increasing in the rate value between (380-524%). The angle of internal friction has the rate value of increasing (between untreated soil and treated soil by mixing cement with lime) between (17.86-23.57%), all results shown in the Table 8.

To make a comparison between shear strength treated by cement only and shear strength parameters treated by mixing (cement with lime) after soaking condition, the researcher noticed that:

- Shear strength of soil treated by mixing cement with lime increased more than the soil treated by cement only. The shear strength parameters increased as a result of the ability of lime to absorb the water and to complete the reaction of additives with particles of the soil by the presence of water. Soil treated by 7% cement with 2% lime is the optimum value as a result of increasing the rate value of shear strength parameters; the cohesion was (8.14%) and the angle of friction was (30%), more than soil treated by cement only.
- The shear strength parameters of the soil treated by (3 and 5%) of cement and 2% of lime were increased more than the soil treated by cement only. The effect of lime with cement to improve the shear strength parameters of the sandy soil increases when cement content increase (as it is shown in Figures 15 and 16).

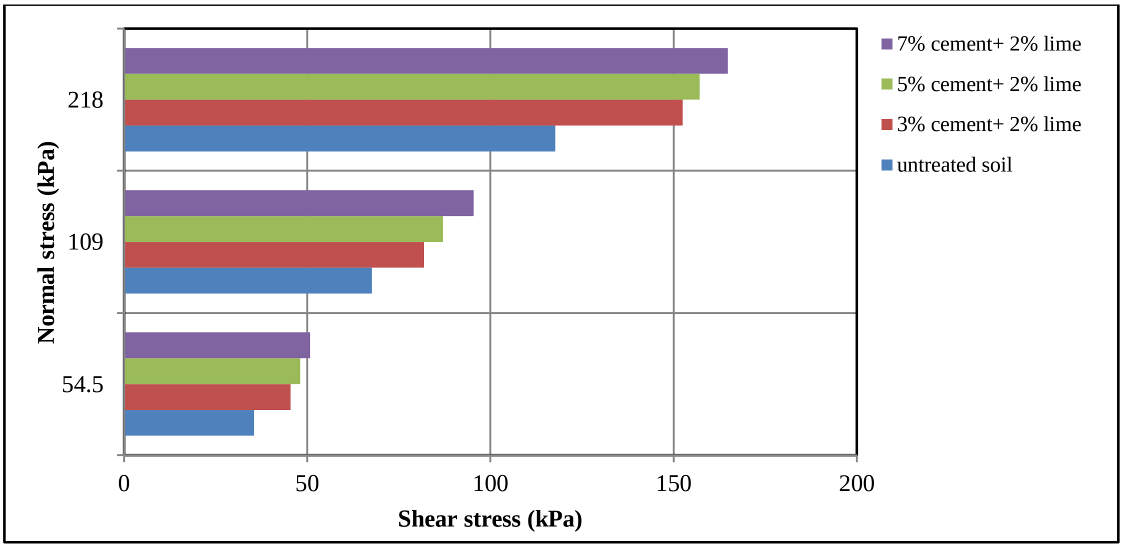

Figure 14. States Shear stress versus normal stress for soil sample treated by mixing cement with lime at 4% of OMC after soaking condition

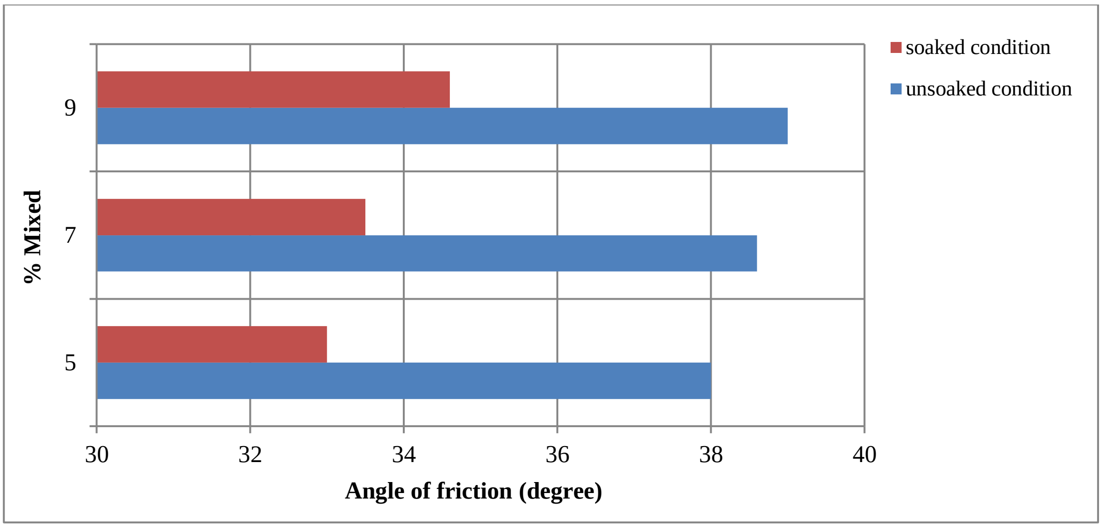

Figure 15. Shows the relationship between the percentages of mixing cement with lime and the angle of internal friction for soil treated at 4% OMC before and after soaking conditions

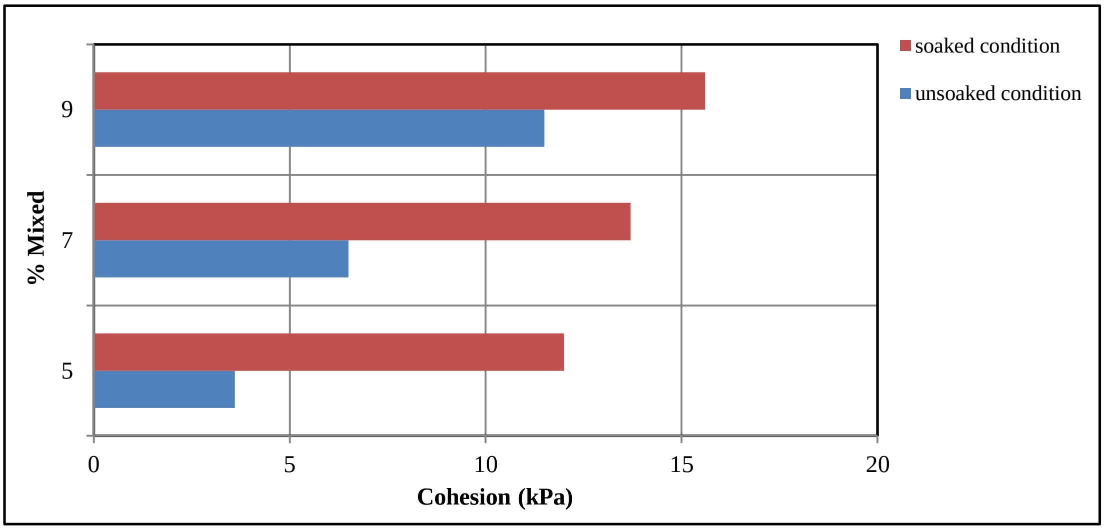

Figure 16. Shows the relationship between the percent of mixing cement with lime and the cohesion for soil treated at 4% OMC before and after soaking conditions

Table 8. Illustrates the results of Direct Shear Test for Soil Treated by Mixture Cement with Lime at 4% of OMC after Soaking Condition

Mixed type	Results of the direct shear test		% Increasing in ∅ for treated soil	% Increasing in c for treated soil	%Different in ∅ for treated soil by cement and by cement with lime	%Different in *c* for treated soil by cement and by cement with lime
	c (kPa)	∅ (degree)				
Untreated soil	2.5	28	-	-	-	-
3%cement+2%lime	12	33	17.86	380	10	26.3
5%cement+2%lime	13.7	33.5	19.64	448	6.35	29.25
7%cement+2%lime	15.6	34.6	23.57	524	8.13	30

3.6. Sixth Group Results

The sixth group included improved sandy soil by mixture 50% of polymer of weight cement added with each percentage of cement, and then treated with 4% of OMC before soaking condition. The relationship between normal stresses versus shear stress is showed in the Figure 17. Practically, the results of shear strength parameters were; the cohesion has a value ranging between (5.5-8) kPa, and the rate value of the angle of internal friction (between untreated soil and treated soil by mixing cement with polymer) between (13.44-20.3%) (See the results in the Table 9).

From the results, the comparison between shear strength treated by cement only and shear strength parameters treated by mixture (cement with polymer) before soaking showed:

- Shear strength of soil treated by mixing cement with polymer increased more than the soil treated by cement only. The shear strength parameters increased due to increase the activity between polymer which contains a high percentage of plasticisers and aluminum which work as a cover to the particles of sand with increasing hydration of cement. This reaction was responsible to increase the strength of soil (see also the results in [18] and [21]). The soil treated by 3% of cement with 1.5% of polymer was the optimum value as a result of increase the rate value of shear strength parameters: the cohesion was (37.5%), and the angle of friction was (3.13%), this is more than soil treated by cement only.
- It was observed that the shear strength increases with increase mixture content. This phenomenon explained that an increase in polymer and cement content led to enhance bond mechanisms of the sandy soil (see Figures 19 and 20).

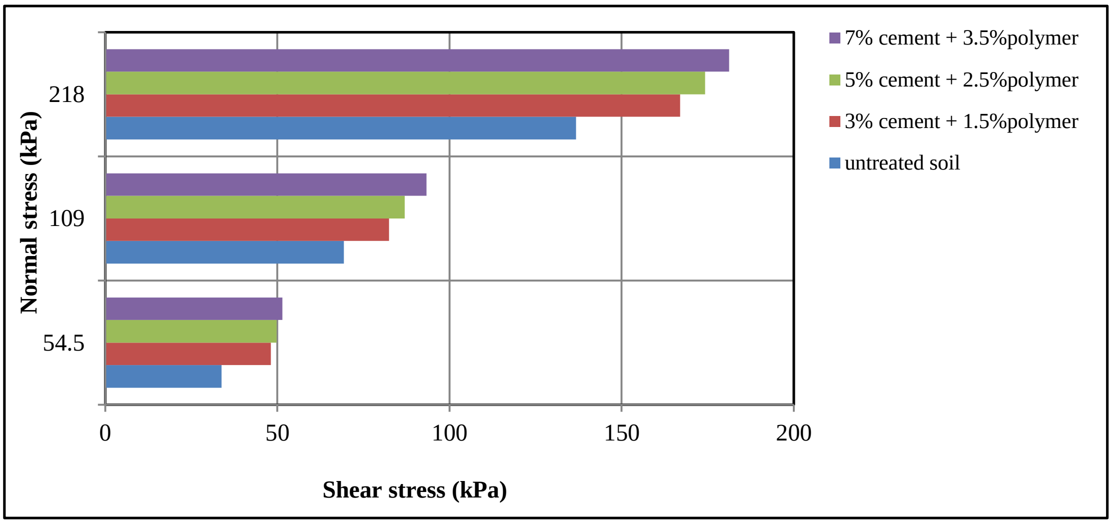

Figure 17. States shear stress versus normal stress for soil sample treated by mixing cement with polymer at 4% of OMC before soaking condition

Table 9. Shows the Results of Direct Shear Test for Soil Treated by Mixture Cement with Polymer at 4% of OMC before Soaking

Mixed type	Results of the direct shear test		% Increasing in Ø for treated soil	%Different in Ø for treated soil by cement and by cement with Polymer	%Different in *c* for treated soil by cement and by cement with Polymer
	c (kPa)	Ø (degree)			
Untreated soil	0	32	-	-	-
3%Cement+1.5% Polymer	5.5	36.3	13.44	3.13	37.5
5%Cement+2.5% Polymer	7	37.5	17.2	2.74	29.6
7%Cement+3.5%Polymer	8	38.5	20.3	3.22	14.3

3.7. Seventh Group Results

The final group included improved sandy soil by mixing 50% of polymer of weight cement added with each percentage of cement, and then treated with 4% of OMC before soaking condition (see Figure 18). The experimental work displayed that; the cohesion has a value range between (2.5-15.6 kPa), and the increasing in the rate value between (380-524%). The angle of internal friction has the rate value of increasing (between untreated soil and treated soil by mixing cement with lime) between (10-15.38%), all results are shown in the Table 10.

To make a comparison between shear strength treated by cement only and shear strength parameters treated by mixture cement with lime after soaking condition, the researcher reached:

- Shear strength of soil treated by mixing cement with polymer increased more than the soil treated by cement only. The shear strength parameters increased as a result of the complete reaction of additives cement plus polymer with particles of soil in the presence of water. The soil treated by 7% of cement with 3.5% of polymer is the optimum value as a result of increasing the rate value of shear strength parameters; the cohesion became (0.94%), and the angle of friction was (30%) (More than the soil treated by cement only).
- The effect of polymer with cement to enhance the shear strength parameters of the sandy soil increased when cement content and polymer increased as a result of increasing pozzolanic reaction of the additives. This led to

the increasing strength of soil, but they decreased as compared with the samples before soaking as it is shown in the Figures 19 and 20. This was also mentioned by [5].

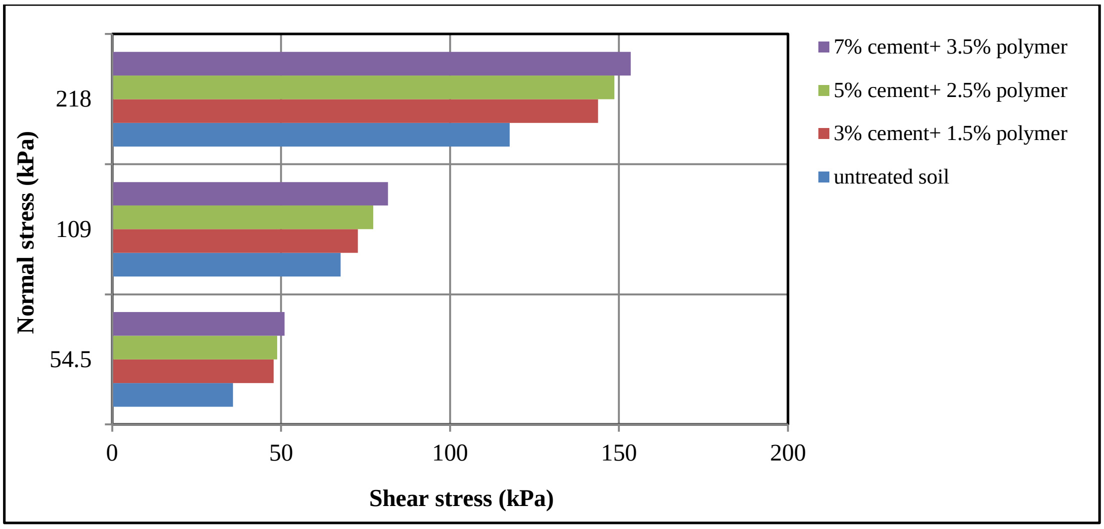

Figure 18. Shows Shear stress versus normal stress for soil sample treated by mixture cement with polymer at 4% of OMC after soaking condition

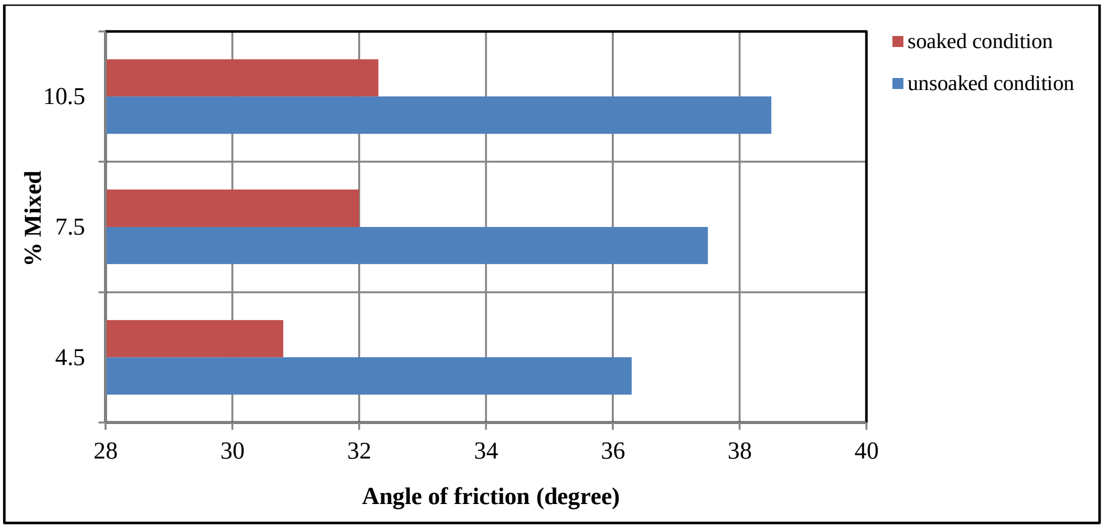

Figure 19. States the relationship between the percentages of mixing cement with polymer and the angle of internal friction for soil treated at 4% of OMC before and after soaking conditions

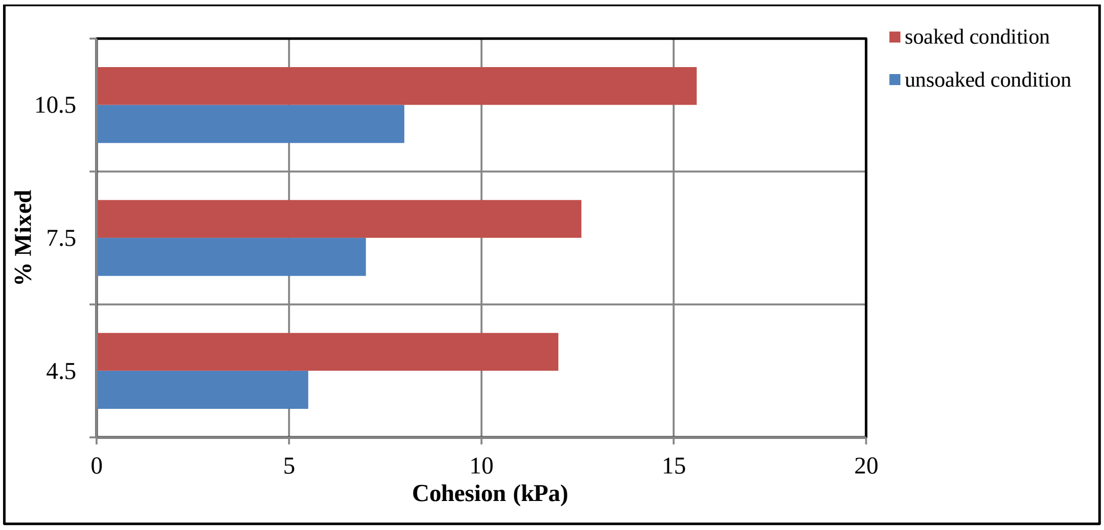

Figure 20. Shows the relationship between the percentages of mixing cement with polymer and the cohesion for soil treated at 4% of OMC before and after soaking conditions

Table 10. Shows the Results of Direct Shear Test for Soil Treated by Mixture Cement with Polymer at 4% of OMC after soaking condition

Mixed type	Results of the direct shear test		% Increasing in Ø for treated soil	% Increasing in c for treated soil	%Different in Ø for treated soil by cement and by cement with Polymer	%Different in c for treated soil by cement and by cement with polymer
	c (kPa)	Ø (degree)				
Untreated soil	2.5	28	-	-	-	-
3%Cement+1.5%Polymer	12	30.8	10	380	2.67	26.32
5%cement+2.5%Polymer	12.6	32	14.3	404	1.59	18.87
7%cement+3.5%Polymer	15.6	32.3	15.38	524	0.94	30

4. Conclusions

According to the results obtained from the experimental tests. The following results can be summarized:

- Shear strength parameters: the angle of friction (Ø), and cohesion (c) of sandy soil treated by a mixture of cement with lime, and cement with polymer was increased more than the soil treated by cement only.
- The results of the direct shear test showed that the optimum moisture content (OMC) was 4% that has been obtained from the soil treated by cement with three percentages of water content before soaking condition.
- The high increase of angle of internal friction (Ø) is found at rate (23.57%), when treatment of the soil with 7% of cement with 2% of lime after soaking conditions, as compared with the samples before soaking condition. This belongs to complete chemical interaction between the additives and the soil in soaking condition.
- To compare between two mixtures (cement with lime), and (cement with polymer), it was noticed that tradition additives (cement with lime) is still more effective than non-tradition additives (cement with polymer) and also from the cost aspect.

5. Conflicts of Interest

The authors declare no conflict of interest.

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