Improvement of Shear Strength of Sandy Soil by Cement Grout with Fly Ash

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ABSTRACT

The effects of the permeation cement grout with fly ash on the sandy soil skeleton were studied in the present work in two phase; first phase the shear strength parameters, and the second phase effect of these grouted materials on volume grouted zone by injection (51) cm^3 of slurry in sandy soil placed in steel cylinder model with dimension 15 cm in diameter and 30 cm in height. The soil sample was obtained from Karbala city and it is classified as poorly graded sand (SP) according to USCS. The soil samples were improved by cement grout with three percentages weight of water cement ratio (w:c); (0.1w:0.9c, 0.8w:0.2c, and 0.7w:0.3c), while the soil samples were dehydrated for one day curing time. Fly ash class (F) was used with cement grout as filler material; it was added to the mixture as a replacement material for cement in weight percentages; 10%, 25% and 40%. According to the results of tests, both shear strength and approximate volume of the effective grouted zone for treated samples soil with cement grout was increased when the water cement ratio decreased. Fly ash with cement grout needs to increase the water demand for the grout mixing to give best results in both shear strength and filling the soil voids.

Key words: Soil improvements, grouting with cement, filler materials, fly ash (F).

تحسين مقاومة القص للترب الرملية باستخدام الحقن بالاسمنت و الغبار المتطاير

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الخلاصة

ركزت الدراسة الحالية على تأثير الحقن باستخدام مادة الاسمنت مع الرماد المتطاير على مقاومة القص للتربة الرملية وكذلك تم دراسة تأثير الواد المستخدمة في عملية الحقن على حجم المنطقة المحقونة بواسطة حقن (51) سم^3 في تربة رملية موضوعة في موديل حديدي اسطواني الشكل ذو قطر (15) سم وارتفاع (30) سم. عينات الترب الرملية تم جلبها من محافظة كربلاء وتم تصنيفها اعتماداً على التصنيف التربة الموحد و كانت ذات تدرج ضعيف (sp). التربة الرملية في البحث تم تحسنها باسلوب الحقن بالاسمنت باستخدام ثلاث نسب وزنية من نسبة الماء الى الاسمنت وهي (0,9/0,1 ، 0,8/0,2، و 0,7/0,3) وتم ترك النماذج المعالجة بالحقن يوم واحد لغرض التصلب . الرماد المتطاير من صنف (F) تم استخدامه مع الاسمنت كمادة مالئة وتم اضافته للخليط كمادة بديلة عن الاسمنت وبثلاث نسب وزنية (10% ، 25%، و 40%) . وقد لوحظ من نتائج الفحص ان مقدار مقاومة القص مع الحجم المتأثر بمنطقة الحقن تمت زيادتهما كلما قلت نسبة (الماء\الاسمنت). اما بالنسبة للغبار المتطاير فانه يحتاج الى زيادة في كمية الماء لخليط المستخدم في الحقن لاعطاء افضل لمقاومة القص و املاء اكثر لفجوات التربة.

الكلمات الرئيسية : تحسين تربة ، الحقن بالاسمنت ، مواد مالئة ، الغبار المتطاير صنف F.

1. INTRODUTION

Grouting is the most common technical method used for soil improvement and strengthening. The principle of the grout is to introduce a substance into the rock fissure or into soil by pumping fluid or slurry down a small diameter tube to the required location, **Stadler, 2001.**

Grouting materials can be classified in two classes : (suspension type grouts and solution type grouts), the suspension type grout includes soil, cement, lime, asphalt, emulsion, etc., and the solution grout includes a wide variety of chemicals such as sodium silicates acrylamide, lignosulphonates, aminoplast, phenoplast, etc , **Shroff, A.V. , 2009.**

Permeation grouting is an effective method to send the grout materials into the ground without disturbing the soil structure, while increasing in cement content will increase load carrying capacity of the sandy soil, **P. Dayakar et al. 2012.**

Cement grout is most commonly used for sandy soil, it is a mixture of Portland cement, water, and, frequently, chemical and mineral additives. Cement grout can only travel in large voids. In the finer sized materials, the voids of the soils are too small to accept the cement grout. Fly ash is pozzolanic materials, which is fine gray powder resembling cement. It can be used in both concrete and grouting, it consists of impurities released by burning coal, which escapes and are carried away in exhaust gases of coal – burning furnace. Because there is considerable variety in the chemistry of different coals, the properties of the resulting by-product are likewise variable. Particles of fly ash are almost solid and hollow, and usually, contain varying amount of iron alumina and calcium as well as a very minor of other constituents. By itself, fly ash has little or no cementation properties but can react within the presence of moisture with the calcium hydroxide of lime or cement. The chemical reaction with Portland cement occurs when lime becomes free during cement hydration, this reaction forms addition cementation material, **Waner, 1989, 2004.** Fly ash may be used both as filler and an admixture with cement grout. It is used as filler for economic reason where substantial quantities of grout are required to fill large cavities in rock or in soil, trenches, and cavities, and to stem bore holes, shaft and tunnels, **U.S. Army Corps of Engineering, 1984.**

Fly ash is an important component in cement grout mix design because the particles are very small, which is helpful in increasing the density of the grout, and their spherical shape significantly reduces frictional losses during pumping, and decrease the cost of the grout when a large volume are wanted to gout, **Baker and Broadrick, 1997**.

Fly ash is primarily used to reduce cost, decrease shrinkage; increase flow ability, reduction of shrinkage upon drying, reduces heat generation during curing, and can give chemical stability **Vipulanandan et al, 2000** **.**

Polattty, (1982) pointed out that the water demand of cement fly ash in grout mix compared with using fine sand as filler material would be more so there is potentially more bleed with fly ash .

The objective of this research is to improve shear strength of sandy soil by cement grout with fly ash as filler material through laboratory testing for three (w:c) ratios with three percent of fly ash , and to show the effect of cement grout with fly ash in filling soil voids and how to influence on volume grouted zone.

2. MATERIALS USED

2.1 Sand soil

The sand is poorly graded clean sand obtained from Karbala city. Prior to testing, the sand is dried by the oven at (105 ° C) for (24 hrs.). Standard laboratory tests were used to obtain its physical properties. The tests are performed with loose sand corresponding to a dry unit weight of 15.5 kN/m^3.

The test of grain size distribution curve that is shown in **Fig. 1** was done according to (ASTM D24884-2007) procedure. The sand is classified poorly graded sand, where the coefficient of uniformity (Cu) and coefficient of curvature (Cc) was (3.6) and (0.06) respectively. Other physical properties are shown in **Table 1**.

2.2 Cement Used

The cement used was sulphate resisting cement. The physical and chemical properties of cement were listed in **Table 2**. The tests were done in the National Center for Construction Laboratories and Research (NCCLR) - Ministry of Construction and Housing.

2.3 Fly ash used

The physical and chemical properties of fly ash class (F) were listed in **Table 3**. The tests were done in the National Center for Construction Laboratories and Research (NCCLR) - Ministry of Construction and Housing.

3. TESTING APPARATUS

In present work, cement grout with three weight percentages of water: cement ratio were used; (0.9w:0.1w, 0.8w:0.2c, 0.7w:0.3c). Fly ash was used as filler material with three percentages (10%, 25%, and 40%), and this material was added to the mixing as replacement material from cement. A rotary mixer with control speed was used for all mixes to have a homogeneous mixture.

3.1 Cylinder model Apparatus

The height of steel cylinder model that was used for the grouting process is (30) cm with diameter (15) cm. The cylinder was filled to (25) cm sand with dry unit weight 15.5 kN/m^3. The slurry was injected under (1) kPa to depth (12.5and 16.7) cm by using cylinder pipe for each (w:c). Slurry volume was used for this process is (51) cm^3, this volume was chosen according to injected (1) cm^3 (as grout material) in unconfined compressive strength model, so this rate has slight effect in soil structure.

After one day curing time by the humidity, the approximate dimensions were measured by vernier and then volumes of these grout zones were calculated.

3.2 Shear strength of the soil

Shear strength parameters of sandy soil before and after the grouting process was measured by direct shear test (for the sandy soil without any additive; the cohesion is equal zero). This test was carried out in accordance with the procedure given in ASTM D 3080-1998. A standard direct shear box of (60) mm square specimen was prepared in the steel box. After careful placing, an unconsolidated undrained direct shear test was conducted. The normal stresses applied were: 27.25, 54.5 and 109 kPa. The values of friction angle (Φ) and cohesion (C) were obtained according to Mohr-Coulomb failure criteria.

At a center of the direct shear box, (1) cm³ of the slurry was injected, as in **Fig. 1,** and after one day as curing time, the test was done.

Figure 1. The cylinder model

4. RESULTS AND DISCUSSION

4.1. Cylinder model test

According to the concept of the grout, the soil voids are filled, and to know correlation resulting between grout materials and soil voids and its impact on the volume of the grouted zone, approximate volume of the grouted zone is calculated as shown in **Figs. 2, 3** and **4**. A comparison of the percentage of the grouted volume zone with and without the fly ash is shown in **Table 4** and in **Figs. 5 to 7**.

From the result, approximate volume of the grouted zone was increased when the (w:c) decreased as a result of decrees of bonding material.

When using fly ash with cement grout as filler materials, and for (w:c) (0.9 w : 0.1 c) the approximate volume of the effective grouted zone was increased (when it was compared with approximate volume of the effective grouted volume zone for only cement grout) with three percent of fly ash (10%, 25%, and 40%). For the other (w:c) (0.8w : 0.2c) , the approximate volume of the effective grouted zone increase when using (10%) and (25%) of fly ash, while in (40%) of fly ash the approximate volume of the effective grouted zone decrease. The last (w:c) (0.7w:0.3c), the approximate volume of the effective grouted volume zone decreased with all the percentages of fly ash .

4.2. Shear strength of sand improvement by cementation gel grouted with fly ash additive

In this part, five groups of the sample with variable state sand were tested. The soil in the first group was natural loose sand with relative density (30%) and tested at its dry in-situ condition, while the second group for cement grouted sand with three (w:c) (0.9w:0.1) , (0.8w:0.2c) and (0.7w:0.3c). The third, fourth and fifth groups were with the same (w:c) but three percent of fly ash as filler material was used (10%, 25%,and 40%). The shear stresses versus horizontal displacement were plotted for selected tests. In addition, a relation between the maximum shear stress versus normal stress was drawn and the shear strength parameters, the angle of internal friction (ϕ) and cohesion (c) were measured.

In addition, the corresponding parameters are also presented in **Figs. 8 to 11**. The results have pointed out that the cohesion parameter is equal to zero for sandy tested at natural dry state, whereas for soil grouted with cement and cement – fly ash, the cohesion had a value ranging between (2.1 to 8) kPa.

The result of the direct shear test for all cases and the rate of increase in angle of friction between treated soil by cement grout with and without fly ash and untreated are shown in **Table 5**. Then the rate of increase in angle of friction value ranged between (0%-15.6%) for treated with cement –fly ash and untreated soil. The shear stresses versus horizontal displacements and with normal stress were plotted for selected tests as shown in **Figs. 12 to 24.** The figures show that the displacement increases with the increase in shear stress to peak and then gradually decreases with less degree

The experimental work results show that angle of friction and cohesion increases when water cement ratio decreases without any additive as shown in **Figs. 25 and 26,** so the degree of the soil improvement and the shear strength of the soil increase in order to fill the soil voids and the bonding force that arise between the soil particles and the hydrated cement.

The relationship between the three (w:c) ratio used in present work (with all the percent of fly ash) and cohesion and angle of friction are shown in **Figs. 27 and 28.**

Using of fly ash in the present work, came for a reason which is the ability of fly ash to react chemically with Portland cement and produce cementations materials and for economic reason where the fly ash is available and environmentally friendly materials.

Shear strength for grouted gel at (w:c) (0.9w: 0.1c) increased (when it compared with grouted with only cement) when the rate of fly ash as filler materials increases in cement grout was limited. Cement grout with (40%) of fly ash as filler material decrease the shear strength for grouted gel at (w:c) (0.8w:0.2c) in order to decrease both the cohesion between the soil particles and angle of friction. The shear strength increased when (10%) of fly ash is used with cement grout as a filler material for (w: c) (0.7w: 0.3c). While shear strength for the same grouted gel at (w:c) with (25%) of fly ash is equal to shear strength for soil grouted with cement only, and the (40%) of fly ash with cement grout as a filler materials decrease the shear strength for grouted gel at (w:c) (0.7w:0.3c).

So, when the water cement ratio is decreased for cement grout with fly ash, both effective grouted volume zone and shear strength decreased in order to effect of fly ash on hydration water that wanted to continue the cement interactions between it and water to create harden material, so grout gel with cement and fly ash need to increase the water demand for the mixture.

5. CONCLUSIONS

The research work focuses on studying how to improve shear strength of sandy soil by using cement grout with fly ash as filler materials. The conclusions can be summarized as follows:

1. The water cement ratio for grouted sandy soil plays an important role by increasing the degree of the soil improvement and shear strength of soil, for bonding force that arises between the soil particles and the hydrated cement.

2. The shear strength parameters of the soil, the angle of internal friction (ϕ) and cohesion (c), increased together when the water cement ratio for the cement grout decreased.

3. Fly ash with cement grout can give a high degree of improvement by increasing both the shear strength of the soil and effective grouted volume zone but with limits.

4. Approximate volume of the grouted zone was increased when the (w:c) decreased as a result of decrease of bonding material.
5. When using fly ash with cement grout as filler materials and for (w:c) (0.9 w : 0.1 c) the approximate volume of the effective grouted zone was increased (when compared with approximate volume of the effective grouted volume zone for only cement grout) with three percent of fly ash (10%,25%,and40%). For the other (w:c) (0.8w : 0.2c) , the approximate volume of the effective grouted zone increased when using (10%) and (25%) of fly ash, while in (40%) of fly ash the approximate volume of the effective grouted zone decreased. The last (w:c) (0.7w:0.3c), the approximate volume of the effective grouted volume zone decreased with all the percent of fly ash.
6.The rate of increase in angle of internal friction (ϕ) between the treated soil by cement grout with fly ash as a filler materials and untreated soil value ranged between (0%-15.6%) for (w:c) (0.1w:0.9c, 0.8w:0.2c, and 0.7w:0.3c)with fly ash percentages as; (10%, 25% ,and 40%.).
7. The cohesion for the treated soil by cement grout with fly ash as filler material has a value ranged between (2.5 to 8) kPa for (w:c) (0.1w:0.9c, 0.8w:0.2c, and 0.7w:0.3c) with fly ash with percentages as (10%, 25% ,and 40%.)
8 .Cement grout with the high percent of fly ash can effect on required hydration water for cement and cause the decrease in both of effective grouted volume zone and shear strength, so the grout gel with cement and fly ash needs to increase the water demand for the mixture.
9. Fly ash with cement grout needs to increase the water demand for the grout mixing to give best results , so cement grout with fly ash can be used in sites when high water table or to reduce the permeability of the soil.

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NOMENCLATURE

ASTM	American society for testing and materials
H	Height of the injected from the surface of the cylinder
C_u	Coefficient of uniformity
C_c	Coefficient of curvature
D_{10}, D_{30}, D_{60}	Particle sizes corresponding to 10%, 30%, and 60%
D_r	Relative density
G_s	Specific gravity
ϕ	Angle of internal friction
γ_{max}.	Maximum dry density
γ_{min}.	Minimum dry density
σ	Normal stress
C	Cohesion of soil
w:c	water cement ratio
w	water
c	cement

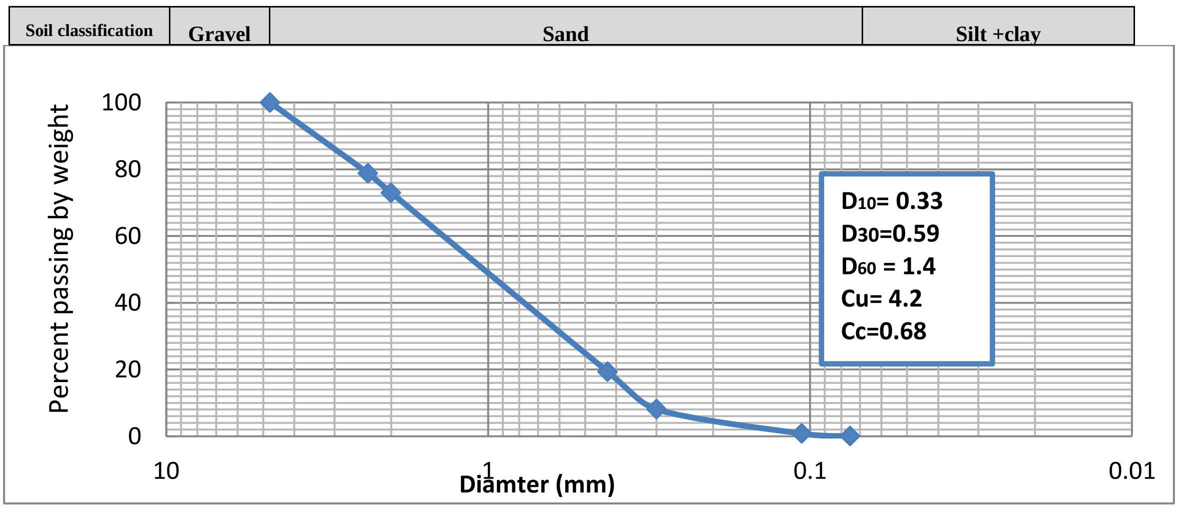

Figure 1. Grain size distribution of the soil.

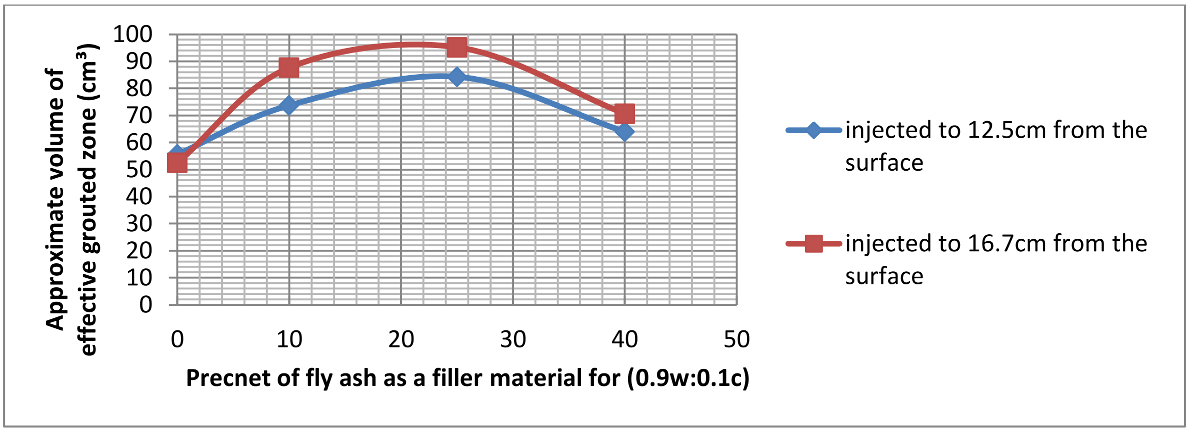

Figure 2. Approximate volume of the effective grouted volume zone after one day curing time when using cement as (0.9w : 0.1 c) with fly ash.

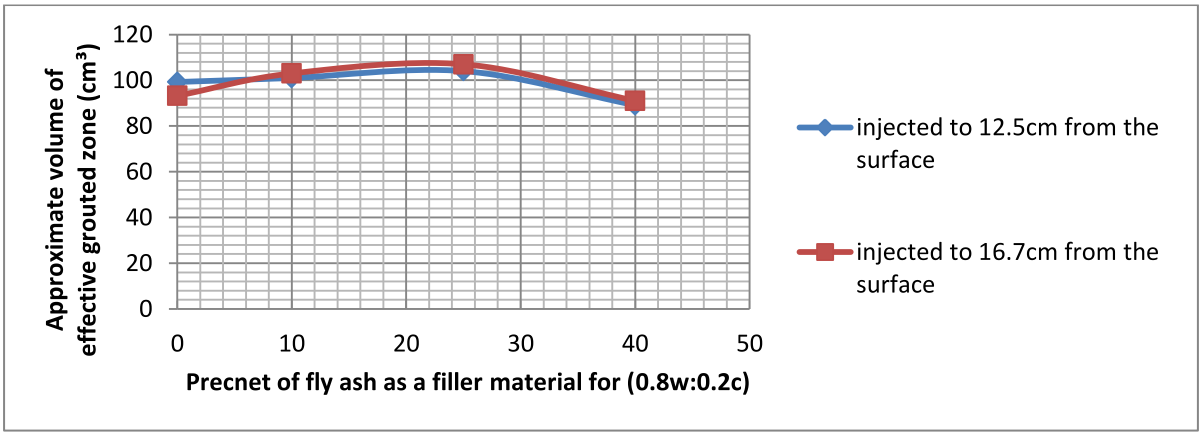

Figure 3. Approximate volume of the effective grouted volume zone after one day curing time when using cement as (0.8w : 0.2c) with Fly ash.

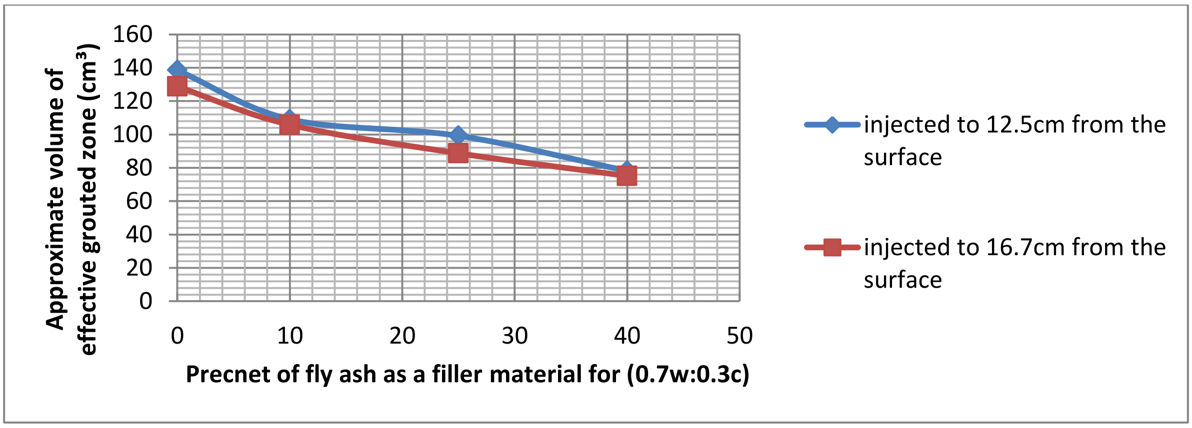

Figure 4. Approximate volume of the effective grouted volume zone after one day curing time when using cement as (0.7 w : 0.3 c) with fly ash.

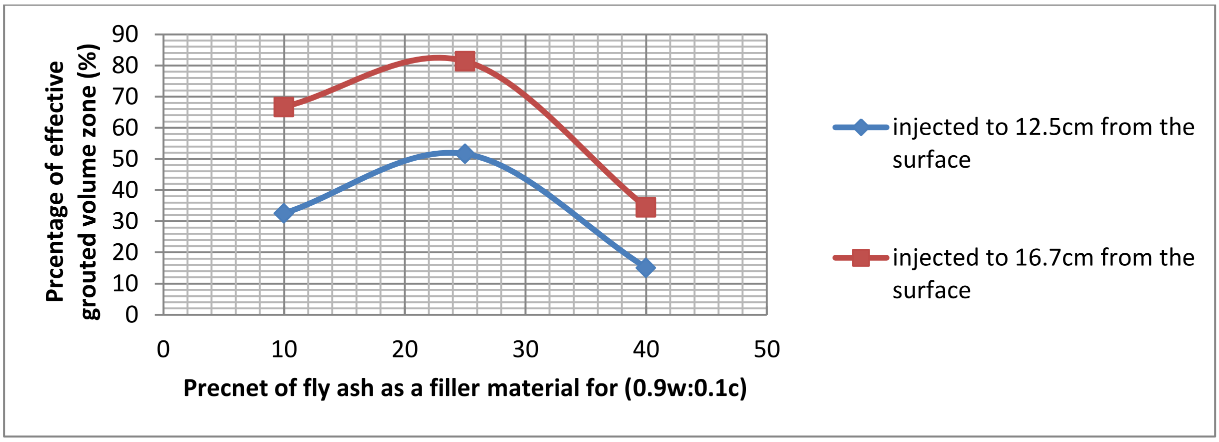

Figure 5. The comparison between the percentage of grouted zone effective volume with and without the fly ash for (w:c) (0.9 w : 0.1c).

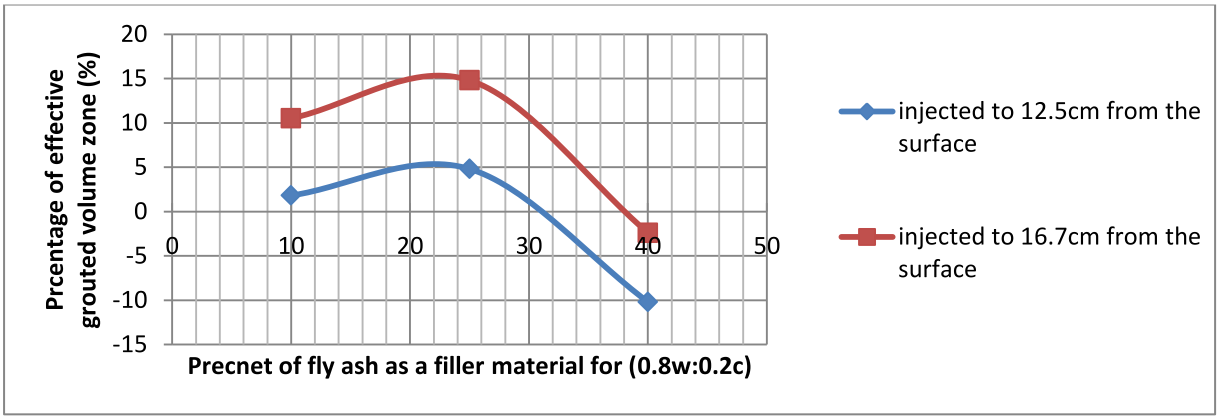

Figure 6. The comparison between the percentage of grouted zone effective volume with and without the fly ash for (w:c) (0.8 w : 0.2c).

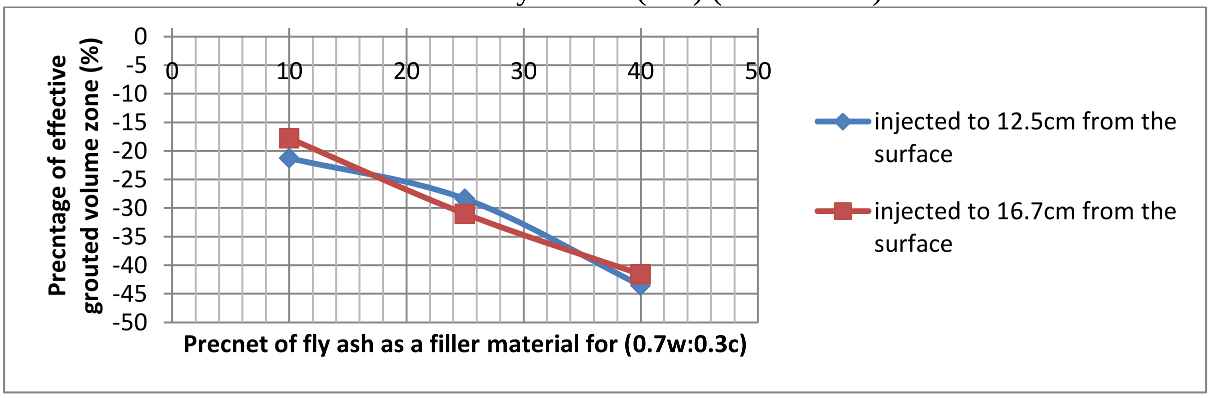

Figure 7. The comparison between the percentage of grouted zone effective volume with and without the fly ash for (w:c) (0.7 w : 0.3c).

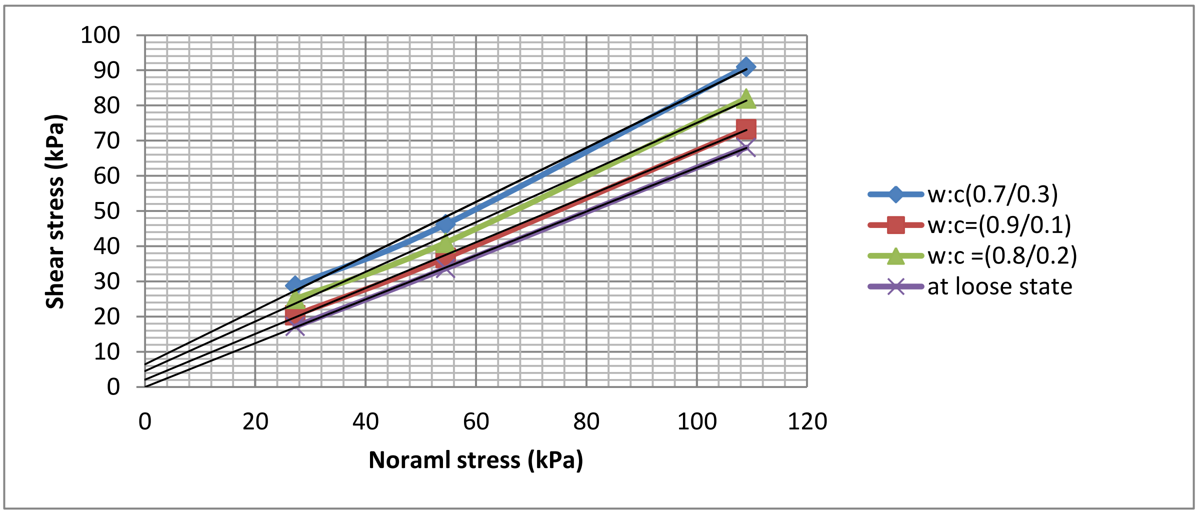

Figure 8 . Shear stress verses normal stress for soil sample with and without cement grout by direct shear .

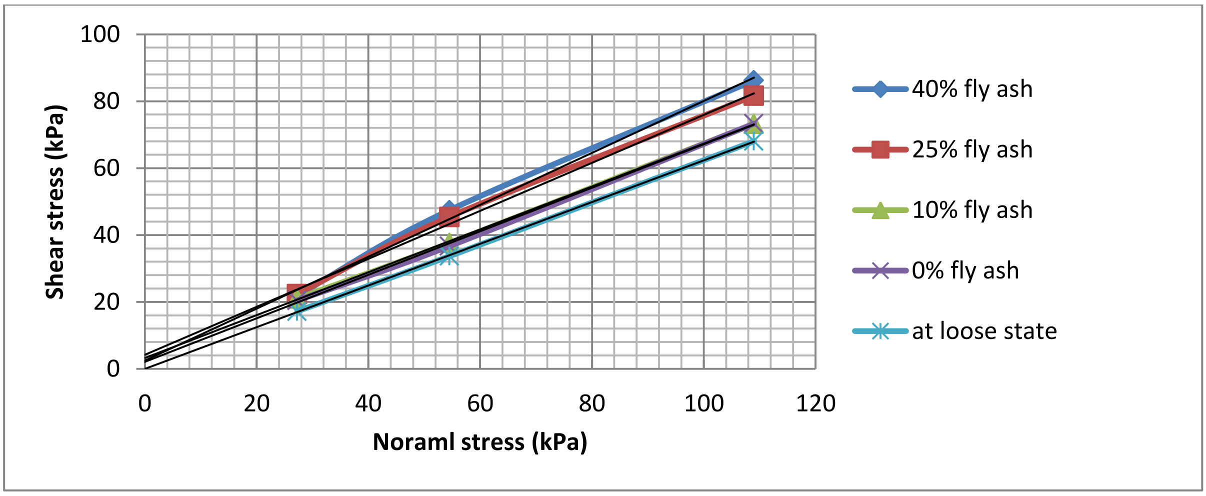

Figure 9. Shear stress verses normal stress for soil sample with and without cement grout with fly ash for grout gel at (w:c) (0.9w: 0.1c) by direct shear.

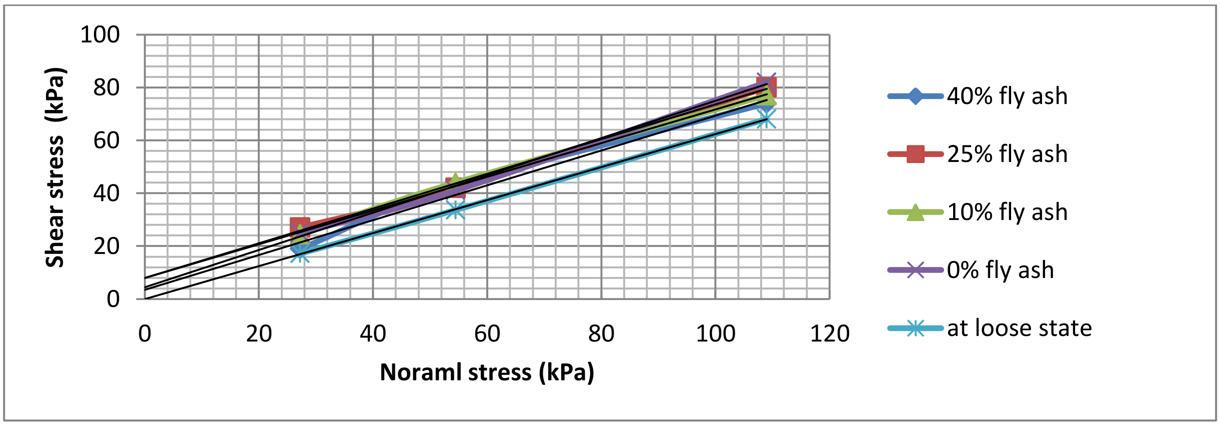

Figure 10. Shear stress verses normal stress for soil sample with and without cement grout with fly ash for grout gel at (w:c) (0.8w: 0.2w) .

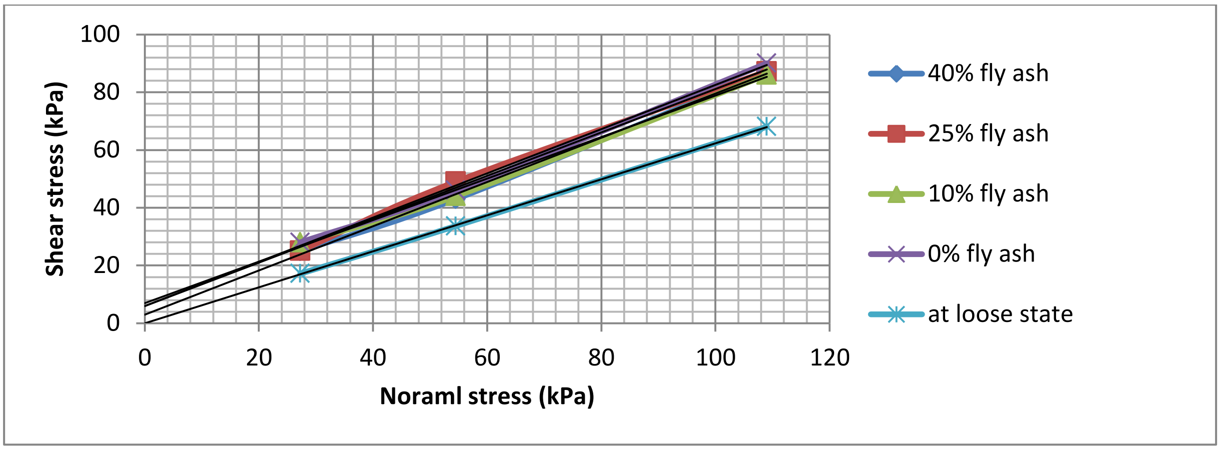

Figure 11. Shear stress verses normal stress for soil sample with and without cement grout with fly ash for grout gel at (0.7w: 0.3c) .

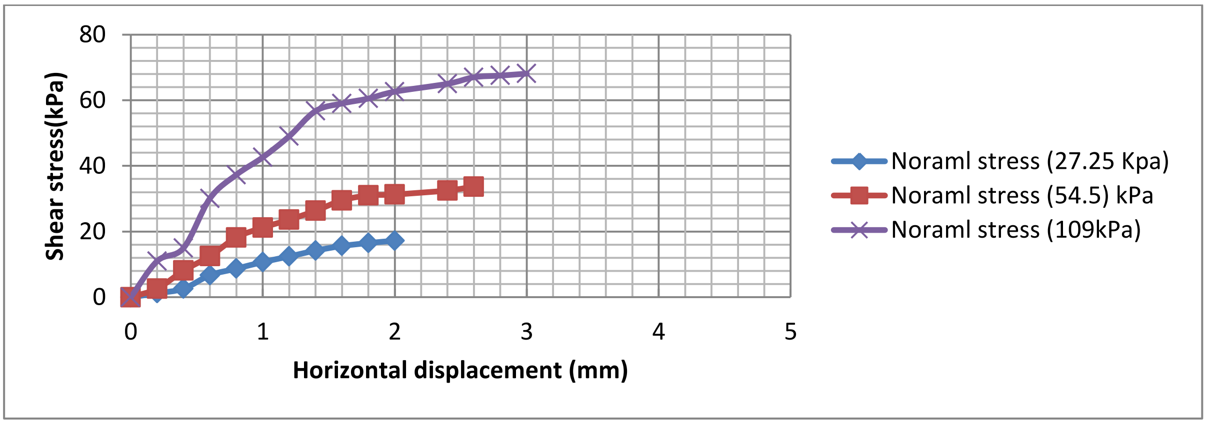

Figure 12 . Shear stress–horizontal displacement relationships at loose state.

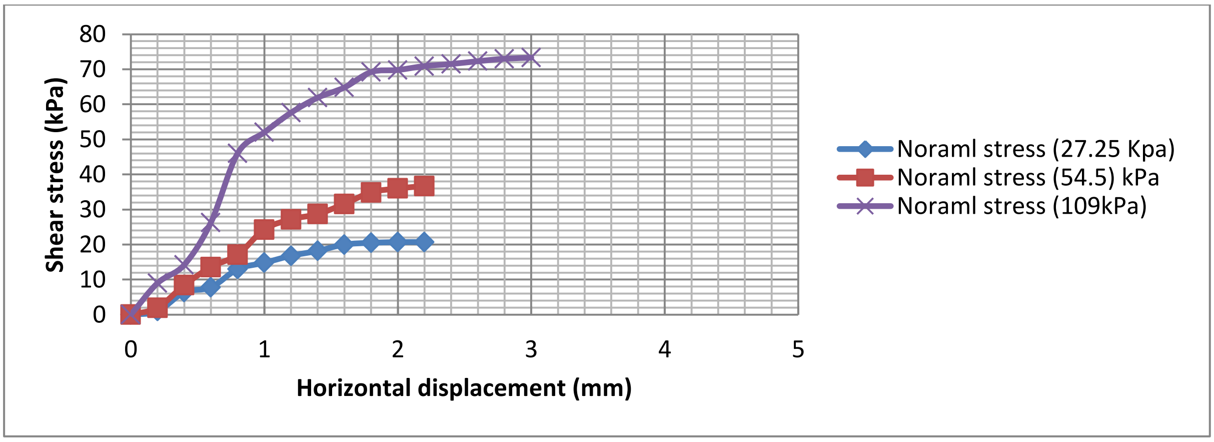

Figure 13 . Shear stress–horizontal displacement relationship for grout gel at (w:c) (0.9w:0.1c).

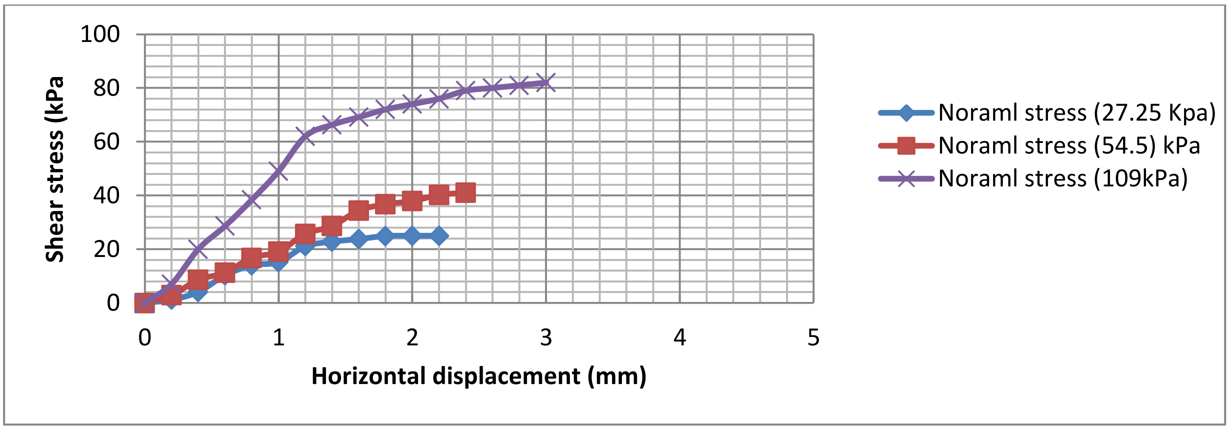

Figure 14 . Shear stress–horizontal displacement relationship for grout gel at (w:c) (0.8w:0.2c).

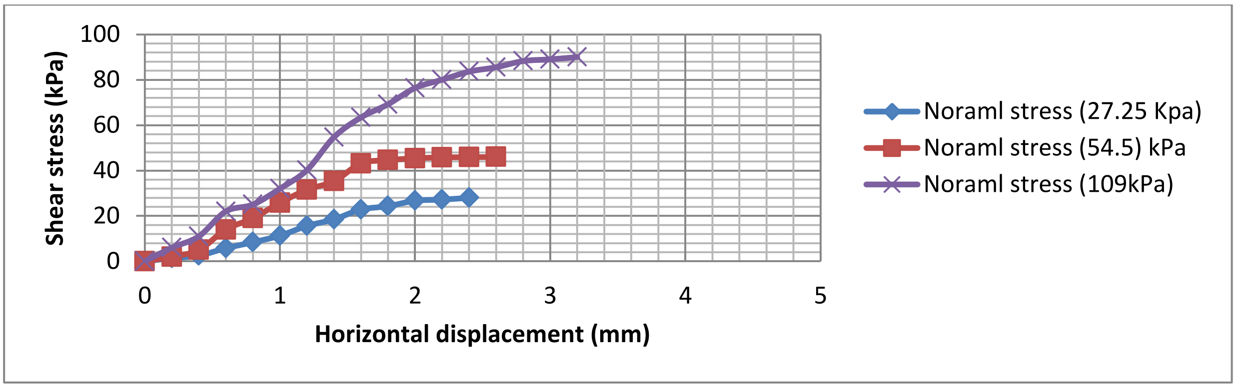

Figure 15 . Shear stress–horizontal displacement relationship for grout gel at (w:c) (0.7w:0.3c).

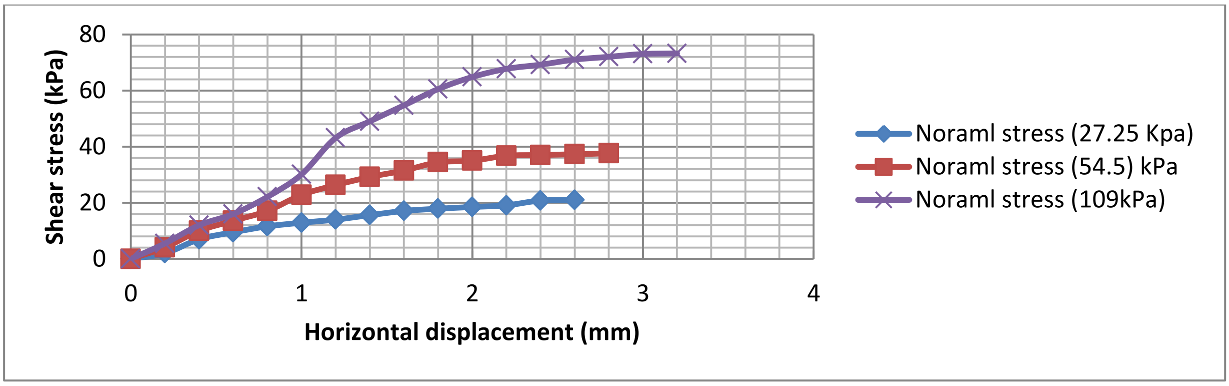

Figure 16 . Shear stress–horizontal displacement relationship for grout gel at (w:c) (0.9w:0.1c) with 10% fly ash .

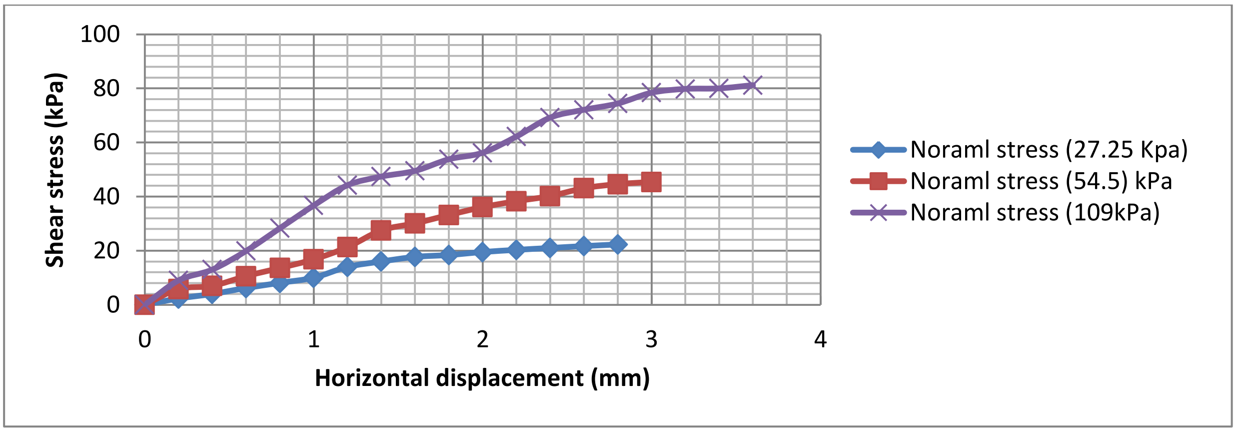

Figure 17 . Shear stress–horizontal displacement relationship for grout gel at (w:c) (0.9w:0.1c) with 25% fly ash

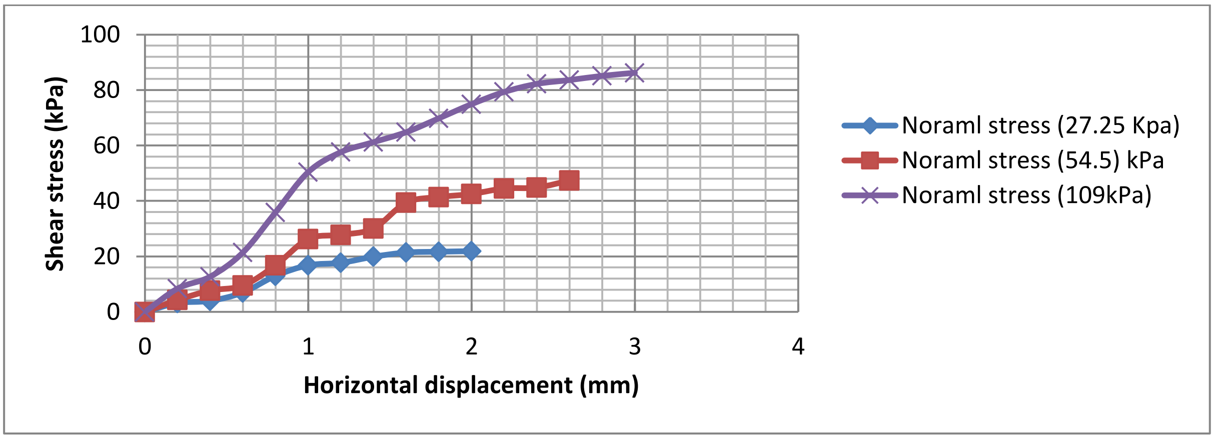

Figure 18 . Shear stress–horizontal displacement relationship for grout gel at (w:c) (0.9w:0.1c) with 40% fly ash.

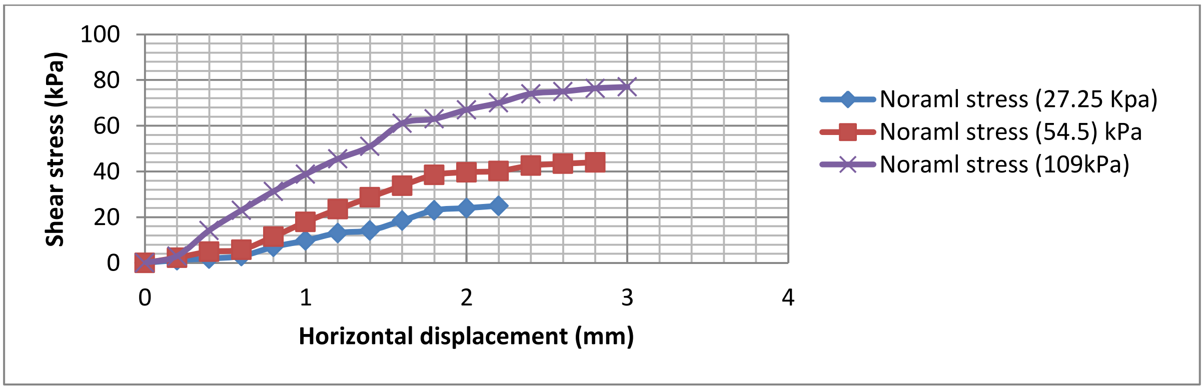

Figure 19 . Shear stress–horizontal displacement relationship for grout gel at (w:c) (0.8w:0.2c) with 10% fly ash.

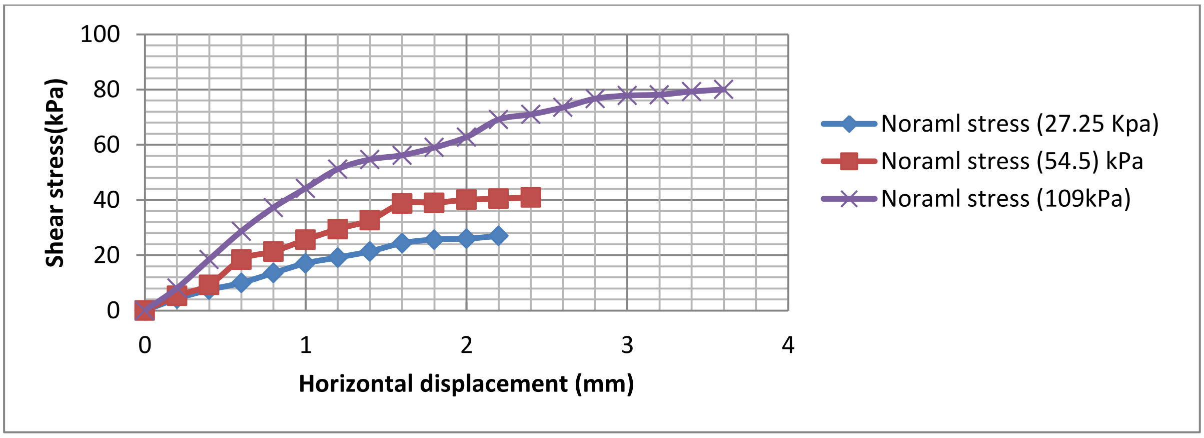

Figure 20 . Shear stress–horizontal displacement relationship for grout gel at (w:c) (0.8w:0.2c) with 25% fly ash .

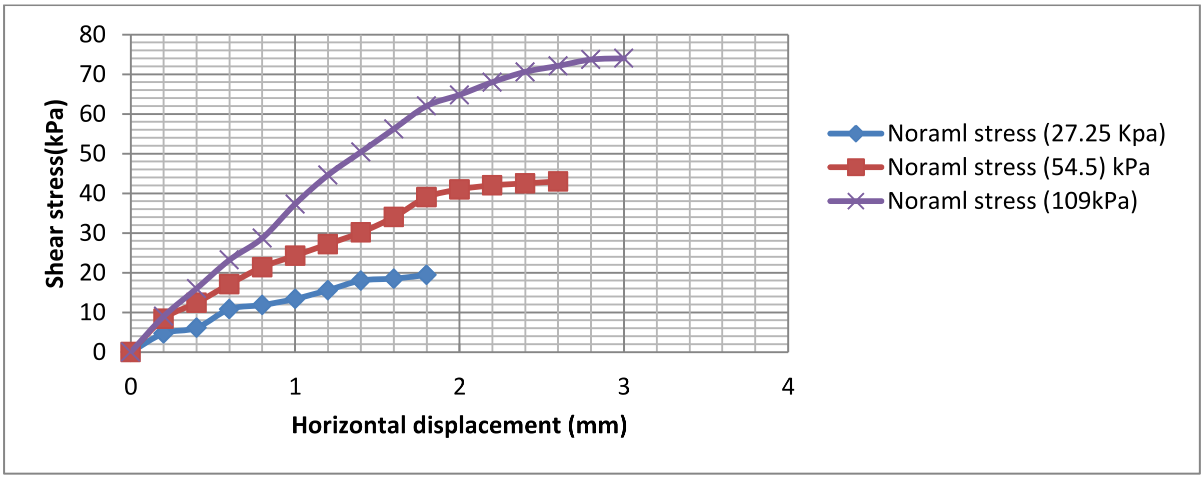

Figure 21 . Shear stress–horizontal displacement relationship for grout gel at (w:c) (0.8w:0.2c) with 40% fly ash.

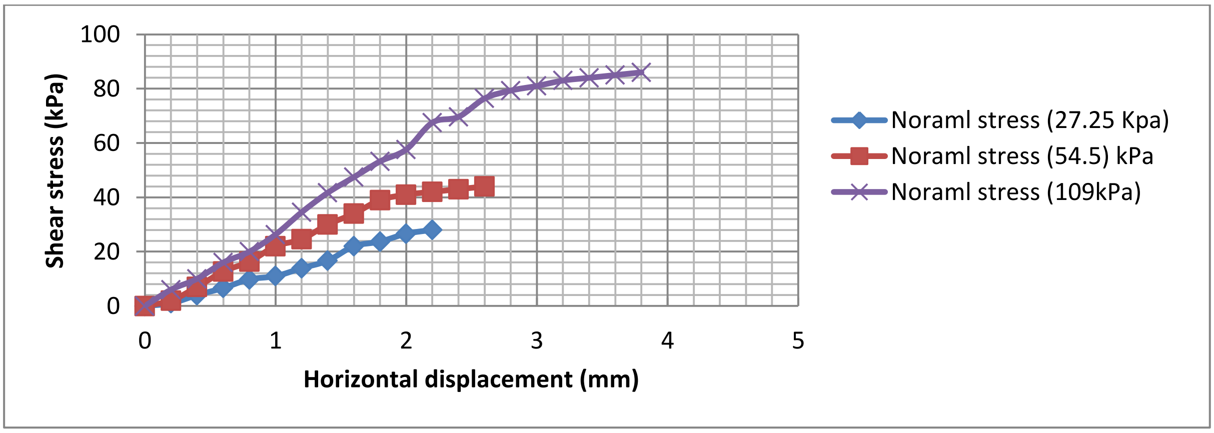

Figure 22 .Shear stress–horizontal displacement relationship for grout gel at (w:c) (0.7w:0.3c) with 10% fly ash.

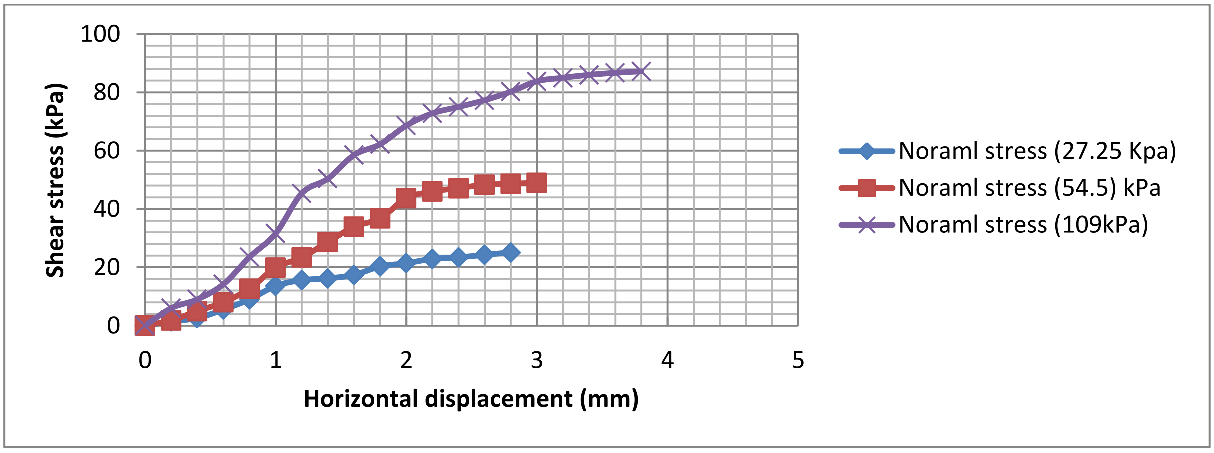

Figure 23 .shear stress–horizontal displacement relationship for grout gel at (w:c) (0.7w:0.3c) with 25% fly ash.

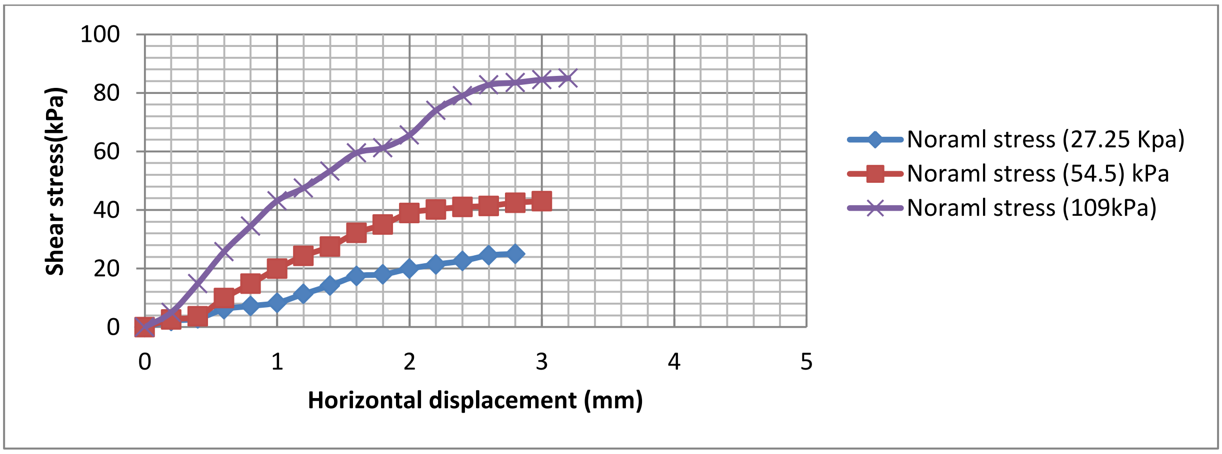

Figure 24 .Shear stress–horizontal displacement relationship for grout gel at (w:c) (0.7w:0.3c) with 40% fly ash.

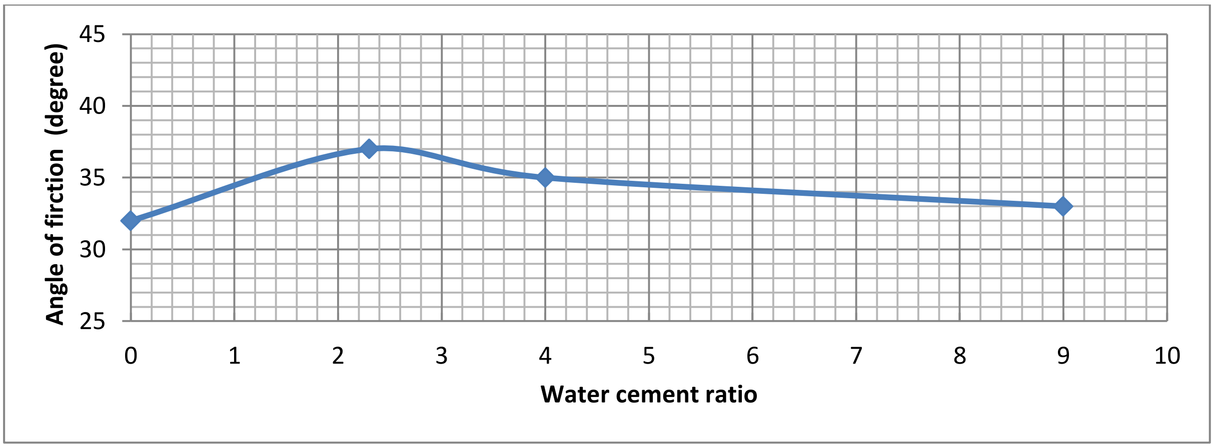

Figure 25. The Relationship between the (w:c) ratio for only cement grout and angle of friction.

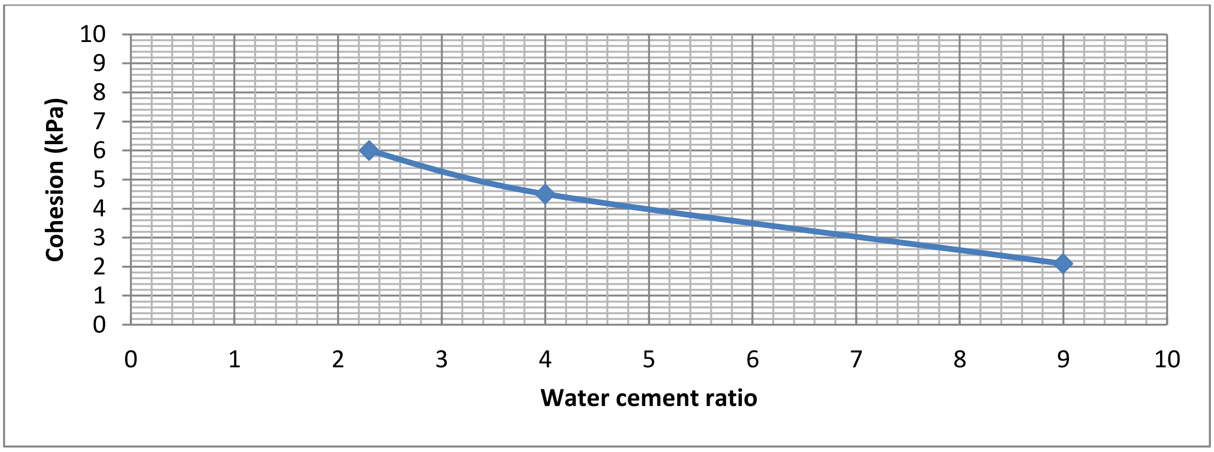

Figure 26. The relationship between the (w:c) ratio for only cement grout and cohesion.

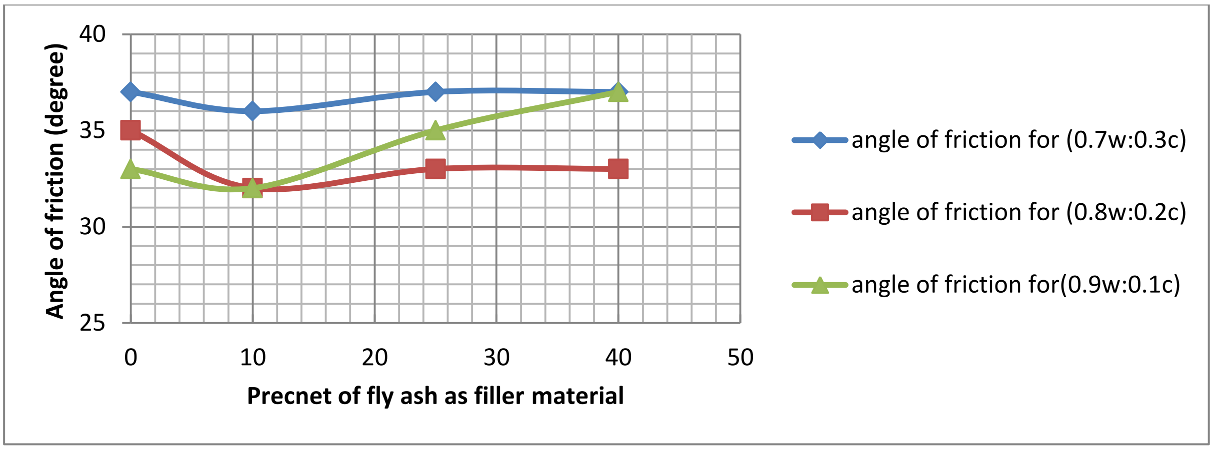

Figure 27. The relationship between the (w:c) ratio for cement grout with fly ash and angle of friction.

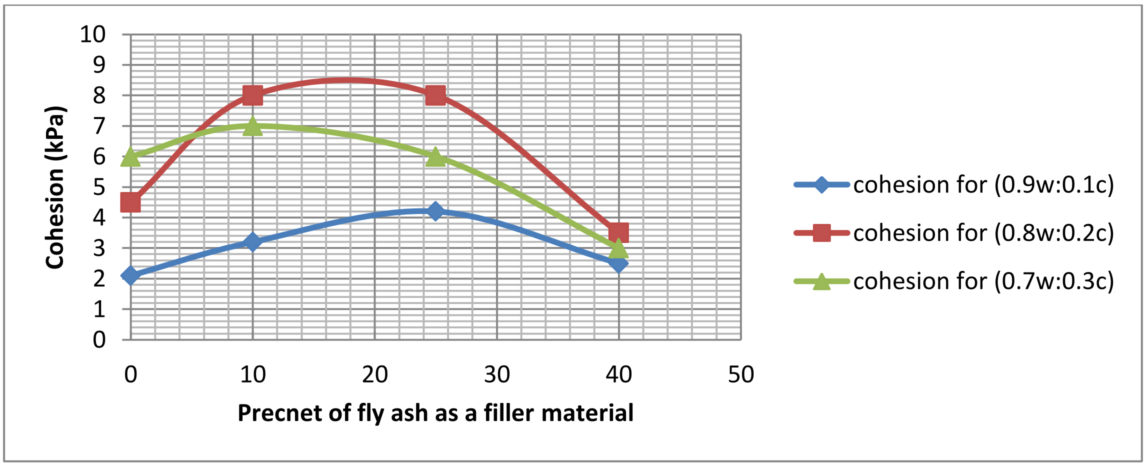

Figure 28. The relationship between the (w:c) ratio for cement grout with fly ash and cohesion.

Table 1. The physical Properties of sand soil.

Specific Gravity (G_s)	2.67	ASTM D854–2005
Maximum unit weight (γ_{max}.)	17.34 KN/m^3	ASTM D4253- 2000
Minimum unit weight (γ_{min}.)	14.79 KN/m^3	ASTM D4254–2000
Relative Density (D_r)	30%	--------
D_{10} , mm	0.33	--------
D_{30} , mm	0.59	--------
D_{60} , mm	1.4	--------
C_u	4.2	--------
C_c	0.68	--------

Table 2. Physical and chemical properties of cement.

Index property	Index value
Compressive strength after 3 days (MPa)	27
Compressive strength after 7 days (MPa)	32.5
Time of initial setting (hour)	2.167
Time of final setting (hour)	4.167
SiO_2 (%)	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 (%)	1.00
Salts insoluble (%)	1.24
Losses in heating (%)	3.25
Fineness of Cement (Blaine s Sp. Surface) (m^2/kg)	370

Table 3. Physical and chemical properties of fly ash.

Index property	Index value
SiO_2 (%)	83.717
K_2O(%)	10.401
Al_2O_3 (%)	2.314
Fe_2O_3 (%)	2.213
CaO (%)	0.908
Sc_2O_3 (%)	0.046
ZnO (%)	0.138
MnO (%)	0.179
PbO (%)	0.023
CuO (%)	0.009
Ir_2O_3 (%)	0.007
Rb_2O (%)	0.004
Y_2O_3 (%)	0.003
SrO (%)	0.010
TiO_3	0.016
ZrO_2	0.013
Fineness (Blaine s Sp. Surface) (m^2/kg)	295

Table 4. The comparison percentage of the grouted zone effective volume with and without the fly ash

Injected depth	Grouted volume zone by cement only (cm³)	Grouted volume zone by cement + fly ash (cm³)	Increase or decrease in grouted volume zone	Picture for the sample after one day curing
For (0.9w:0.1c) + 5% Fly ash				
h= 12.5 cm	55.6	73.69	32.53%	
h= 16.7 cm	52.5	87.65	66.76%	
For (0.9w:0.1c) + 25% fly ash				
h= 12.5 cm	55.6	84.3	51.61%	
h= 16.7 cm	52.5	95.2	81.33 %	
For (0.9w:0.1c) + 40% fly ash				
h= 12.5 cm	55.6	64	15.1 %	
h= 16.7 cm	52.5	70.6	34.48 %	
For (0.8w:0.2c) + 10% fly ash				
h= 12.5 cm	99.25	101	1.8%	
h= 16.7 cm	93.21	103	10.5%	
For (0.8w:0.2c) + 25% fly ash				
h= 12.5 cm	99.25	104 c.m3	4.8 %	
h= 16.7 cm	93.21	107 c.m3	14.8%	
For (0.8w:0.2c) + 40% fly ash				
h= 12.5 cm	99.25	89.1	-10.2 %	
h= 16.7 cm	93.21	91 c.m3	-2.4 %	
For (0.7w:0.3c) + 10% fly ash				
h= 12.5 cm	138.5	109.1	-21.227 %	
h= 16.7 cm	128.7	105.8	-17.793 %	
For (0.7w:0.3c) + 25% fly ash				
h= 12.5 cm	138.5	99.2	-28.4 %	
h= 16.7 cm	128.7	88.7	-31 %	
For (0.7w:0.3c) + 40% fly ash				
h= 12.5 cm	138.5	78.2	-43.537%	
h= 16.7 cm	128.7	75.15	-41.60 %	

- The negative sign refers to decrease in volume.

Table 5. Results of direct shear test for soil treated by grouting method with different (w:c) with and without fly ash

(w:c) with percent of filler materials		Result of direct shear test		Increasing in ϕ (%) for treated soil
(w:c)	percentage of Fly ash	ϕ degree	C kPa	
0	0	32	0	-
(0.9w:0.1c)	0	33	2.1	3%
	10%	32	3.2	0%
	25%	35	4.2	9.4%
	40%	37	2.5	15.6%
(0.8w:0.2c)	0	35	4.5	9.4%
	10%	32	8	0%
	25%	33	8	3%
	40%	33	3.5	3%
(0.7w:0.3c)	0	37	6	15.6%
	10%	36	7	12.5%
	25%	37	6	15.6%
	40%	37	3	15.6%