CHAPTER FOUR

RESULTS ANALYSIS AND DISCUSSION

4.1 Introduction

The results of the various tests carried out during the experimental investigation are presented, analyzed and discussed in this chapter.

4.2 Density of clay soil and stabilizers materials:

The densities of soil, cement waste, fiber glass waste and PET waste are tabulated in Table (4.1) and presented in Fig (4.1).

Table 4.1: Results of Density of soil and waste materials according to ASTM D 792

materials	Average density
Soil	2.43
Cement waste	2.95
Fiber waste	3.71
PET waste	1.35

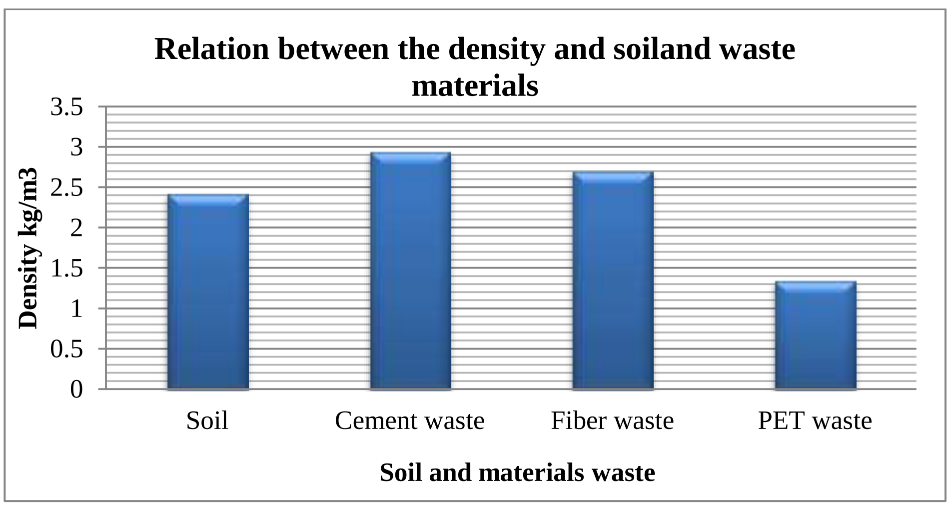


Fig 4.1: Relation between the density and soil and materials waste

4.3 Liquid Limit and Plastic Limits:

Atterberg limits for the natural clay soil and soil treated by 3, 6 and 9% of cement waste were tested and the results tabulated in Table 4.2 and plotted in Fig (4.2) to Fig(4.5). The liquid limit was measured by the Casagrande's apparatus. The results indicate that an increasing of cement waste content decreases the liquid limit from 38.2 to 36.8 %, increases the plastic limit from 27.85 to 33.56 and decreases the plastic index from 9.14 to 3.24%. Clay soil after addition of 9% or more of cement waste became non plastic.

From Fig (4.6) the empirical equation predicted by using Microsoft Excel **(**linear equation) for the relation between the plastic index and added % of cement waste is:

$$PI = 1.685PC^2 - 10.29PC + 18.96 \quad (R^2 = 1) \ldots\ldots\ldots (4.1)$$

Where:

PI: plastic index

PC: percentage added of cement waste

Table 4.2: Values of liquid limit, plastic Limit and plastic index

Percentages	***0%***	***3% cement***	***6% cement***
LL	38.2	36.9	36.8
PL	27.85	31.79	33.56
PI	10.35	5.11	3.24

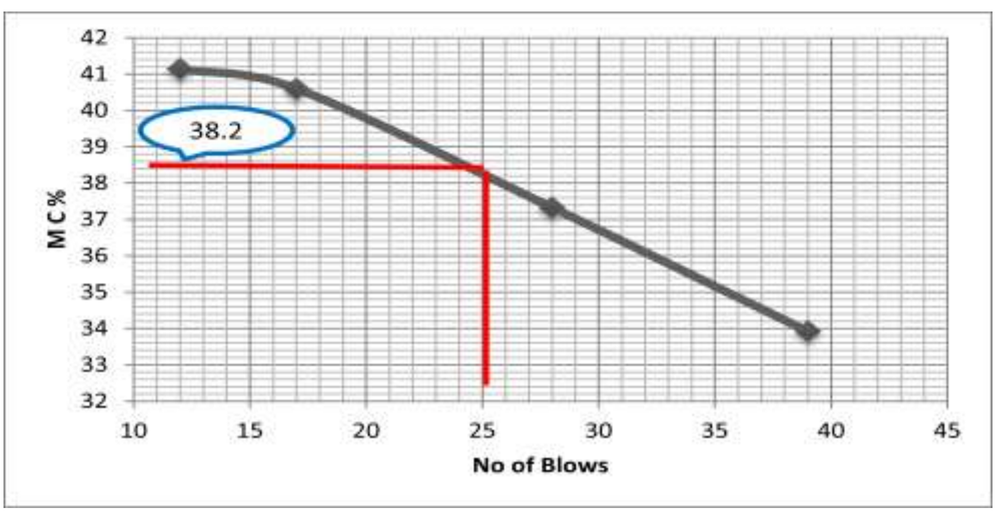


Fig 4.2: Relation between moisture content and no of blows for clay soil

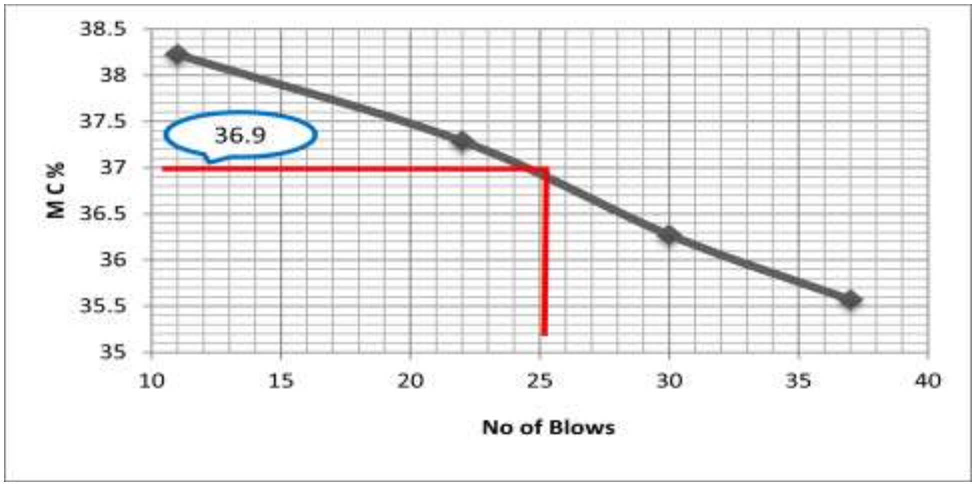


Fig 4.3: Relation between MC and no of blows for clay soil + 3% cement waste

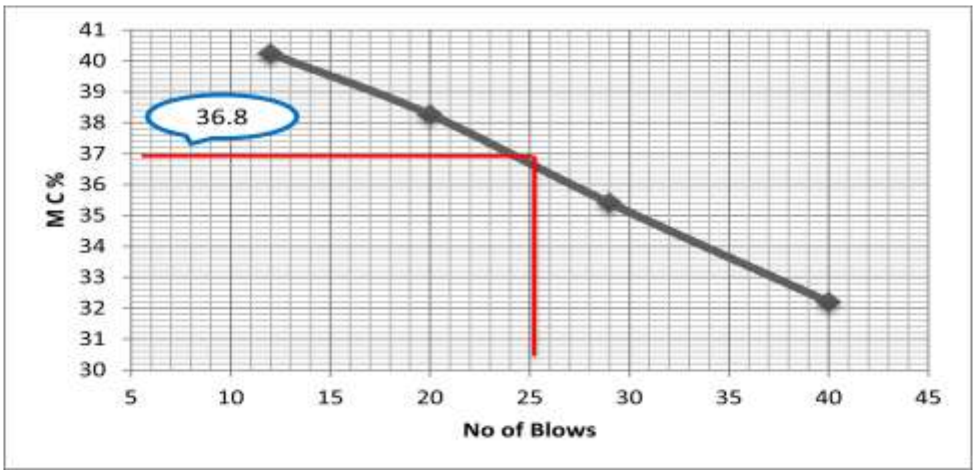


Fig 4.4: Relation between MC and no of blows for clay soil + 6% cement waste

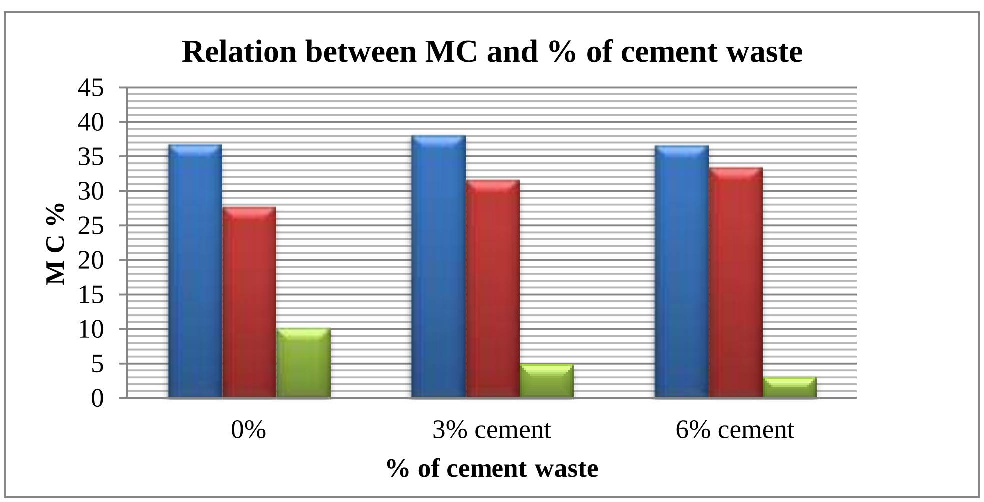


Fig 4.5: Relation between MC and added% of cement waste

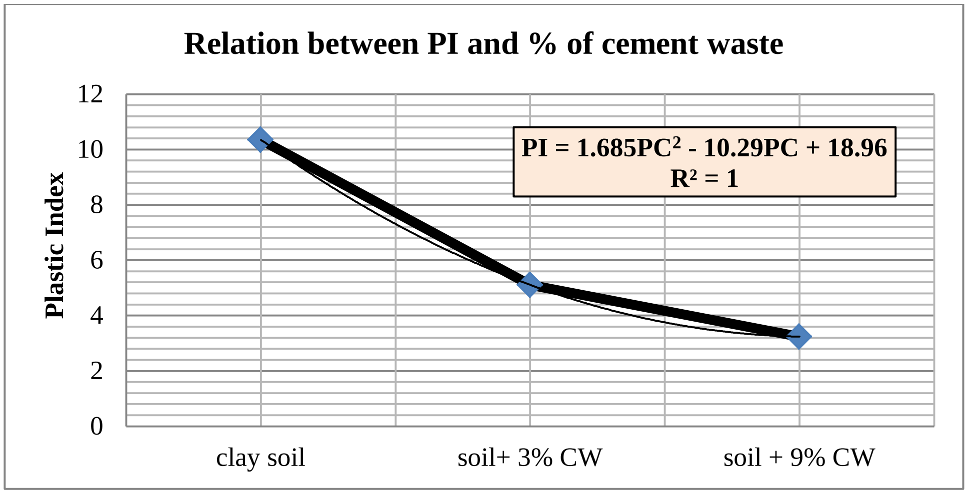


Fig 4.6: Relation between PI and added% of cement waste

4.4 Particle Size Distribution

The grain size distribution for the clay soil is found out by conducting wet sieve analysis and the results are tabulated in Table (4.3) and plotted in Fig (4.7)

Table 4.3: Results of sieve analysis test (clay soil)

Sieve Size	Mass of soil retained on each sieve, *g*	Cumulative mass of soil retained, *g*	Cumulative mass of soil passing each sieve, *g*	Percent finer %
10	0	0	300	100
6.25	0	0	300	100
4.75	0	0	300	100
2	2.51	2.51	297.49	99.16
1.25	1.06	3.75	296.25	98.75
0.6	1.86	5.43	294.57	98.19
0.425	2.44	7.87	292.13	97.38
0.150	14.45	22.32	277.68	92.56
0.075	24.2	46.52	253.48	84.49
< 0.075	253.48	300	0	0

*Mass of total dry soil = 300g

Percent finer = $\frac{\textbf{cumulative mass of soil passing each sieve}}{\textbf{mass of the total dry soil}} \times \mathbf{100}$

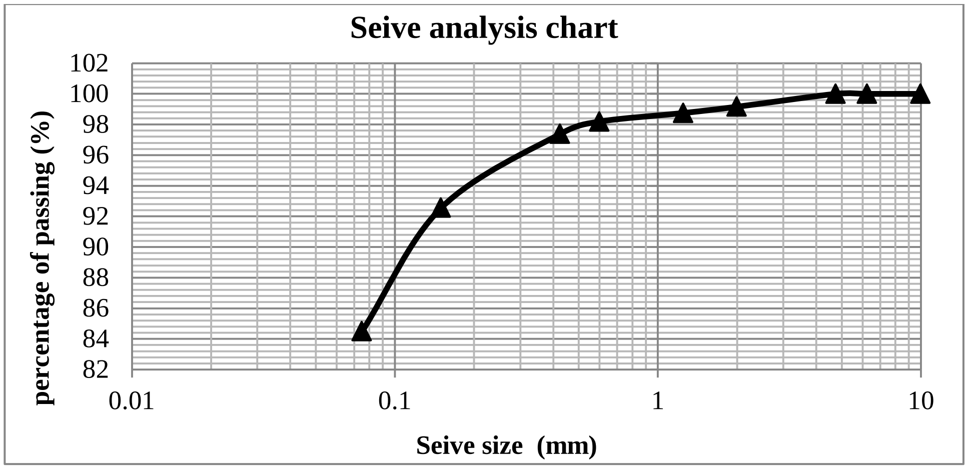


Fig 4.7: Sieve analysis chart

4.5. Standard Proctor Compaction Test

A series of standard proctor compaction Test had been performed to study the effect of the use of cement waste as chemical stabilizer of clay soil and the effect of fiber glass waste and plastic PET bottles waste as soil reinforcement on the optimum moisture content (OMC) and the maximum dry density (MDD).

4.5.1 Clay soil

The dry density and water content relationship was obtained from Standard Proctor Test. The OMC and MDD of the plain soil are obtained from the Fig (4.8) as given: OMC = 18 % and MDD = 1.67 g/cm^3

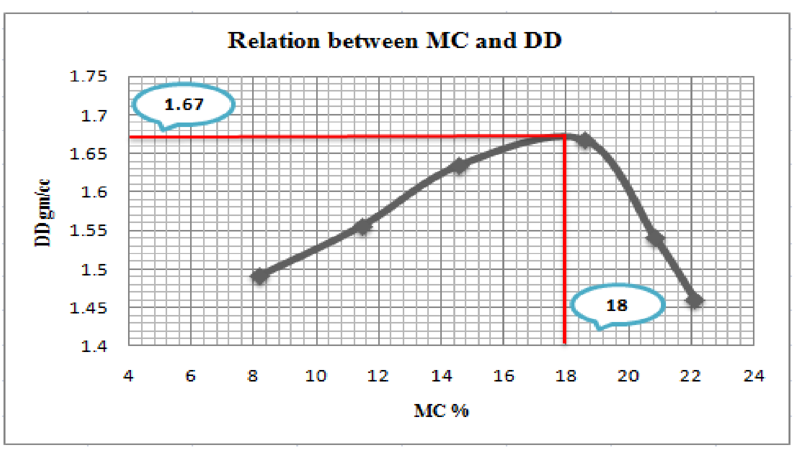


Fig 4.8: Relation between dry density and moisture content (clay soil)

4.5.2 Soil treated by cement waste:

Similar results from standard proctor test for soil treated by 3%, 6%, 9%, 12% and 15% of cement waste were obtained and are presented in Fig (4.9) to Fig (4.13) respectively.

The OMC and MDD for the clay soil treated by the cement waste are reported in Table (4.4) and plotted in Fig (4.14). Also the relation between the OMC and the percentages of cement waste are presented in Fig (4.15) and the relation between the MDD and percentages of the cement waste are plotted in Fig (4.16). The results indicate that an addition of 3% to 12% of cement waste content gave similar results of optimum moisture content (OMC=30) then it decreases (to 28) with addition of 15% of cement waste content. This conclusion agree with the findings of Keerthi (2013) [36] and disagrees with the findings of Roy (2014) [73]. This may be attributed to the difference in the material properties which are used in the two works. Also it can be seen that an increasing of cement waste content decreases the maximum dry density (MDD)

The new formula obtained from Fig (4.16) by using excel sheet to determine the MDD based on the % of the cement waste is as follow:

$$MDD = 1.385PC^{-0.03} \quad (R^2=0.967)\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.2)$$

Table 4.4: Results of compaction test for different %s added of cement Waste)

Percentage	OMC	MDD
3%	30	1.56
6%	30	1.52
9%	30	1.51
12%	30	1.48
15%	28	1.48

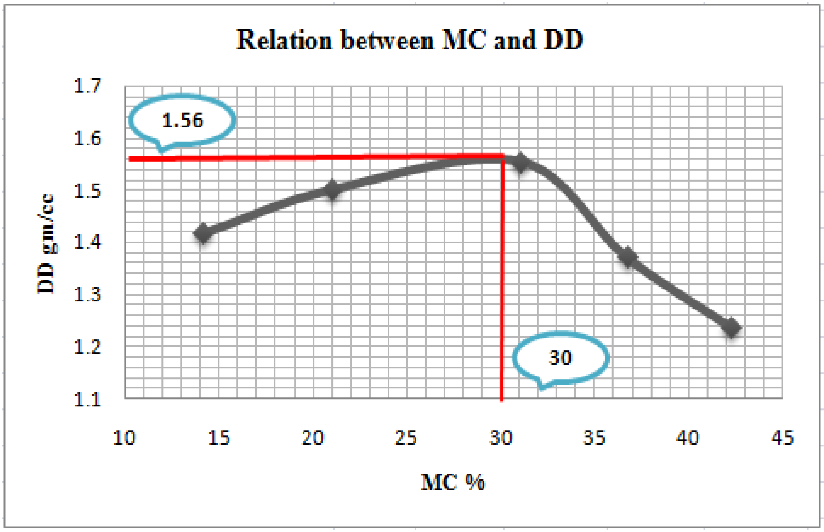


Fig 4.9: Relation between dry density and moisture content (soil+ 3% cement waste)

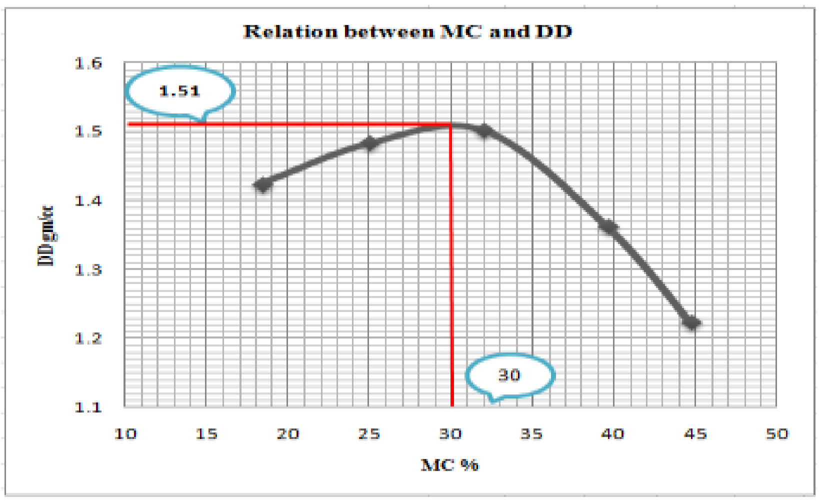


Fig 4.10: Relation between dry density and moisture content (soil+ 6% cement waste)

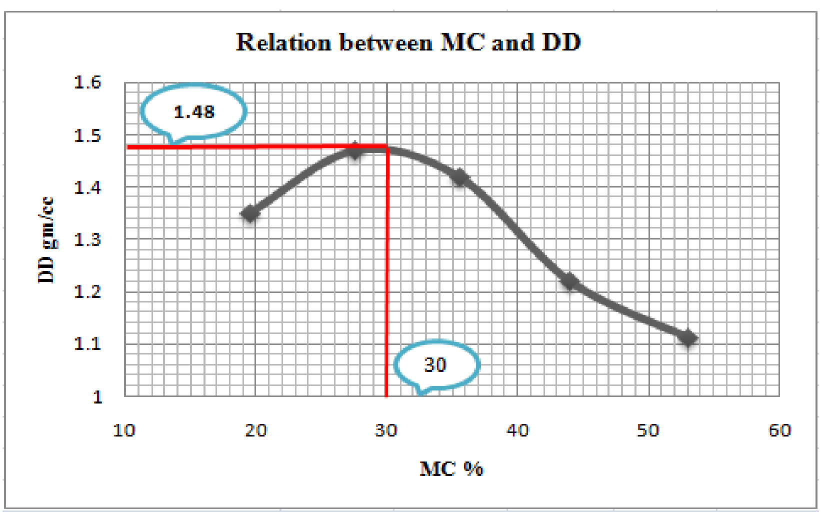


Fig 4.11: Relation between dry density and moisture content (soil+ 9% cement waste)

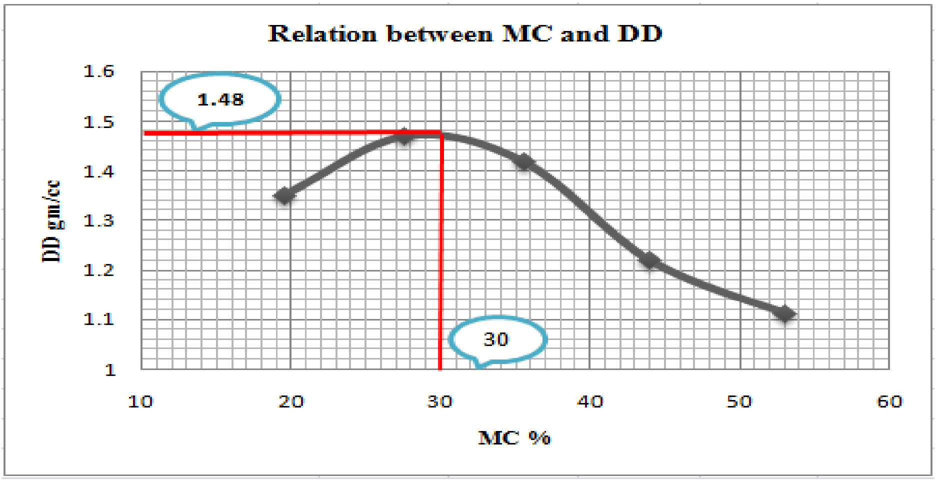


Fig 4.12: Relation between dry density and moisture content (soil+ 12% cement waste)

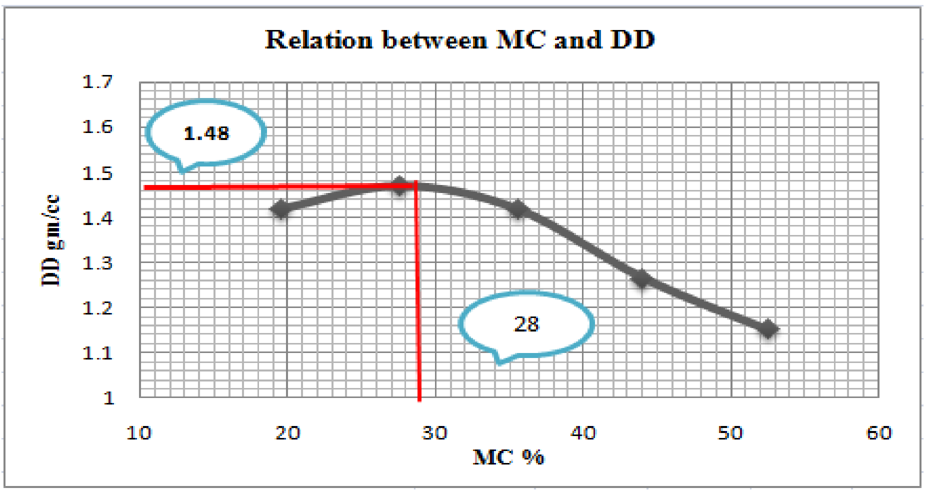


Fig 4.13: Relation between dry density and moisture content (soil+ 15% cement waste)

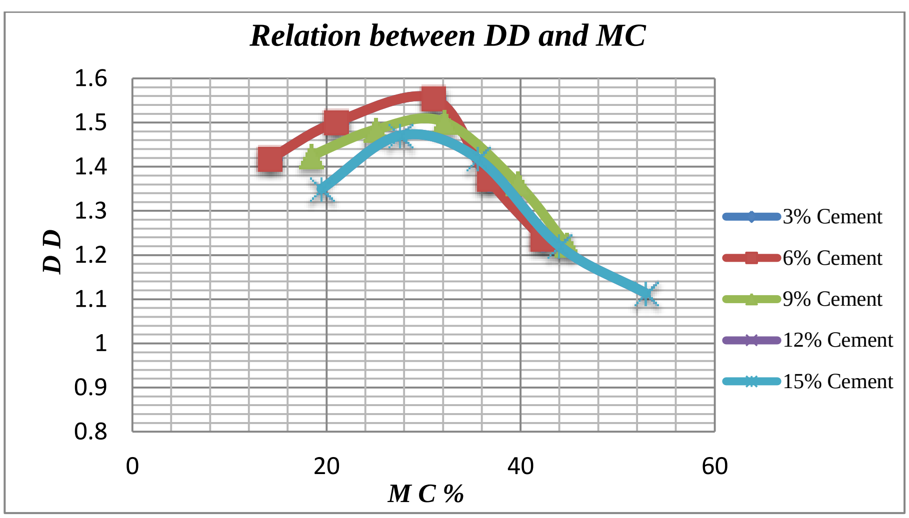


Fig 4.14 Moisture content and dry density (soil treated by different % added of cement waste)

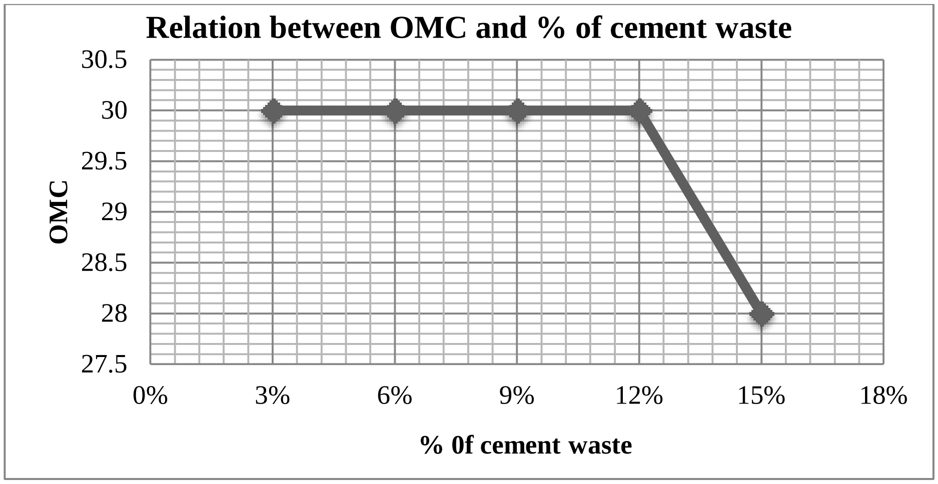


Fig 4.15 Relation between OMC and %added of cement waste

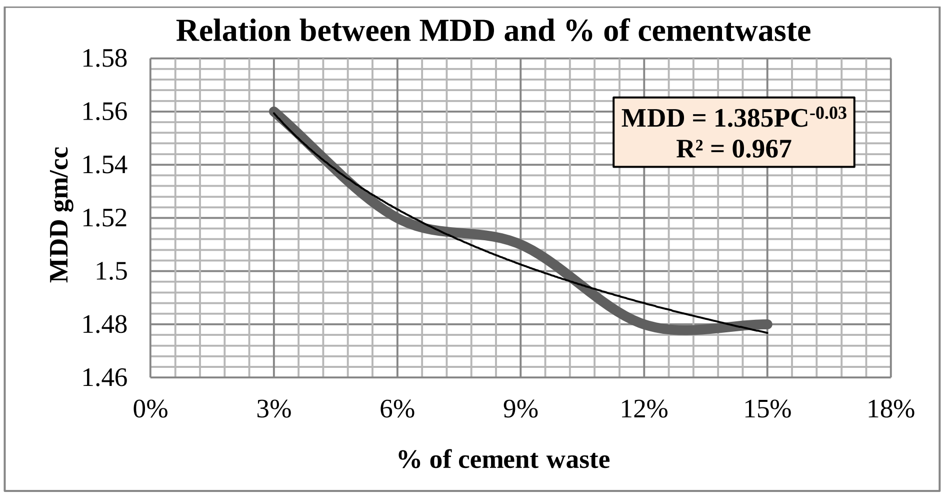


Fig 4.16 relation between MDD and % added of cement waste

4.5.3 Clay Soil Reinforced by Fiber Waste:

The compaction curves for soil reinforced by randomly adding fiber glass are presented in Fig (4.17) to Fig (4.21) for soil reinforced by 3, 6, 9, 12 and 15% of fiber glass waste content respectively.

The OMC and MDD for different added percentages of fiber glass are tabulated in Table (4.5) and plotted in Fig (4.22). Also the relation between the OMC and the added percentages of fiber glass are presented in Fig (4.23) and the relation between the MDD and the percentages of fiber glass presented in Fig (4.24). These indicate that an increasing in fiber waste content causes increases in optimum moisture content from 34 to 52% and decreases the maximum dry density from 1.24 to 1.08 *g/cm³*.

From the scatter diagram plotted by Microsoft excel sheet in Fig (4.23) and Fig 4.24 the following empirical equations are obtained:

$OMC = 30.62e^{3.726PF}$. ($R^2 = 0.946$)...................................... (4.3)

$MDD = 4.761PF^2 + 2.19PF + 1.30$ ($R^2 = 0.991$)................ (4.4)

Where *PF*: the percentages of fiber glass waste.

Table 4.5: Results of compaction test for Different percentages of added Fiber Waste

Percentage	OMC	MDD
3%	34	1.24
6%	39	1.18
9%	41	1.15
12%	51	1.10
15%	52	1.08

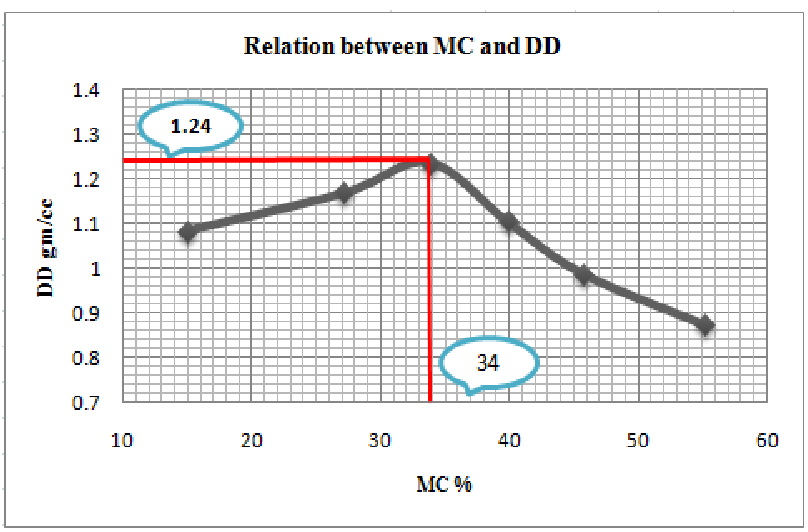


Fig 4.17 Moisture content and dry density (soil + 3% of fiber waste)

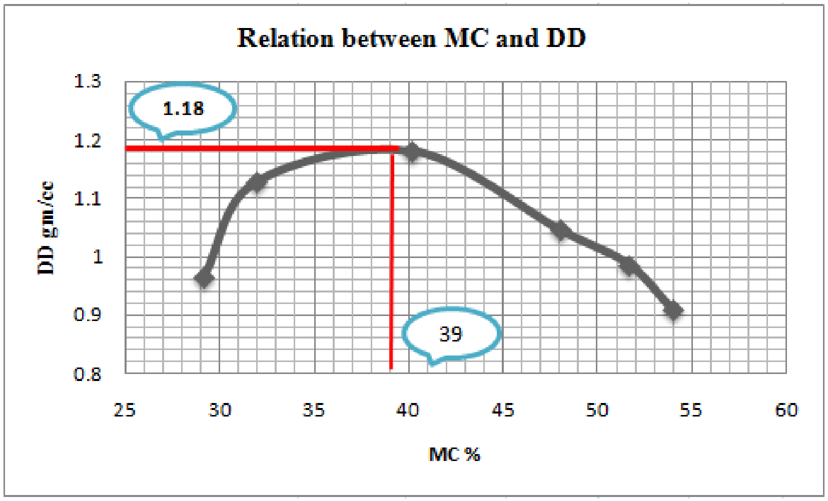


Fig 4.18 Moisture content and dry density (soil + 6% of fiber waste)

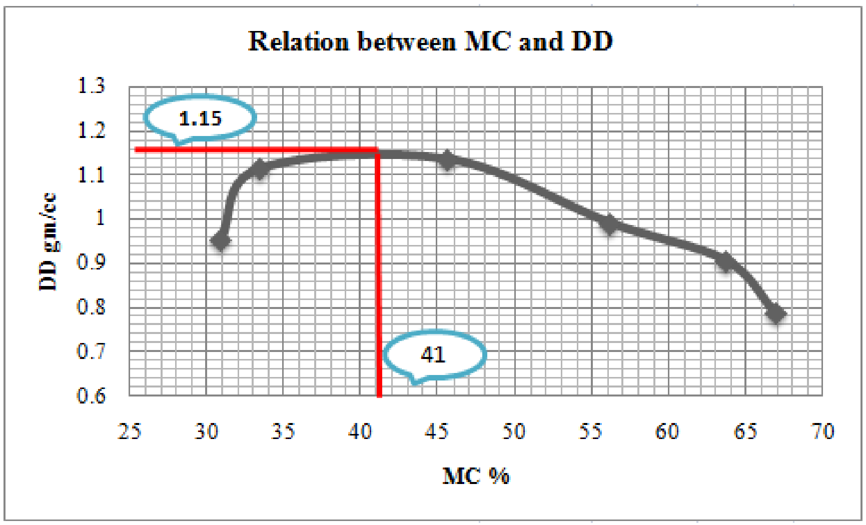


Fig 4.19 Moisture content and dry density (soil + 9% of fiber waste)

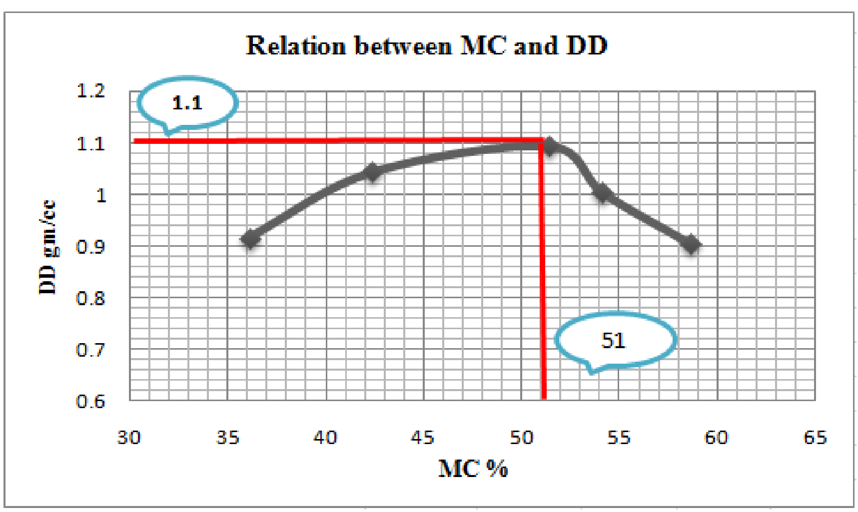


Fig 4.20 Moisture content and dry density (soil + 12% of fiber waste)

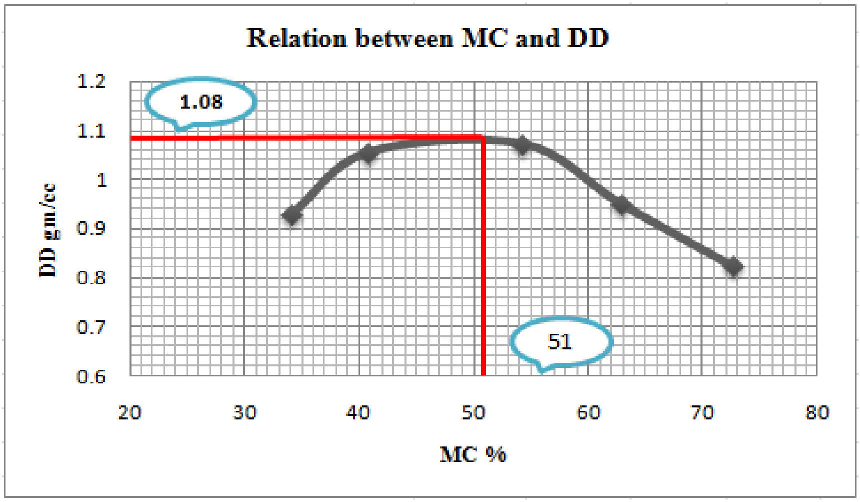


Fig 4.21 Moisture content and dry density (soil + 15% of fiber waste)

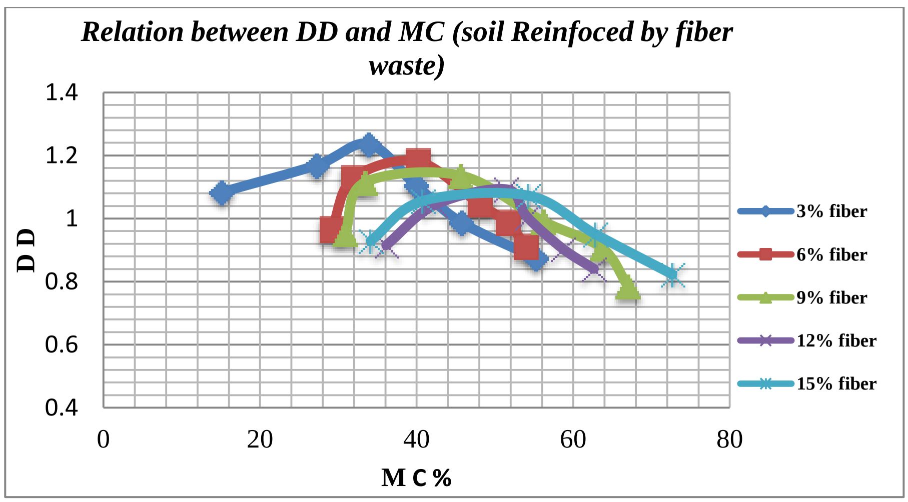


Fig 4.22 Relation between moisture content and dry densities

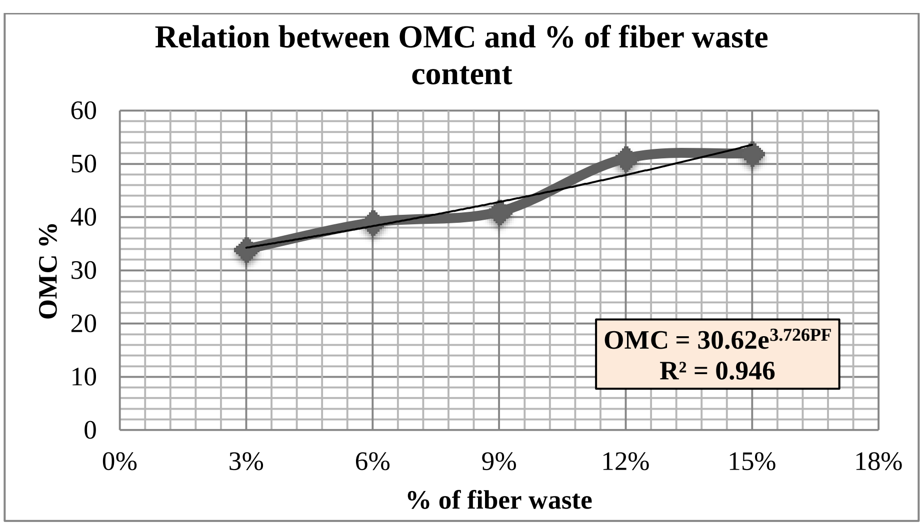


Fig 4.23 Relation between OMC and % added of fiber waste

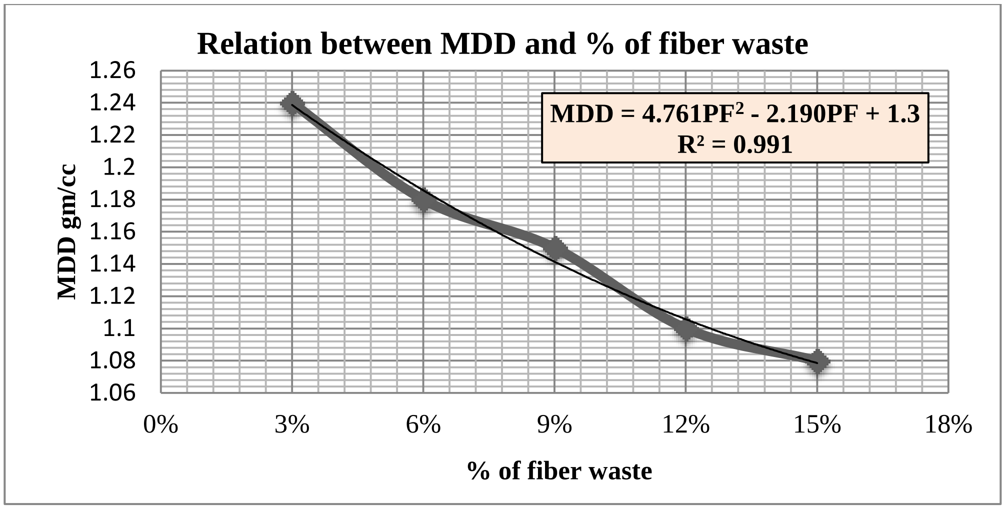


Fig 4.24 Relation between MDD and %added of fiber waste

4.5.4 Clay soil Reinforced by PET Waste:

Similar compaction curves plotted for soil reinforced by 3, 6, 9, 12 and 15% of PET bottle waste are presented in Fig (4.25) to Fig (4.29) respectively.

The OMC and MDD results are reported in Table (4.6) and the relation between the OMC and the MDD and the added percentages of PET waste is presented in Fig (4.30). The relation between the OMC and added percentages of PET waste is plotted in Fig (4.31) and the relation between the MDD and added percentages of PET waste in Fig (4.32). The results indicate that the OMC increased from 27 to 35 % with the increasing of the plastic PET bottle content and MDD decreased from 1.50 to 1.28 *g/cm*^{3} with the increasing of plastic PET bottle contents in mixed soil.
New formulae are obtained by excel sheet to determine the OMC and MDD based on the added percentages of PET waste (Fig (4.31) and Fig (4.32)) as followS:

$OMC = 60PP + 5.26$ (R^2=952)……….……..……………………….… (4.5)

$MDD = -308.6PP^3 + 81.74PP^2 - 7.936PP + 1.672$ (R^2=0.998)…… (4.6)

Where PP: percentage of plastic PET bottle waste

Table 4.6: Results of compaction test for Different % s added of PET Waste

Percentage	OMC	MDD
3%	27	1.50
6%	31	1.42
9%	30	1.40
12%	32	1.36
15%	35	1.28

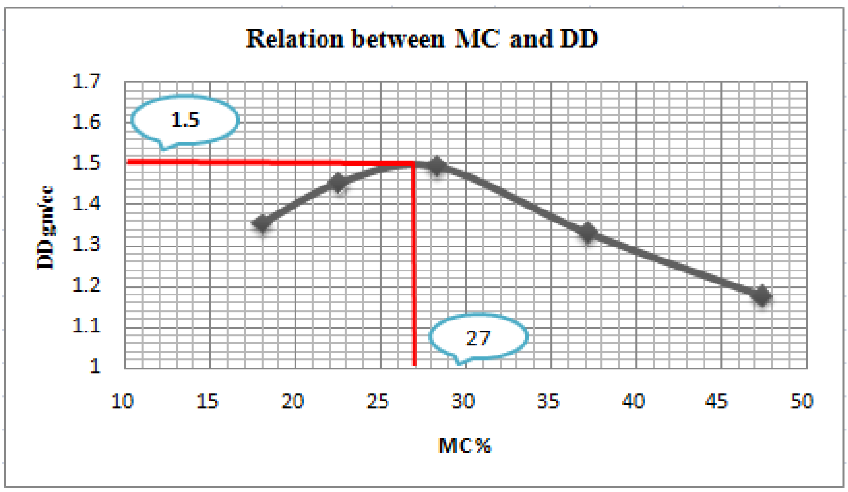


Fig 4.25 Relation between MC and DD (soil +3% PET waste)

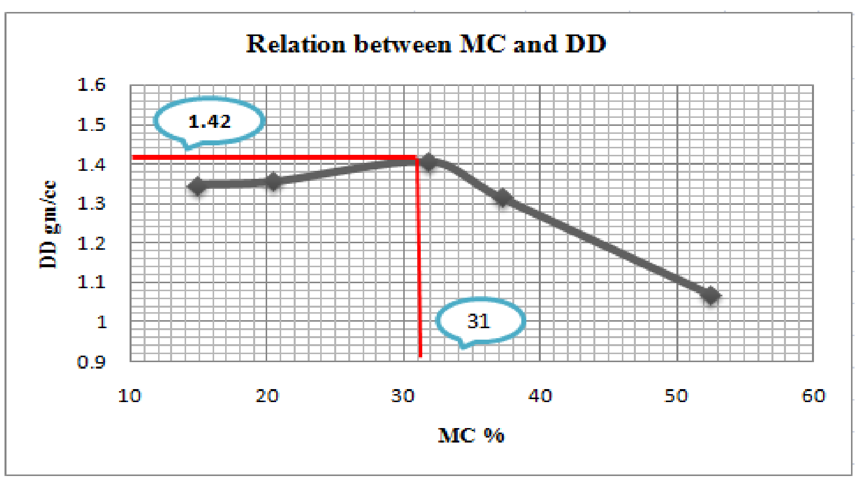


Fig 4.26 Relation between MC and DD (soil +6% PET waste)

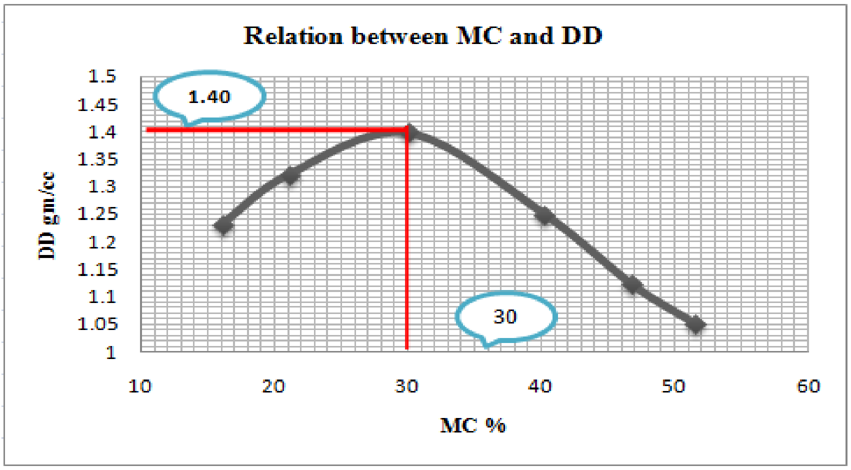


Fig 4.27 Relation between MC and DD (soil +9% PET waste)

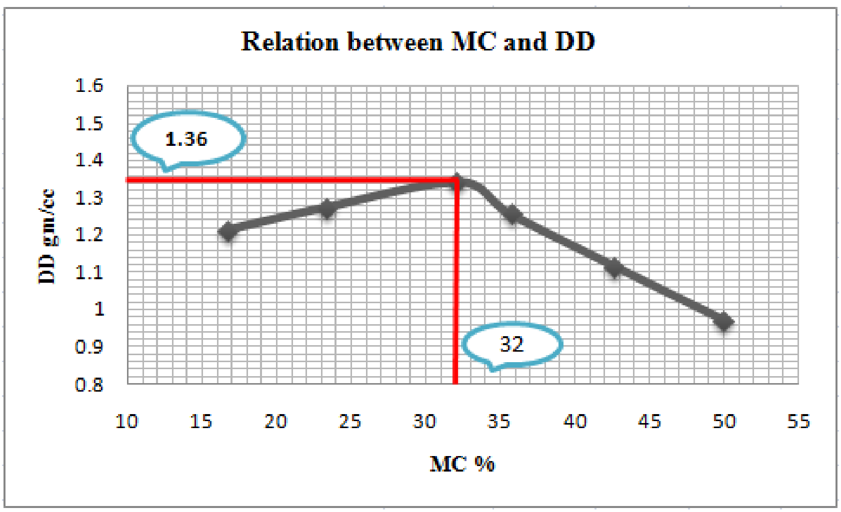


Fig 4.28 Relation between MC and DD (soil +12% PET wastes)

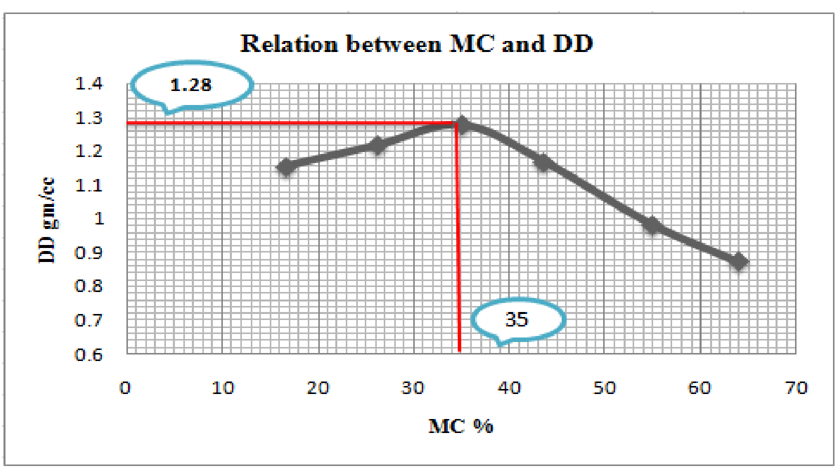


Fig 4.29 Relation between MC and DD (soil +15% PET wastes)

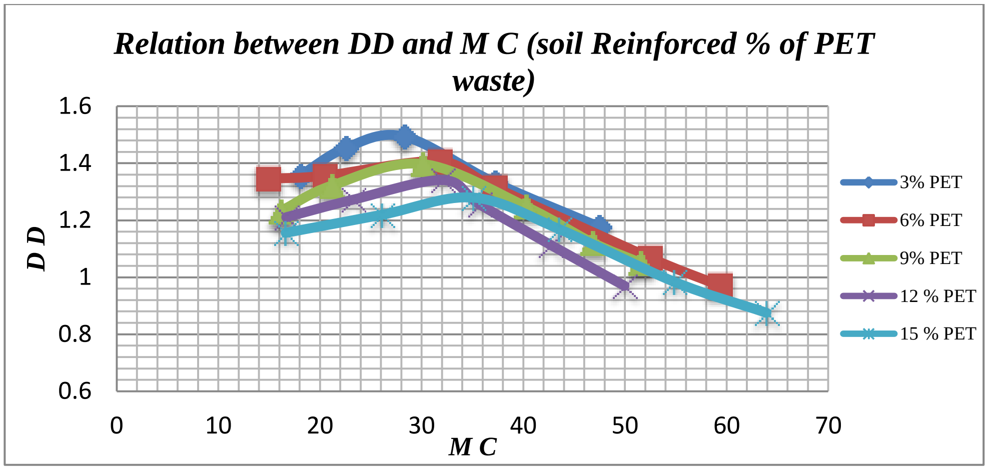


Fig 4.30 Relation between DD and M C (soil + % of PET waste)

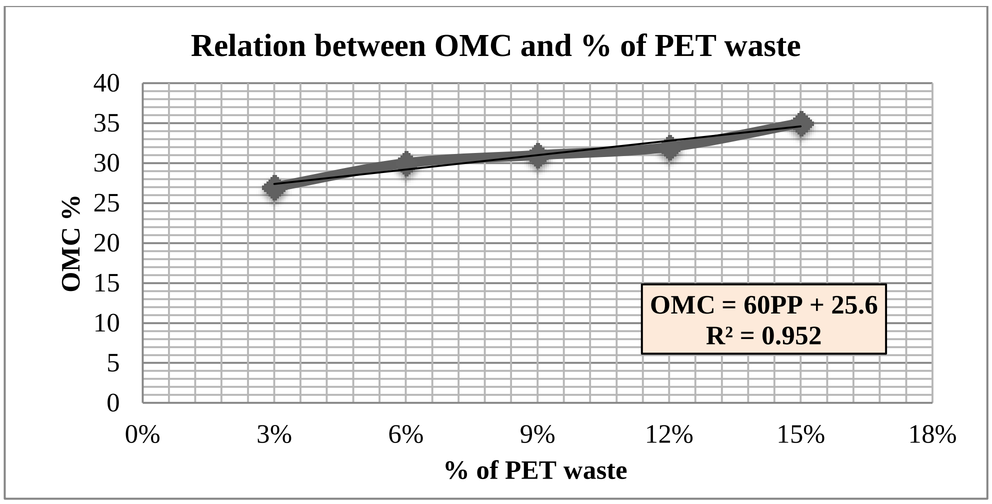


Fig 4.31 Relation between OMC and % of PET waste

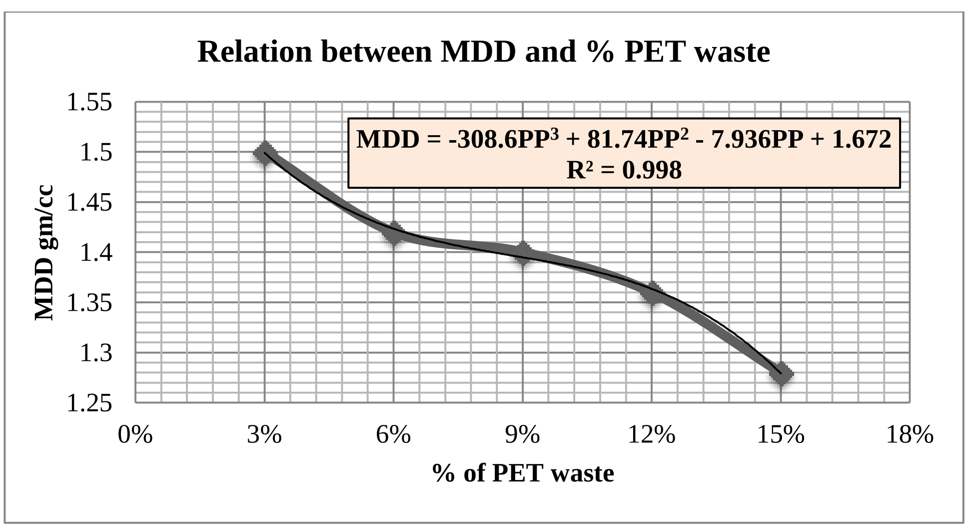


Fig 4.32 Relation between MDD and % of PET waste

The OMC and MDD for natural soil and soil stabilized by cement waste, fiber waste and plastic PET bottle waste are summarized in Table (4.7) and presented in Fig (4.33) and Fig (4.34). The results indicate that an increasing of content of waste materials used as chemical stabilizer the OMC results in a constant value up to 12% addition then decreases at 15% addition and decreases the MDD while with an increasing of content of waste materials used as soil reinforcement increases the OMC and decreases the MDD.

Table 4.7: Results of compaction test (clay soil, cement waste, fiber waste and PET waste)

Percentage (%)		*0% waste material*	*Cement Waste*	*Fiber waste*	*PET waste*
00	OMC	18			
	MDD	1.67			
3	OMC		30	34	28
	MDD		1.56	1.24	1.5
6	OMC		31	39	29
	MDD		1.52	1.18	1.48
9	OMC		30	41	30
	MDD		1.51	1.15	1.4
12	OMC		30	40	32
	MDD		1.48	1.18	1.36
15	OMC		28	41	35
	MDD		1.52	1.18	1.28

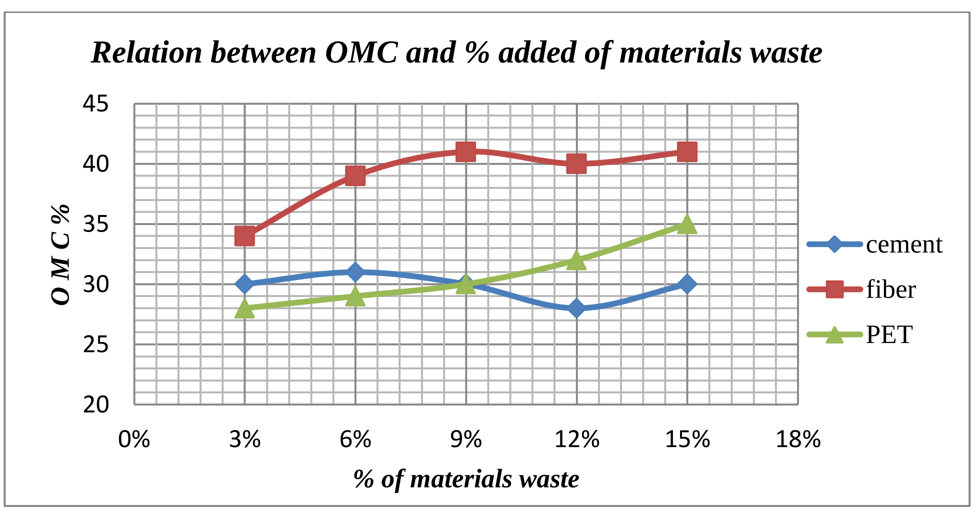


Fig 4.33 Relation between OMC and % of materials waste

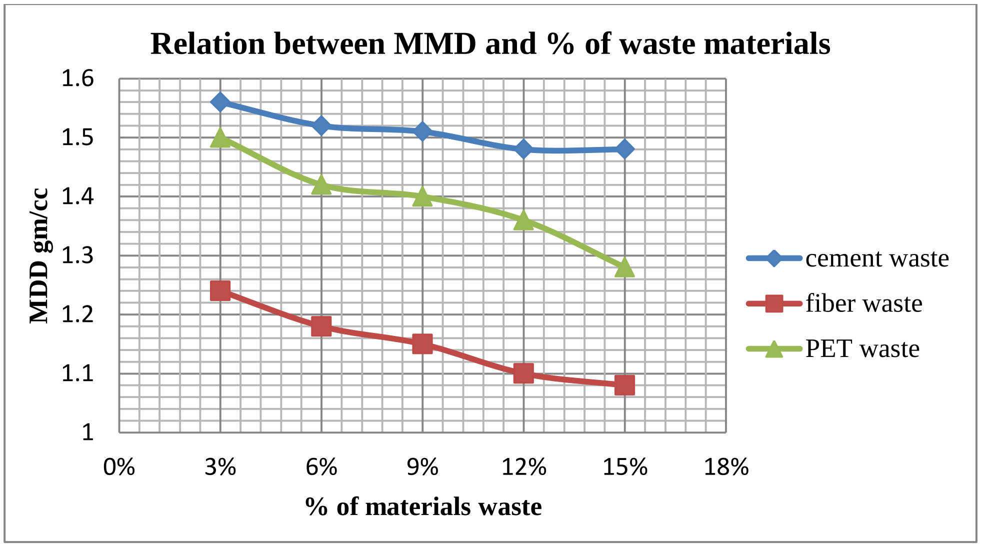


Fig 4.34 Relation between MDD and % materials waste

4.6. Triaxial Test Results:

A series of consolidated triaxial tests had been performed to study the effect of the use of waste materials on the shear parameters (cohesion (c) and angle of friction (Φ)) and the shear strength of clay soil treated by cement waste and reinforced by fiber glass and PET bottle wastes.

4.6.1 Clay Soil:

The stress strain relationship is presented in Fig (4.35) and the maximum stress for the three specimens was found to be equal to 491, 550 and 595 *kPa* respectively. The relation between the shear and total stress presented in Fig (4.36) for clay soil without any addition and the cohesion (c) was found to be equal to 165.4kN/m^2 and the angle of friction equal to18^0

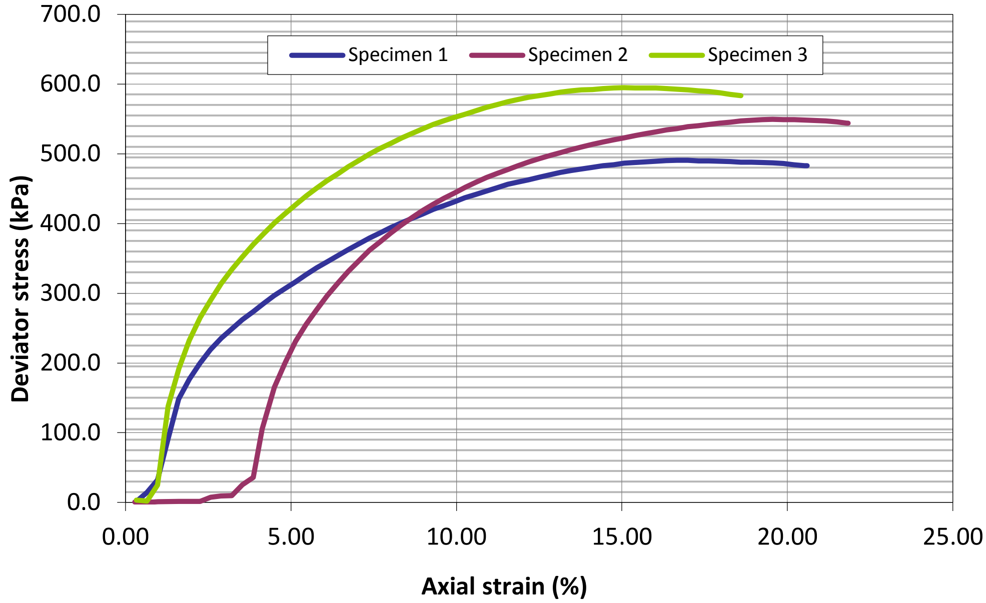


Fig 4.35 Relation between stress and strain (clay soil)

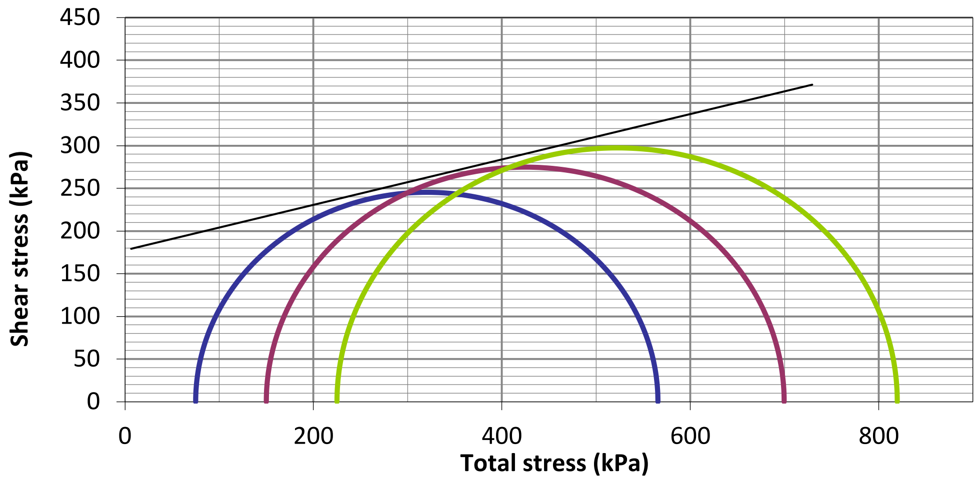


Fig 4.36 Relation between shear and total stress (clay Soil)

4.6.2 Soil treated by cement waste:

A series of triaxial test were done for the clay soil treated by different percentages of cement waste. The results of stress and strain are presented in Fig (4.37) for soil treated by 3% of cement waste and the maximum stress was obtained to be equal to 303, 370 and 381 *kPa* for the specimens 1,2 and 3 respectively. The relation between the shear and total stress is presented in Fig (4.38) and the cohesion was found to be equal to 95 kN/m^2 and angle of friction equal to19^o.

For soil treated by 6% of cement waste the stress and strain relationship is presented in Fig (4.39) and the maximum stress was obtained to be equal to 253, 273 and 366 *kPa* for the specimens 1, 2 and 3 respectively. Also the relation between the shear and total stress is presented in Fig (4.56) and the cohesion was found = 80 kN/m^2 and angle of friction = 17^o

Similarly for soil treated by 9% of cement waste the stress and strain relationship is presented in Fig (4.40) and the maximum stress was obtained to be equal to 371, 484 and 618 *kPa* for the specimens 1, 2 and 3 respectively. Also the relation between the shear and total stress presented in Fig (4.41) and the cohesion was found = 80 kN/m^2 and angle of friction angle = 30^o

Similar relationship between stress and strain presented in Fig (4.42) for soil treated by 12% of cement waste, and the maximum stress was obtained equal to 211, 258 and 257 *kPa* for the specimens 1, 2 and 3 respectively. The relation between the shear and total stress presented in Fig (4.43) and the cohesion was found = 70 kN/m^2 and angle of friction = 15^o

The stress and strain presented in Fig (4.44) for soil treated by 15% of cement waste and the maximum stress was obtained equal to 167, 200 and 228 *kPa* for the specimens 1, 2 and 3 respectively. The relation between the shear and total stress is presented in Fig (4.45) and the cohesion was found = 60 kN/m^2 and angle of fricition = 12^o

The shear parameters for the soil treated by different added percentages of the cement waste are reported in Table (4.9) and the relation between cohesion and added percentages of cement waste is presented in Fig (4.46). These indicate that an increasing of cement waste decreases the cohesion from 165.4 *kPa* to 60*kPa*. Also the relation between the angle of friction and added percentages of cement waste is presented in Fig (4.47) and it indicated that an increasing of cement waste increased the angle of friction to 30^o for up to 9% addition of cement waste.

New formulae obtained by excel sheet to determine the cohesion and angle of friction based on the percentages of cement waste as follows:

$$c = -3.259PC^3 + 39.97PC^2 - 160.7PC + 287.7 \quad (R^2 = 0.987) \ldots\ldots\ldots\ldots (4.7)$$

$$\phi = 5E{+}07PC^5 - 2E{+}07PC^4 + 2E{+}06PC^3 - 10939PC^2 + 1751.PC + 18 \ (R^2 = 1) \ldots (4.8)$$

Table 4.8: Results of cohesion and Angle of friction (cement waste)

% of cement waste	Cohesion *kPa*	Friction Angle
00	165.4	18
3	95	19
6	80	17
9	80	30
12	70	15
15	60	12

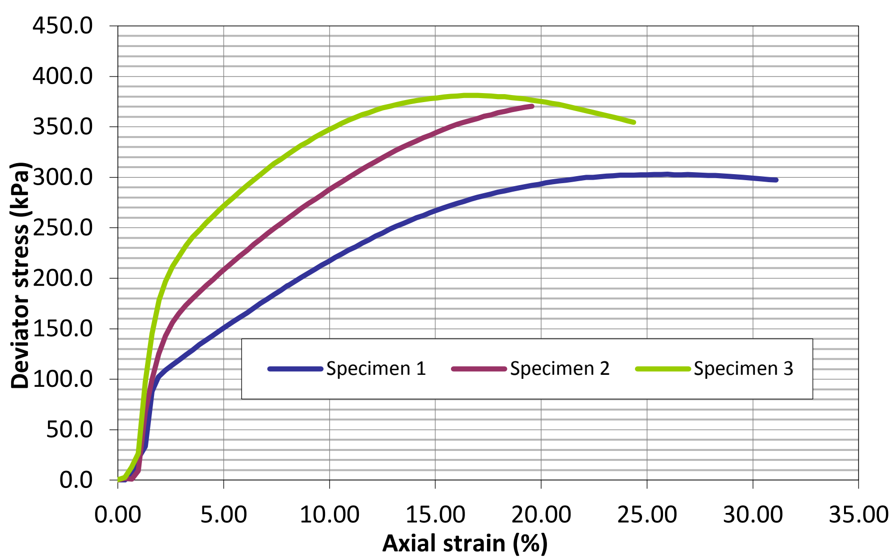


Fig 4.37Relation between stress and strain (clay soil + 3% cement waste)

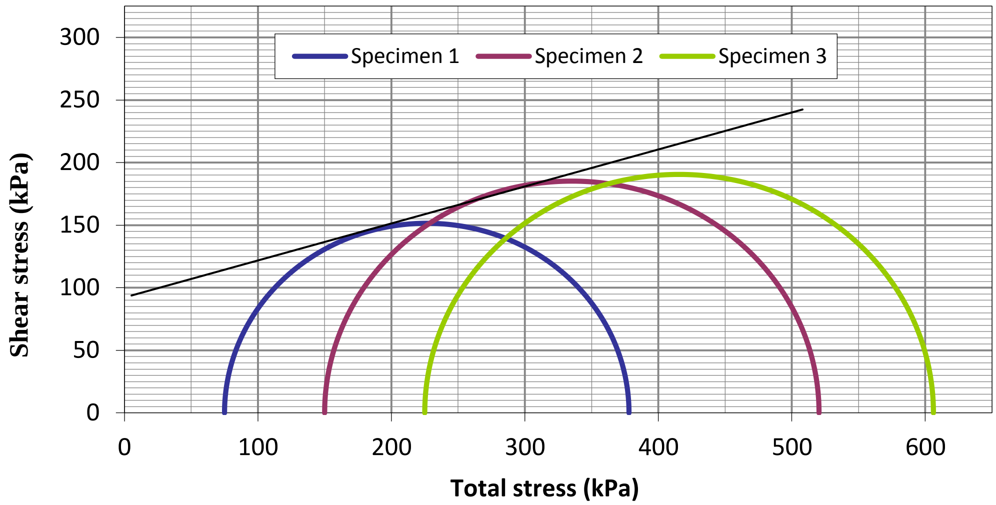


Fig 4.38 Relation between shear and total stress (clay Soil 3% cement waste)

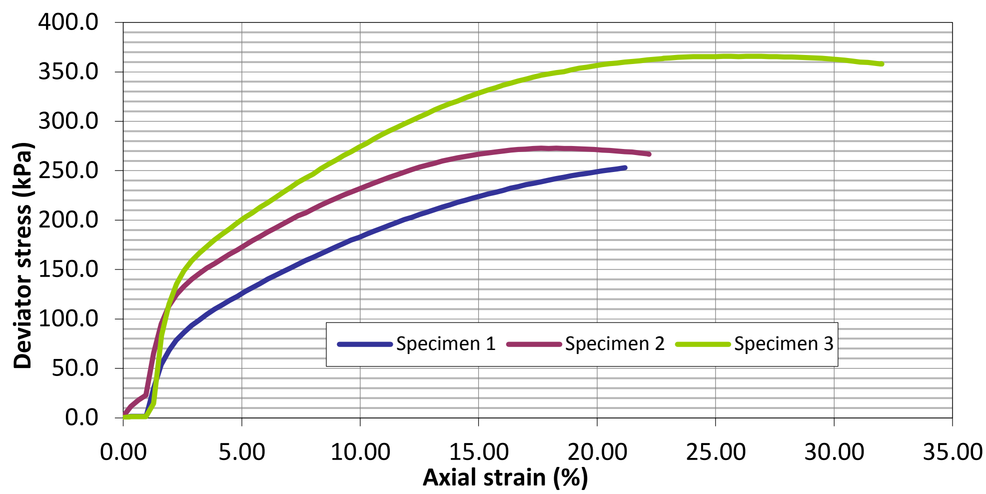


Fig 4.39 Relation between stress and strain (clay soil +6% cement waste)

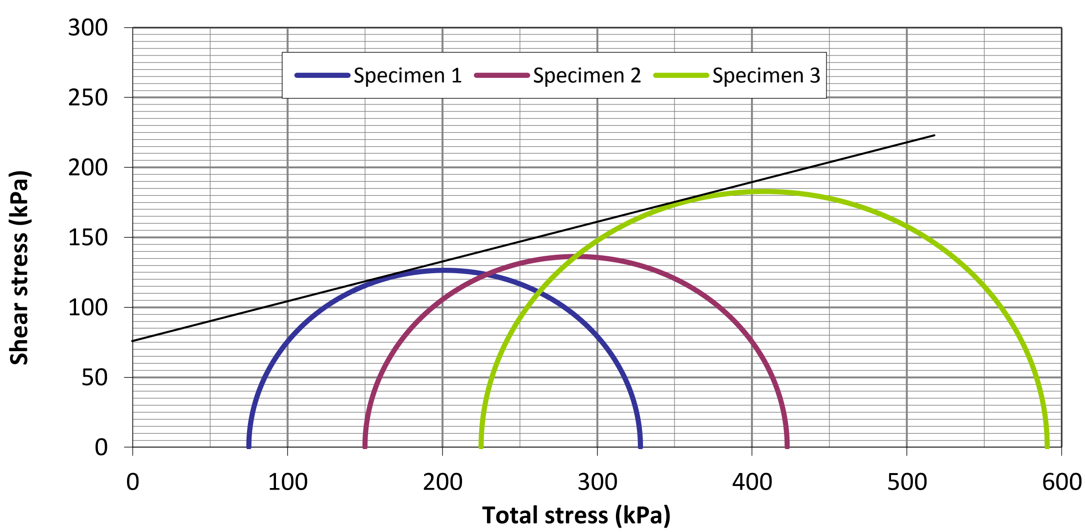


Fig 4.40 Relation between shear and total stress (clay Soil 6% cement waste)

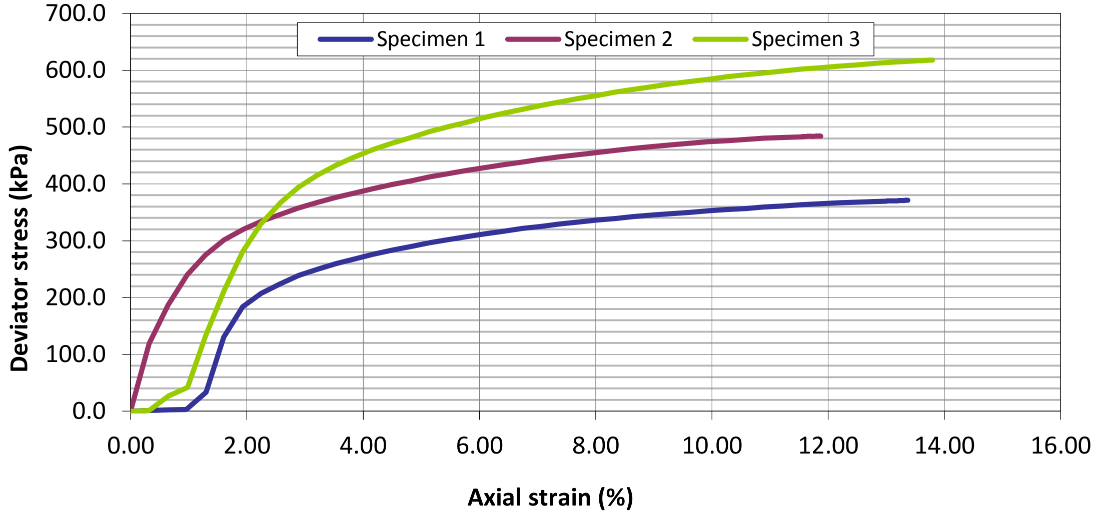


Fig 4.41 Relation between stress and strain (clay soil +9% cement waste)

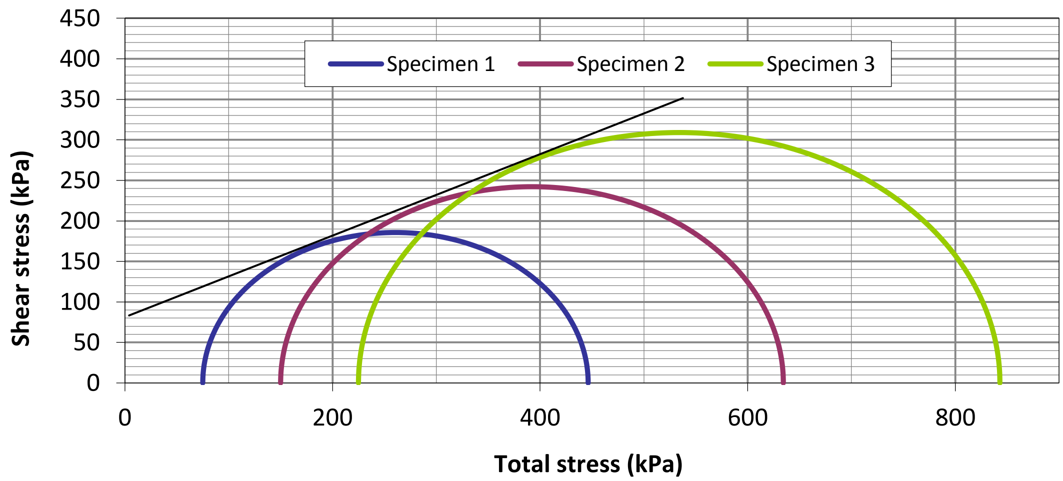


Fig 4.42 Relation between shear and total stress (clay Soil +9% cement waste)

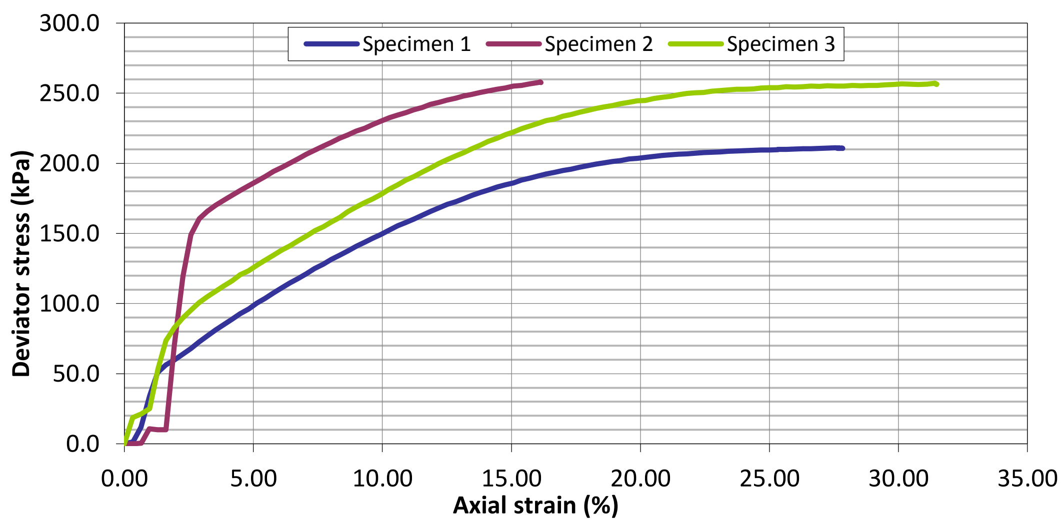


Fig 4.43 Relation between stress and strain (clay soil +12% cement waste)

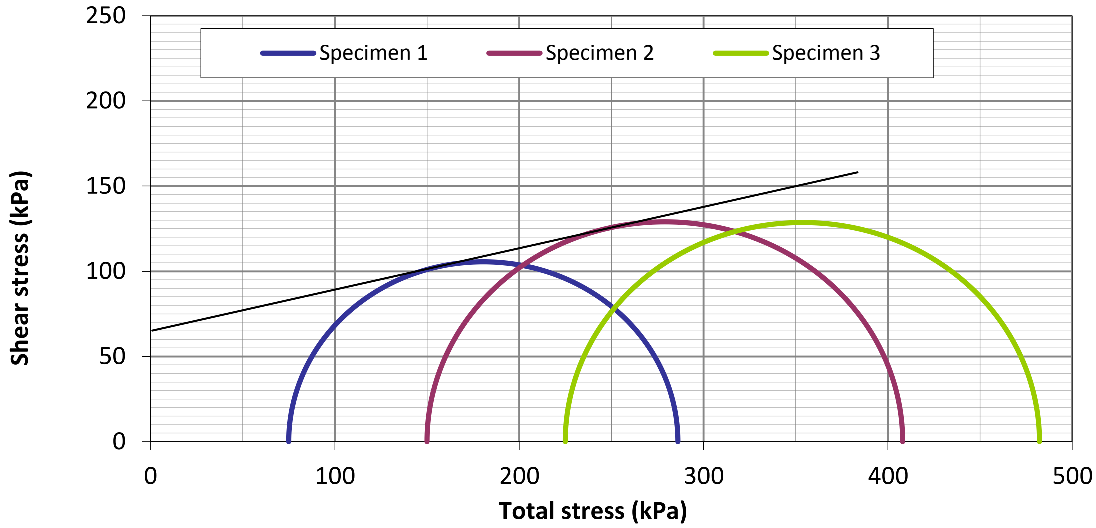


Fig 4.44 Relation between shear and total stress (clay Soil+12% cement waste)

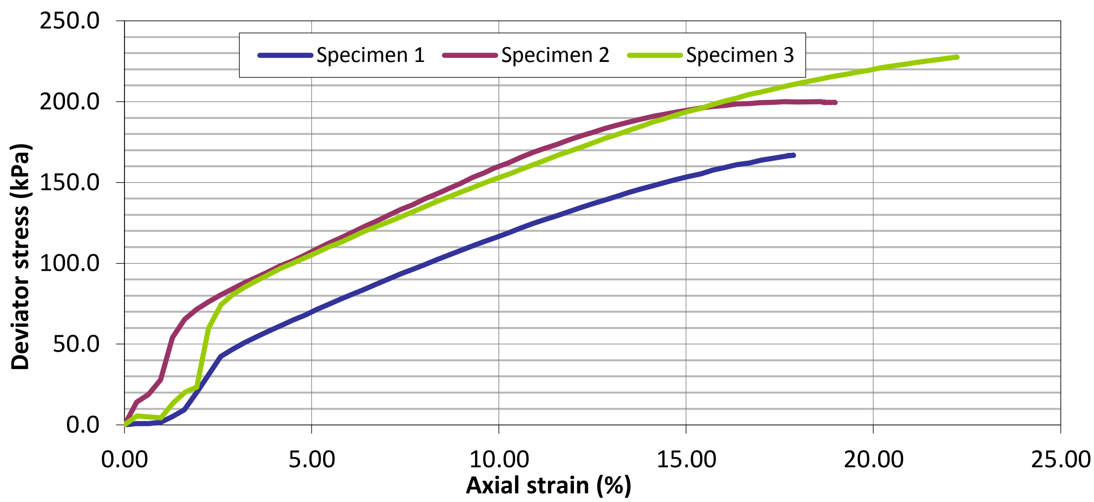


Fig 4.45 Relation between stress and strain (clay soil+15% cement waste)

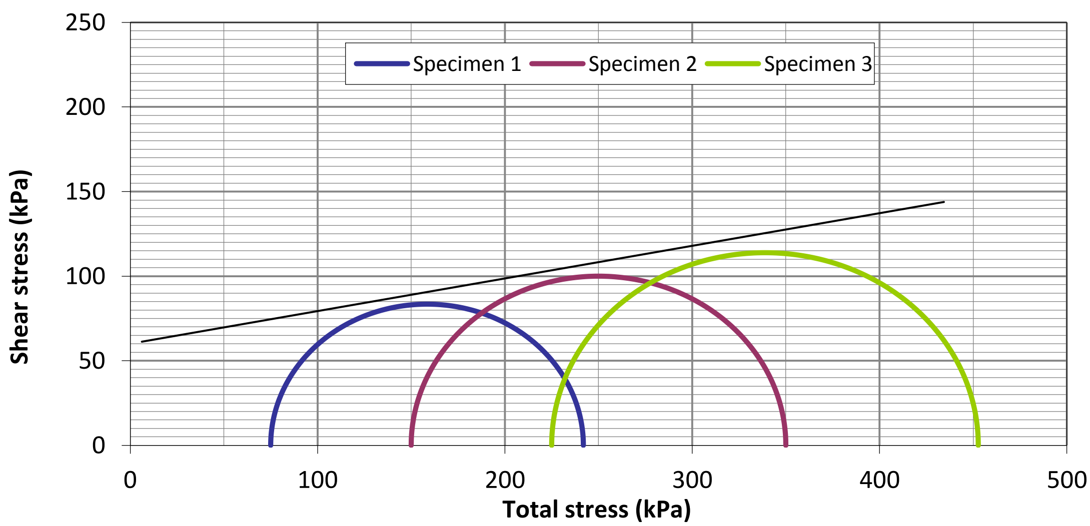


Fig 4.46 Relation between shear and total stress (clay Soil +15% cement waste)

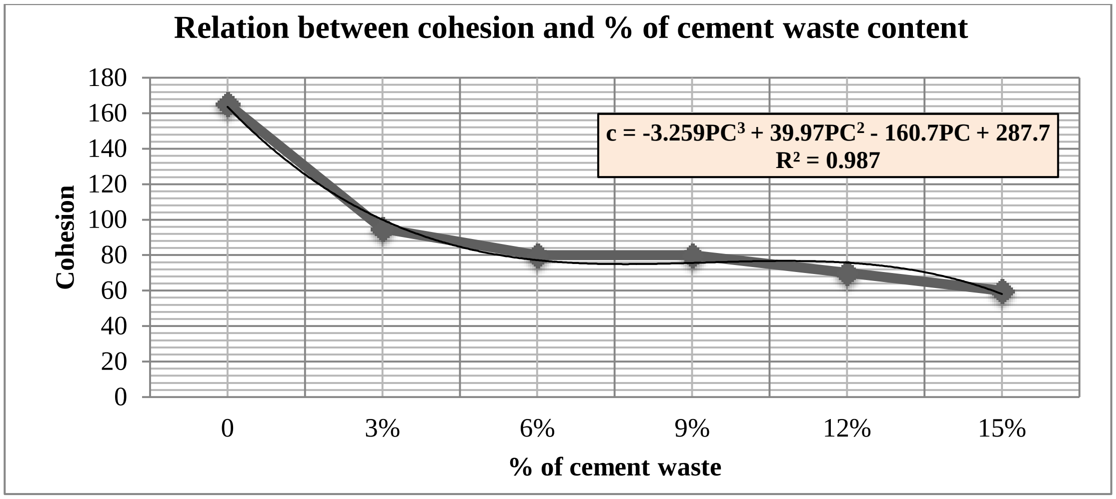


Fig 4.47 Relation between cohesion and % of cement waste

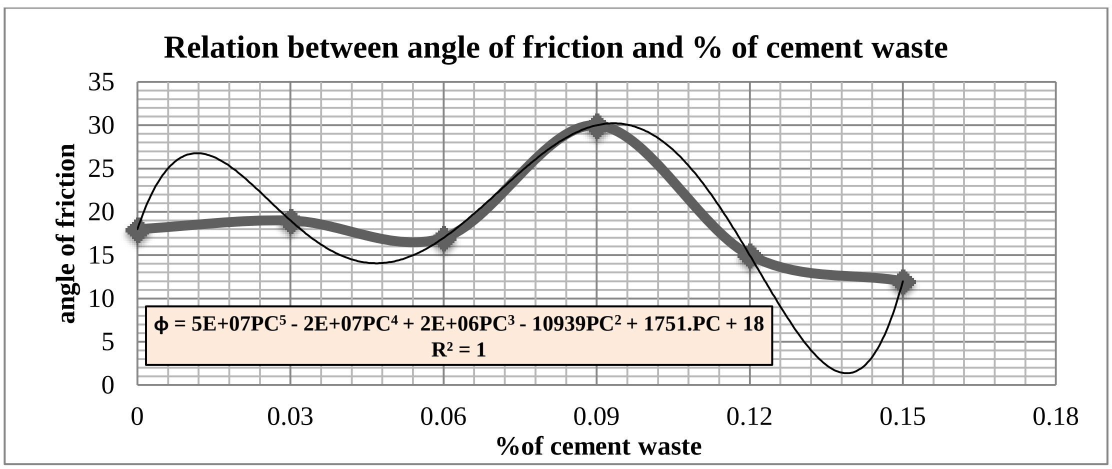


Fig 4.48 Relation between angle of friction and % of cement waste

The results of shear stress of three specimens and the shear strength for various added percentages of cement waste are tabulated in Table (4.8) and plotted in Fig (4.49) and Fig (4.50). These indicate that the highest value of shear strength is achieved at the addition of cement waste equal to 9 % of dry weight of clay soil and Fig (4.51) showed the buckling and cracks failure on stabilized soil samples.

The new formula was obtained by excel sheet to determine the shear strength (SS_C) based on the added percentages of cement waste as follow:

$SS_C = 4E + 08PC^5 - 1E + 0.08PC^4 + 1E + 07PC^3 - 34053PC^2 - 1968PC + 219.6$ ($R^2 = 1$)………………………………………………………… (4.9)

Table 4.9: Results of shear stress % of cement waste after 2 hours

% of cement waste	Specimen 1	Specimen 2	Specimen 3
0 %	245	275	297
3 %	152	185	191
6 %	126	136	183
9 %	186	242	309
12 %	106	129	129
15 %	83	100	114

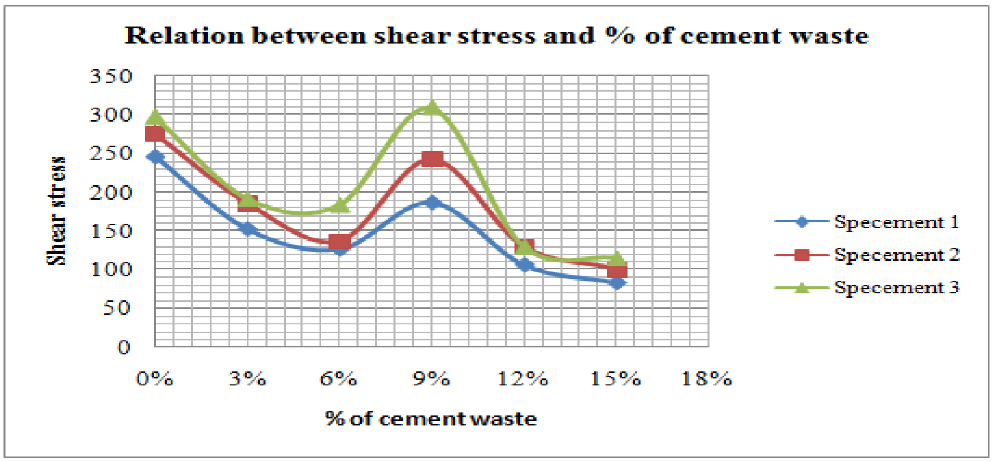
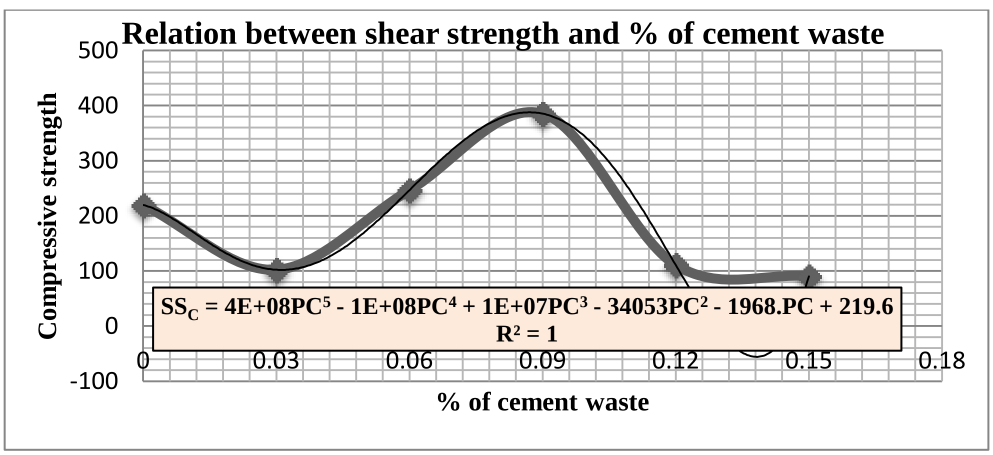


Fig 4.49 Relation between shear stress and % of cement waste after 2 hours



Fia 4.50 Relation between shear strenath and % of cement waste

Fig 4.51 Shape of failure for soil treated by cement waste (buckling and cracks)

4.6.3 Clay Soil Reinforced by Fiber Glass Waste:

Similarly results from series of triaxial test were obtained for the clay soil reinforced by 0.5, 1.5, 3, 6 and 9% of fiber glass waste. The results of stress and strain are presented in Fig (4.52) for soil reinforced by 0.5% of fiber glass waste and the maximum stress was obtained to be equal to 443, 507 and 472 *kPa* for the specimens1, 2 and 3 respectively. The relation between the shear and total stress is presented in Fig (4.53) and the cohesion was found = 140 kN/m^2 and angle of friction = 20^o

The stress and strain relationship is presented in Fig (4.54) for soil reinforced by 1.5% of fiber glass waste; the maximum stress was obtained to be equal to 526, 525 and 520 *kPa* for the specimens 1, 2 and 3 respectively. The relation between the shear and total stress is presented in Fig (4.55) and the cohesion was found = 260 kN/m^2 and angle of friction = 2.93^o

For soil reinforced by 3% of fiber glass waste the stress and strain relationship is presented in Fig (4.56) and the maximum stress was obtained to be equal to 371, 484 and 618 *kPa* for the specimens 1, 2 and 3 respectively. The relation between the shear and total stress is presented in Fig (4.57) and the cohesion was found = 155 kN/m^2 and angle of friction angle = 29^o

Also, for soil reinforced by 6% of fiber glass waste the stress and strain relationship is presented in Fig (4.58) and the maximum stress was obtained to be equal to 37, 49 and 57 *kPa* for the specimens1, 2 and 3 respectively. The relation between the shear and total stress is presented in Fig (4.59) and the cohesion was found = 100 kN/m^2 and angle of fricition = 10^o

Similarly, relation between the stress and strain is presented in Fig (4.60) for soil reinforced by 9% of fiber glass waste, and the maximum stress was obtained to be equal to 42, 40 and 52 *kPa* for the specimens 1, 2 and 3 respectively. The relation between the shear and total stress is presented in Fig (4.61) and the cohesion was found = 25 kN/m^2 and angle of friction = 8^o

Also for soil reinforced by 12% of fiber glass waste the stress and strain relationship is presented in Fig (4.62) and the maximum stress was obtained to be equal to 32, 42 and 47 *kPa* for the specimens 1, 2 and 3 respectively. The relation between the shear and total stress is presented in Fig (4.63) and the cohesion was found = 22 kN/m^2 and angle of friction = 7^o

Also for soil reinforced by 15% of fiber glass waste, the stress and strain relationship is presented in Fig (4.64) and the maximum stress was obtained to be equal to 32, 42 and 47 *kPa* for the specimens 1, 2 and 3respectively. The relation between the shear and total stress is presented in Fig (4.65) and the cohesion was found = 20 kN/m^2 and angle of friction = 5^o

The shear parameters for the soil reinforced by different percentages of the fiber glass waste are tabulated in Table (4.9) and the relation between cohesion and percentages of fiber glass waste is presented in Fig (4.66). These indicate that an increasing of fiber glass waste decreases the cohesion on addition of 3% or more of fiber glass waste from 155 *kPa* to 20*kPa*. Also the relation between the angle of friction and percentages of fiber glass waste is presented in Fig (4.67) and it indicates that an increasing of fiber glass waste decreased the angle of friction on addition of 6% or more of fiber glass waste.

New formulae were obtained by excel sheet to determine the cohesion and angle of friction based on the percentages of fiber glass waste as follows:

$c=-12017PF^{3}+49978PF^{2}-6952.PF+343.3 (R^2 = 0.977)$……………………..….…(4.10)

$\phi=0.703PF^{-1.02}$ $(R^2 = 0.952)$....…………………………………...……… (4.11)

Table 4.10: Results of cohesion and Angle of friction (fiber waste)

% of fiber waste	Cohesion *kPa*	Friction Angle
00	165.4	18
0.5	140	20
1.5	260	2.93
3	155	29
6	100	10
9	25	8
12	22	7
15	20	5

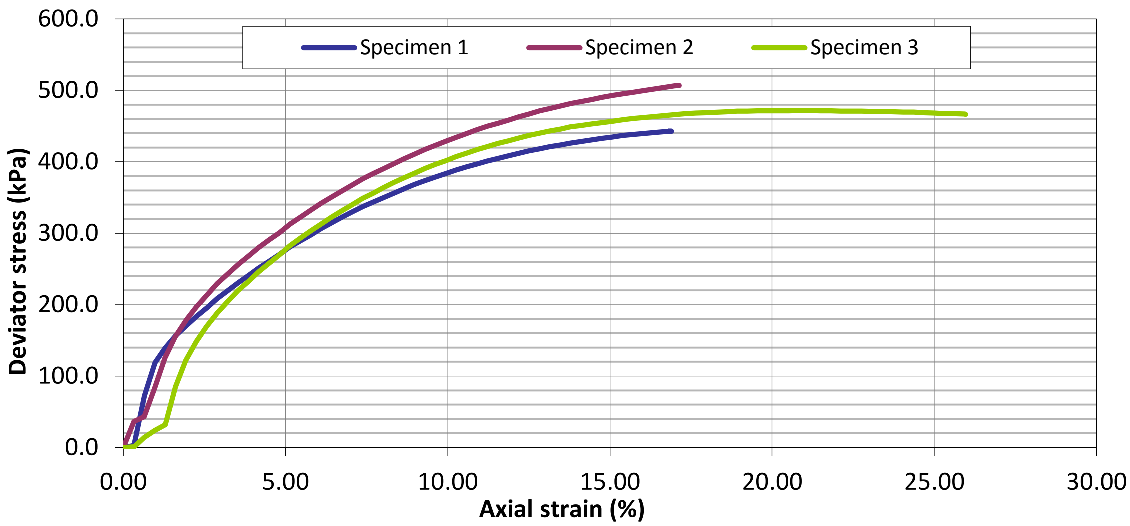


Fig 4.52 Relation between stress and strain (clay soil+ 0.5 fiber waste)

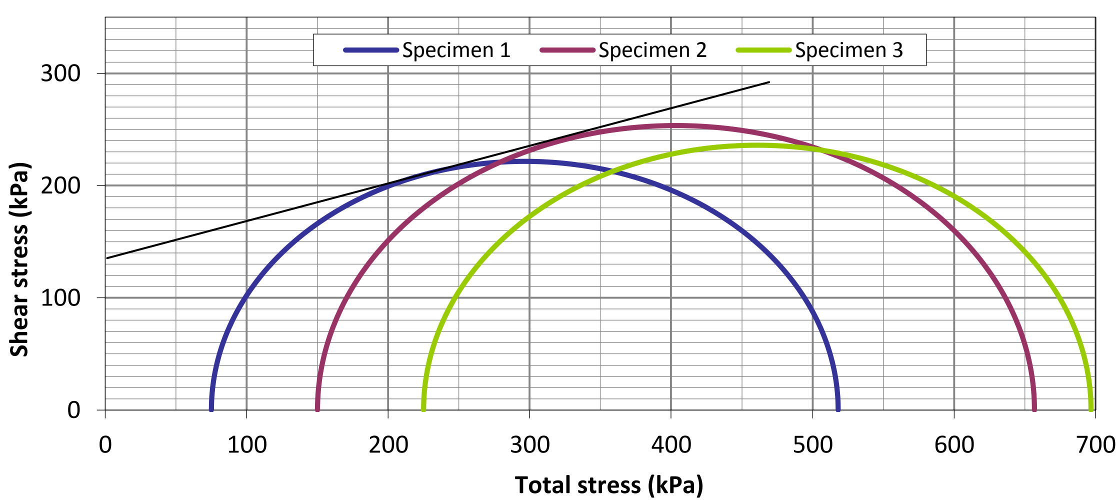


Fig 4.53 Relation between stress and strain (clay soil+ 1.5 fiber waste)

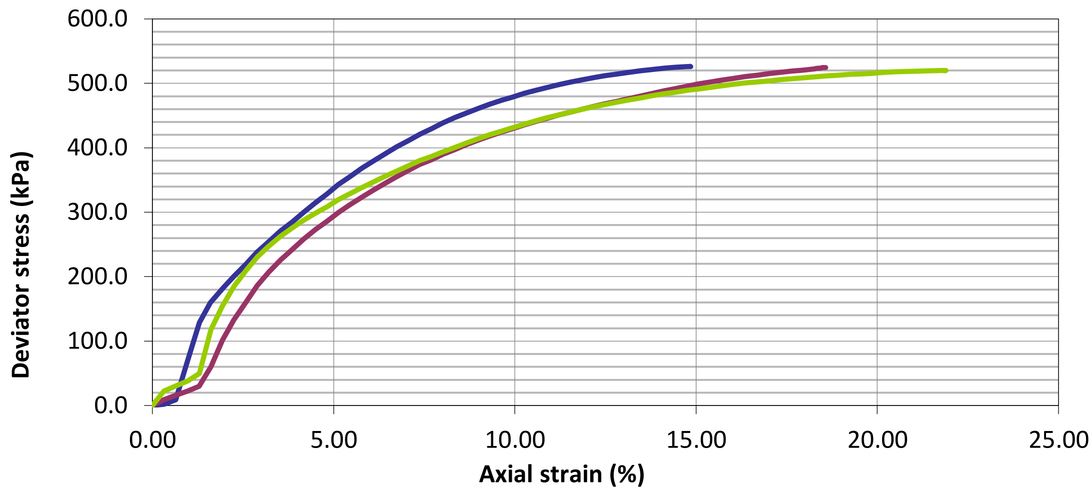


Fig 4.54 Relation between shear and total stress (clay Soil +0.5% fiber waste)

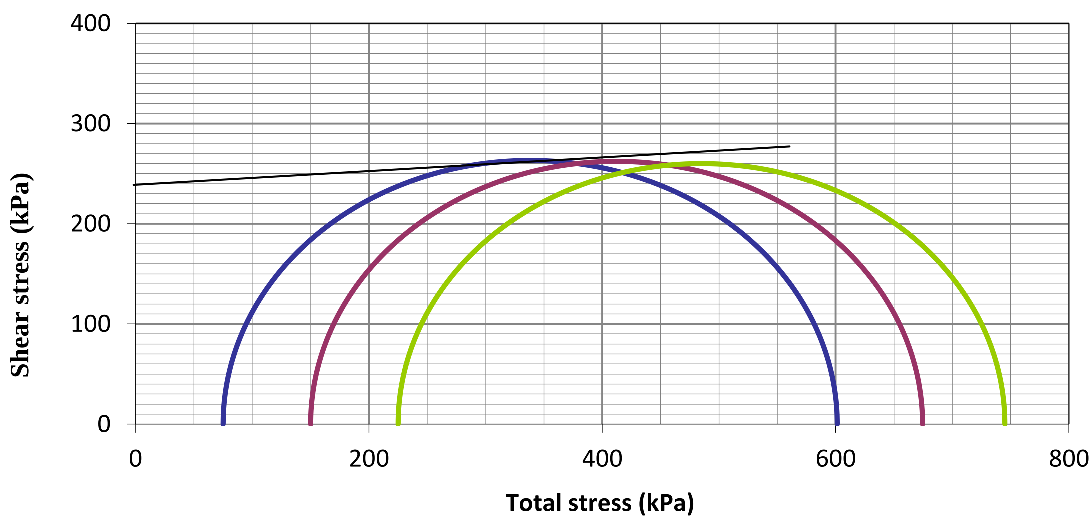


Fig 4.55 Relation between shear and total stress (clay Soil +1.5% fiber waste)

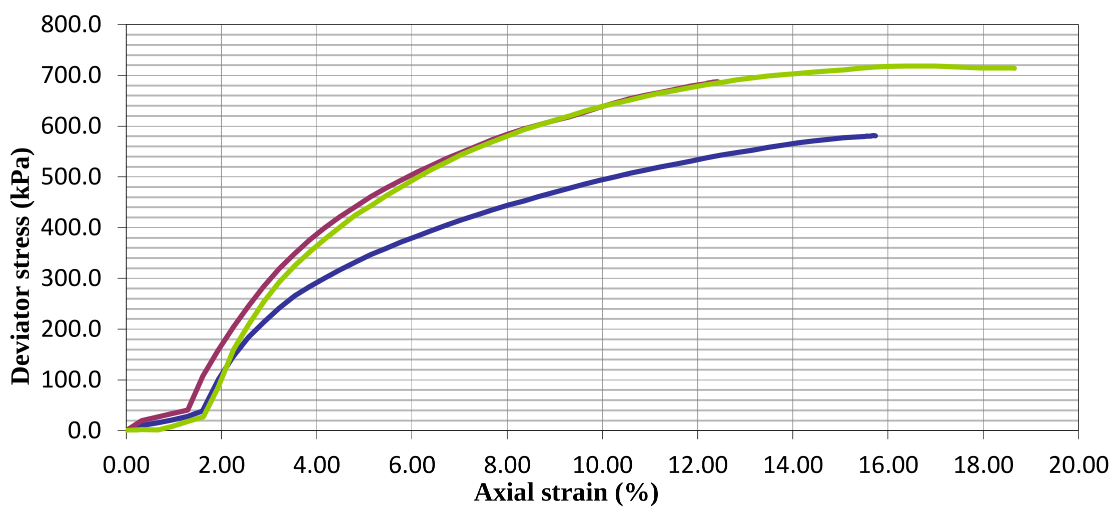


Fig 4.56 Relation between stress and strain (clay soil+ 3 %fiber waste)

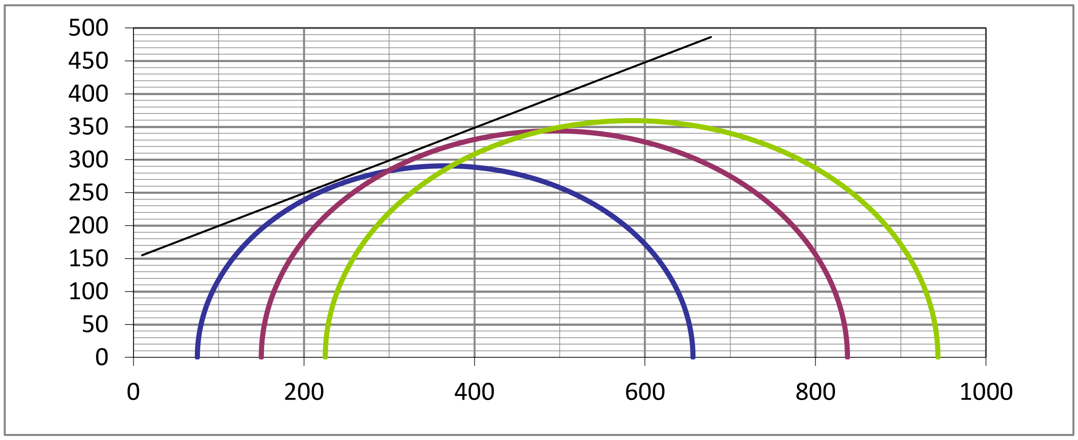


Fig 4.57 Relation between shear and total stress (clay Soil +3% fiber waste)

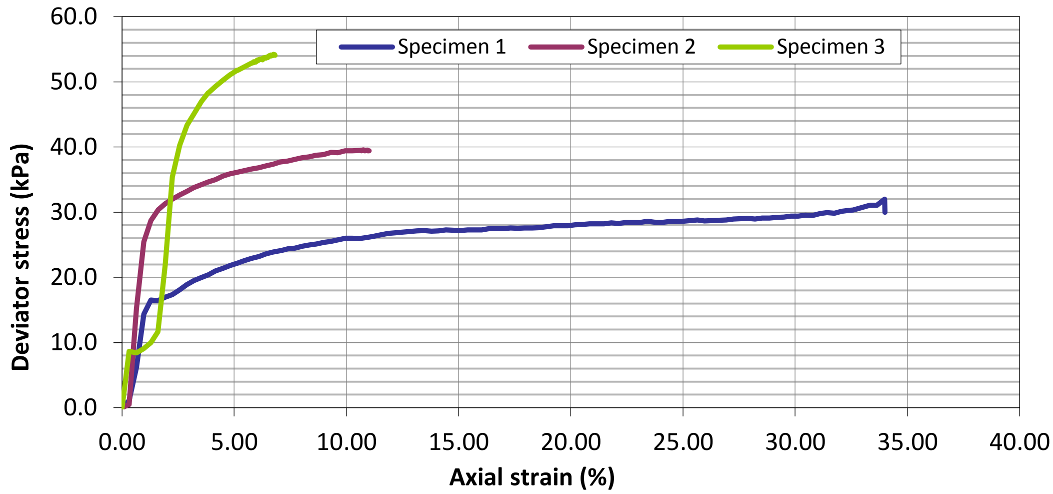


Fig 4.58 Relation between stress and strain (clay soil+ 6% fiber waste)

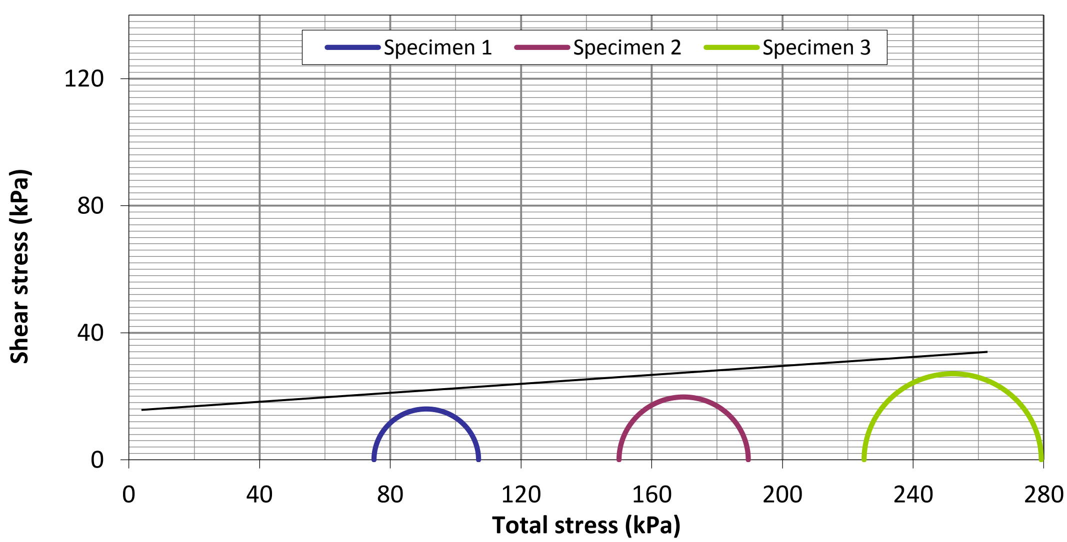


Fig 4.59 Relation between shear and total stress (clay Soil +6% fiber waste)

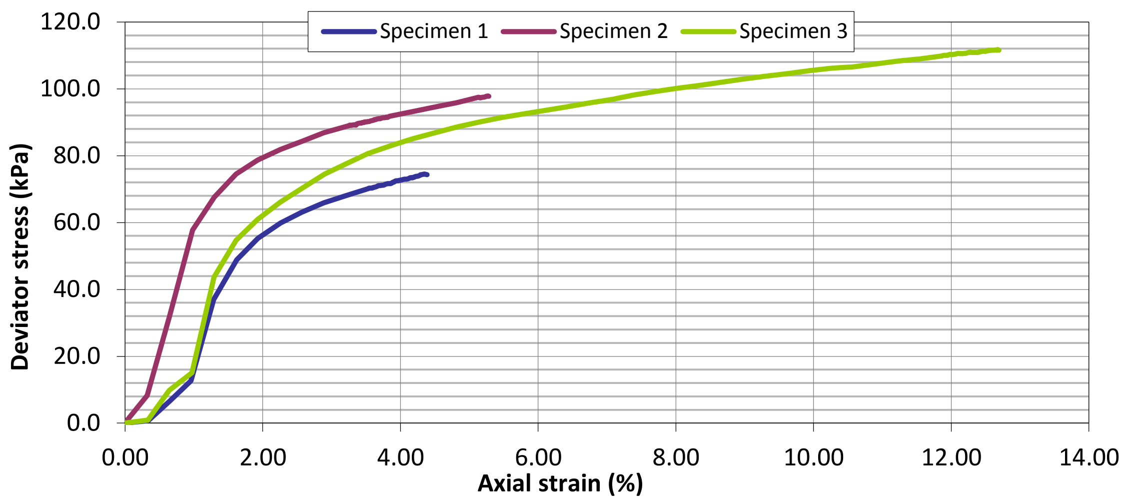


Fig 4.60 Relation between stress and strain (clay soil+ 9%fiber waste)

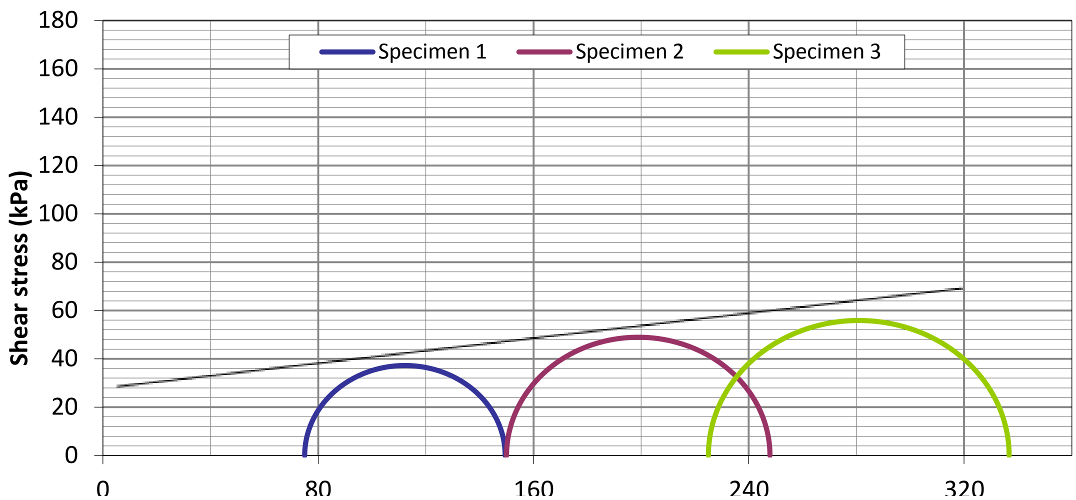


Fig 4.61 Relation between shear and total stress (clay Soil +9% fiber waste)

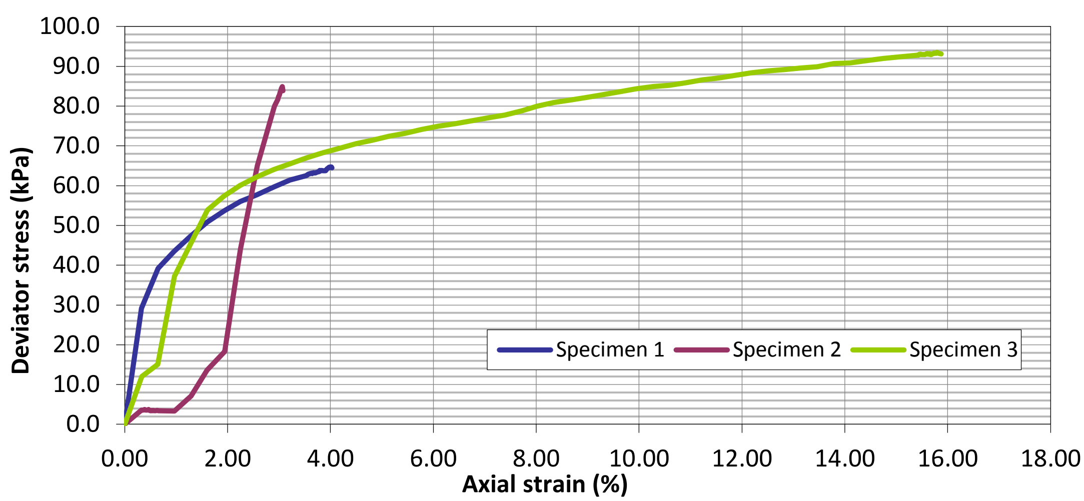


Fig 4.62 Relation between stress and strain (clay soil+ 12% fiber waste)

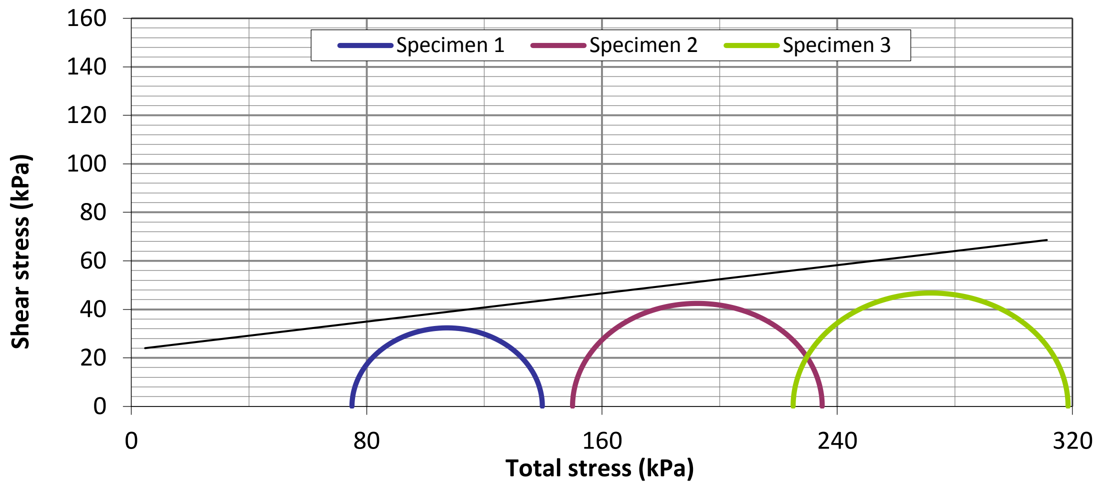


Fig 4.63 Relation between shear and total stress (clay Soil +12% fiber waste)

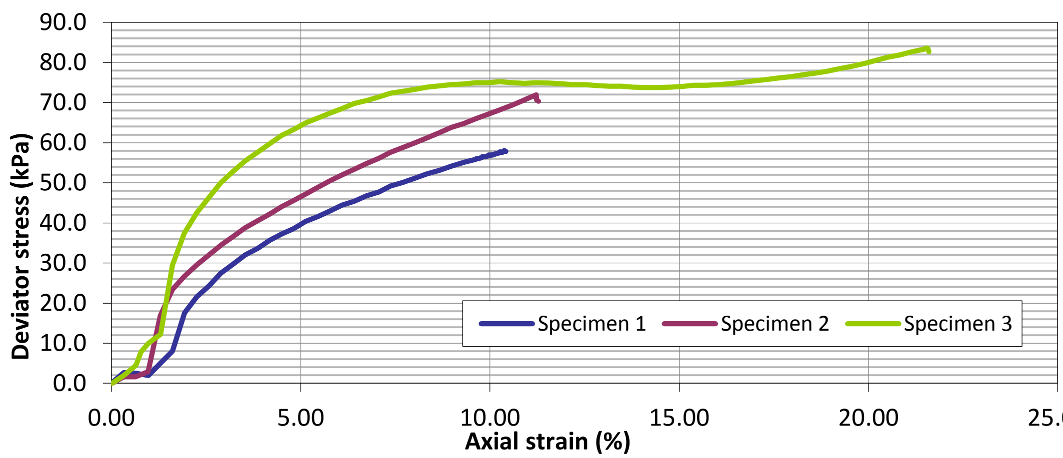


Fig 4.64 Relation between stress and strain (clay soil+ 15% fiber waste)

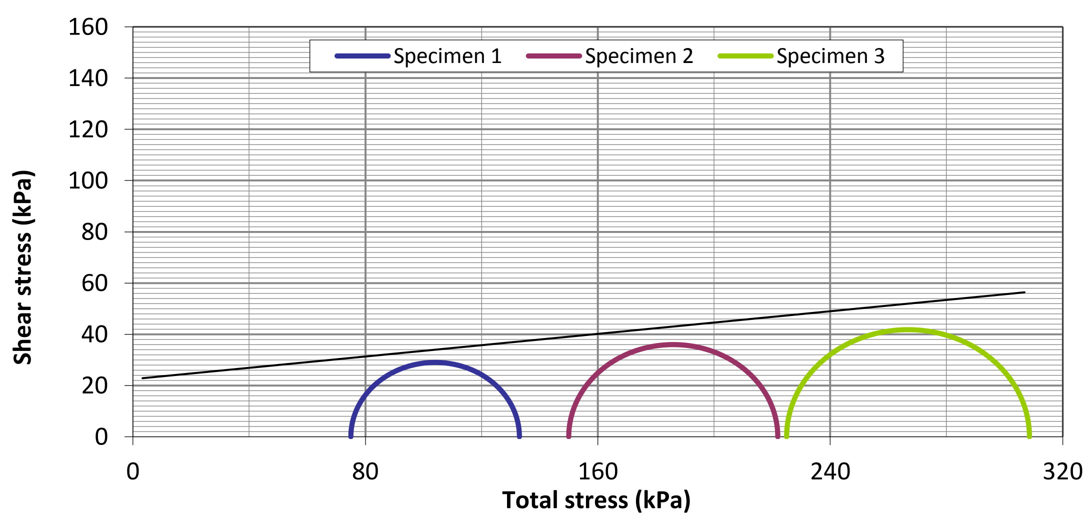


Fig 4.65 Relation between shear and total stress (clay Soil +15% fiber waste)

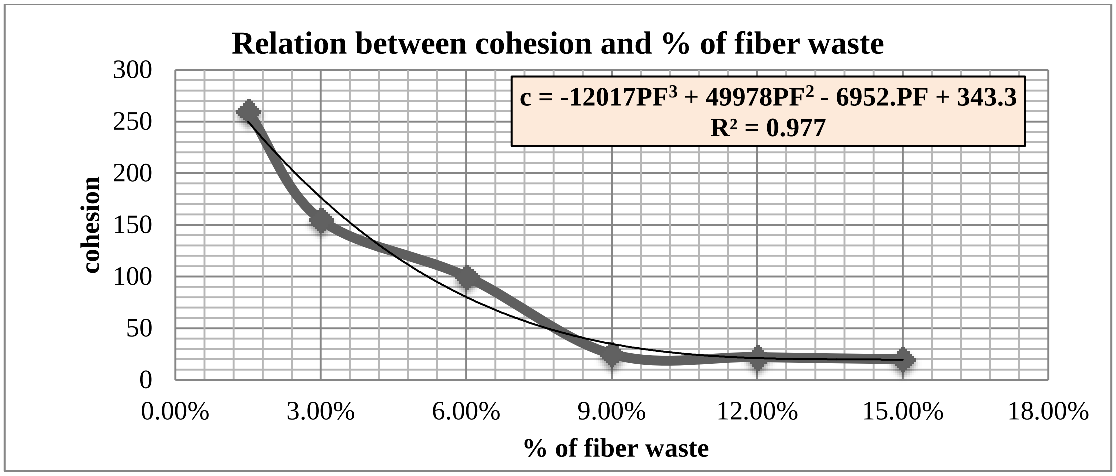


Fig 4.66 Relation between cohesion and % of fiber glass waste

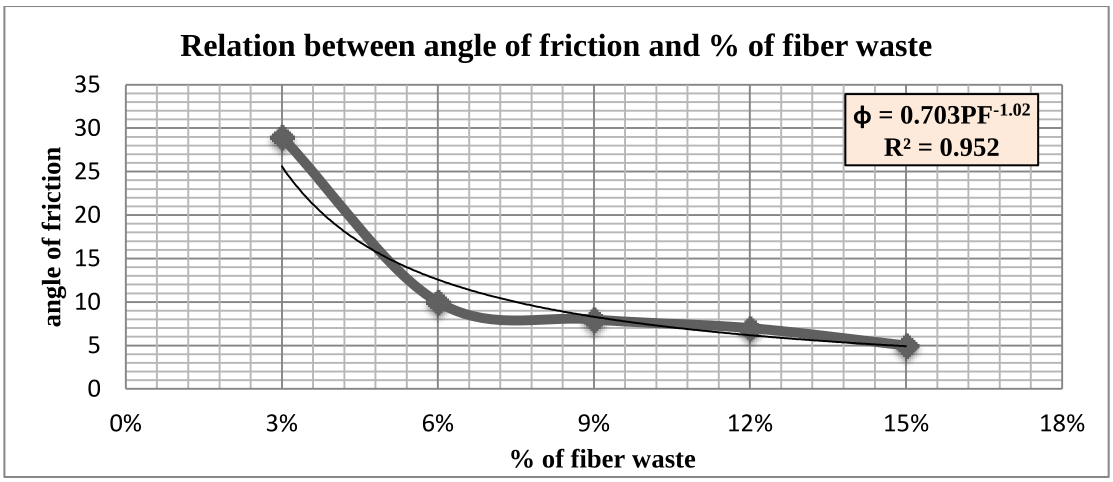


Fig 4.67 Relation between angle of friction and % of fiber glass waste

The results of shear stress of three specimens and the shear strength for various percentages of fiber glass waste are tabulated in Table (4.10) and presented in Fig (4.68) and Fig (4.69). These indicate that the highest value of shear strength achieved at the addition of fiber glass waste equal to 3 % of dry weight of clay soil and Fig (4.70) showed the cracks on reinforced soil samples

Equation (4.12) was obtained by excel sheet to determine the SS_F based on the added percentages of fiber glass waste as follow:

$SS_F = 9E{+}07PF^5 - 4E{+}07PF^4 + 7E{+}06PF^3 - 53513PF^2 + 13587PF + 202.6$ ($R^2 = 0.908$) ………………………………………………………………...…….(4.12)

Table 4.11: Results of shear stress of 3 specimens (fiber waste)

% of fiber waste	Specimen 1	Specimen 2	Specimen 3
0 %	245	275	297
0.5 %	222	255	236
1.5 %	263	262	260
3 %	291	344	359
6 %	37	49	56
9 %	32	42	47
12 %	29	36	42
15 %	16	20	27

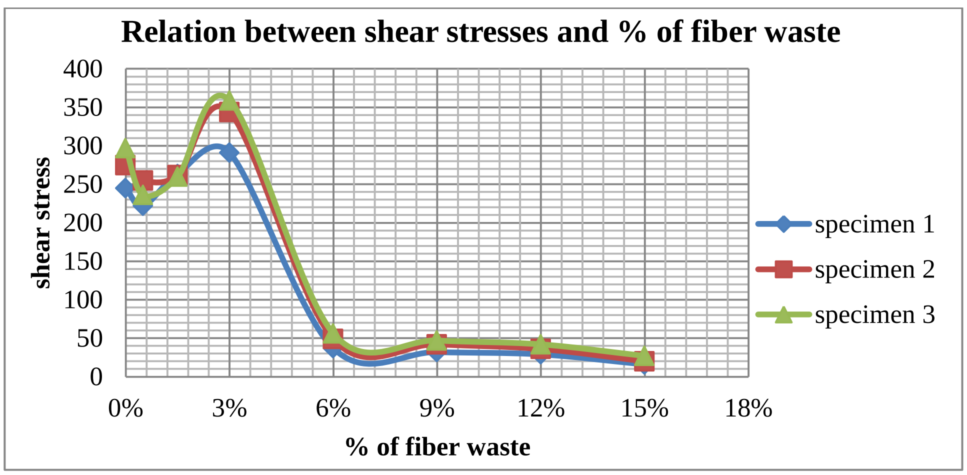


Fig 4.68 Relation between shear stress and % of fiber glass waste

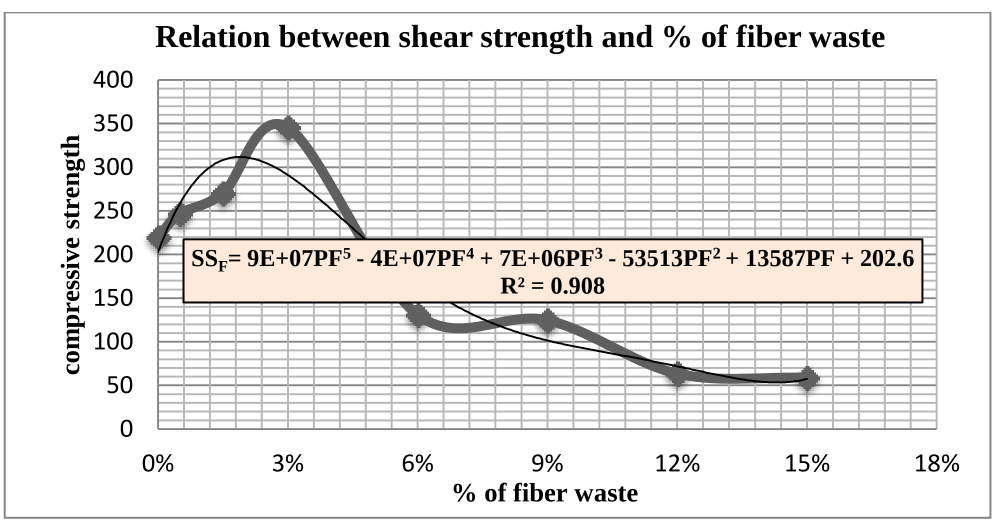


Fig 4.69 Relation between Compressive strength and % of fiber waste

Fig 4.70 Shape of failure on soil Reinforced by fiber glass waste (Cracks failure)

4.6.4 Soil Reinforced by PET Bottle:

Similar results were, also obtained from triaxial test for the clay soil reinforced by 0.5, 1.5, 3, 6 and 9% of plastic PET bottles waste. The results of stress and strain are presented in Fig (4.71) for soil reinforced by 0.5% of PET waste and the maximum stress was obtained to be equal to 332, 377 and 331 *kPa* for the specimens 1m 2 and 3respectively. The relation between the shear and total stress is presented in Fig (4.72) and the cohesion was found = 190 kN/m^2 and angle of friction = 26^o

For soil reinforced by 1.5% of PET waste the stress and strain relationship is presented in Fig (4.73) and the maximum stress was obtained to be equal to 347, 377 and 390 *kPa* for the specimens 1, 2 and 3 respectively. The relation between the shear and total stress is presented in Fig (4.74) and the cohesion was found = 250 kN/m^2 and angle of friction = 14.04^o

Similarly, the relation between the stress and strain is presented in Fig (4.75) for soil reinforced by 3% of PET bottles waste, and the maximum stress was obtained to be equal to 273, 305 and 365 *kPa* for the specimens 1, 2 and 3 respectively. The relation between the shear and total stress is presented in Fig (4.76) and the cohesion was found = 160 kN/m^2 and angle of friction angle = 24^o

Also similar relation between the stress and strain is presented in Fig (4.77) for soil reinforced by 6% of PET bottles waste, and the maximum stress was obtained to be equal to 221, 271 and 363 *kPa* for the specimens 1, 2 and 3 respectively. The relation between the shear and total stress is presented in Fig (4.78) and the cohesion was found = 95 kN/m^2 and angle of friction angle = 32^o

For soil reinforced by 9% of PET bottles waste the stress and strain plotted in Fig (4.79) the maximum stress was obtained to be equal to 188, 229 and 274 *kPa* for the specimens 1,2 and 3 respectively. The relation between the shear and total stress is presented in Fig (4.80) and the cohesion was found = 100kN/m^2 and angle of friction angle = 24^o

The shear parameters for the soil reinforced by 0.5, 1.5, 3, 6 and 9% of the PET bottles waste are summarized in Table (4.13) and the relation between cohesion and percentages of added PET bottles waste is plotted in Fig (4.82) and it indicated that an increasing of PET bottle waste increased the cohesion up to 1.5% and decreased when added greater than 1.5% of PET bottle waste, also the relation between the angle of friction and %s of PET bottle waste plotted in Fig (4.83) and it indicated that an increasing of PET bottle waste increased the angle of friction up to 6% of PET bottle waste.
New formulae obtained by excel sheet to determine the cohesion and angle of friction based on the percentages of cement waste as bellow:

$$c=-61728PP^3+15000PP^2-11778PP+395 \quad (R^2 = 1) \ldots\ldots\ldots (4.13)$$

$$\phi = -8888.PP^2 + 1066.PP - 2E\text{-}13 \quad (R^2 = 1) \ldots\ldots\ldots (4.14)$$

Table 4.13: Results of cohesion and Angle of friction (PET waste)

% of PET waste	Cohesion *kPa*	Friction Angle
00	165.4	18
0.5	190	26
1.5	250	14
3	160	24
6	95	32
9	100	24

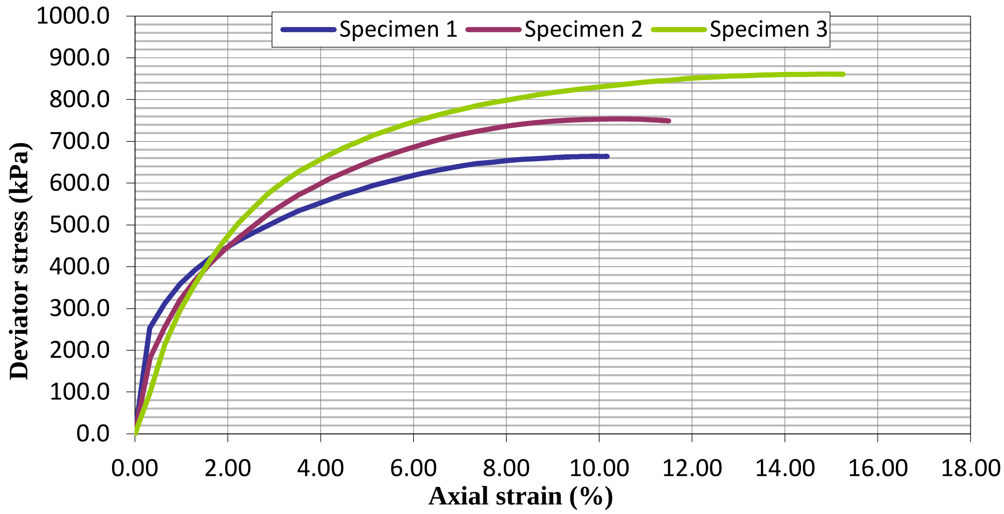


Fig 4.71Relation between stress and strain (clay soil +0.5 PET wastes)

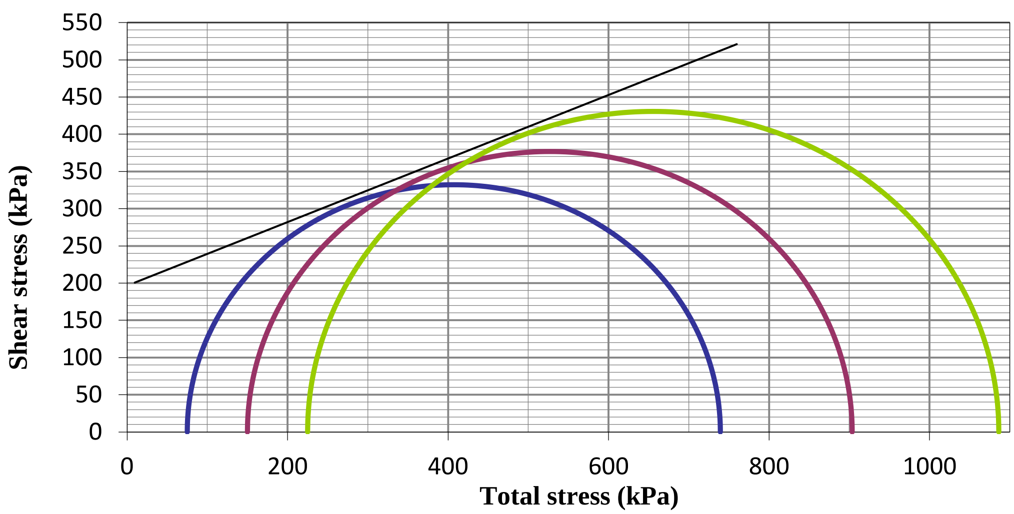


Fig 4.72 Relation between shear and total stress (clay Soil+0.5 PET wastes)

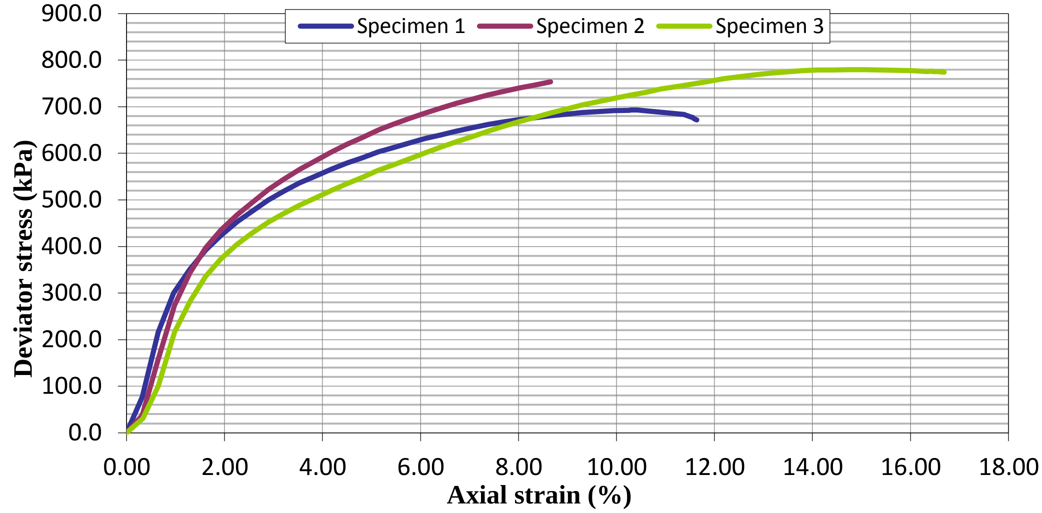


Fig 4.73Relation between stress and strain (clay soil +1.5 PET wastes)

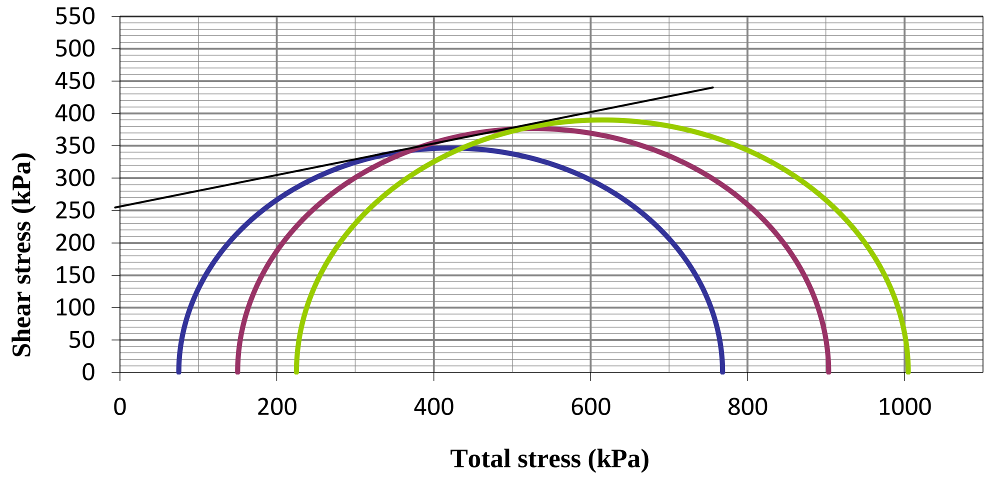


Fig 4.74Relation between shear and total stress (clay Soil +1.5 PET waste)

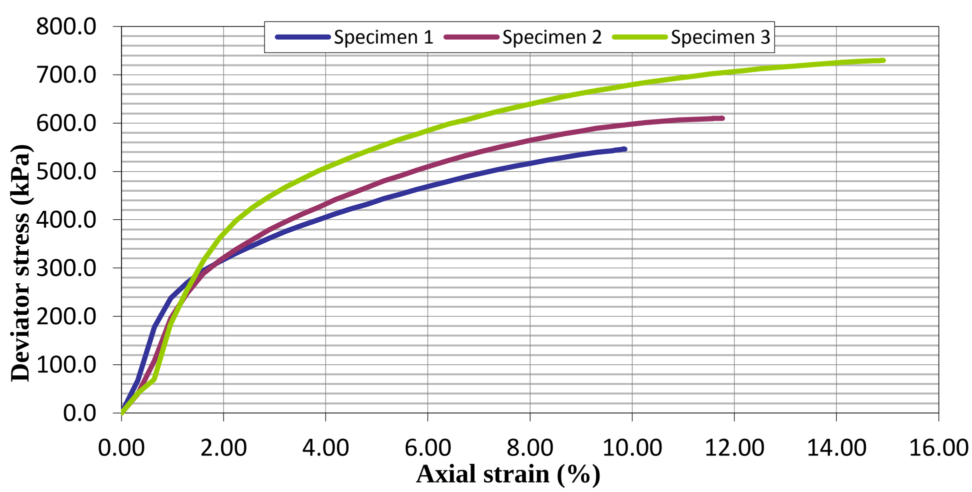


Fig 4.75 Relation between stress and strain (clay soil +3% PET waste)

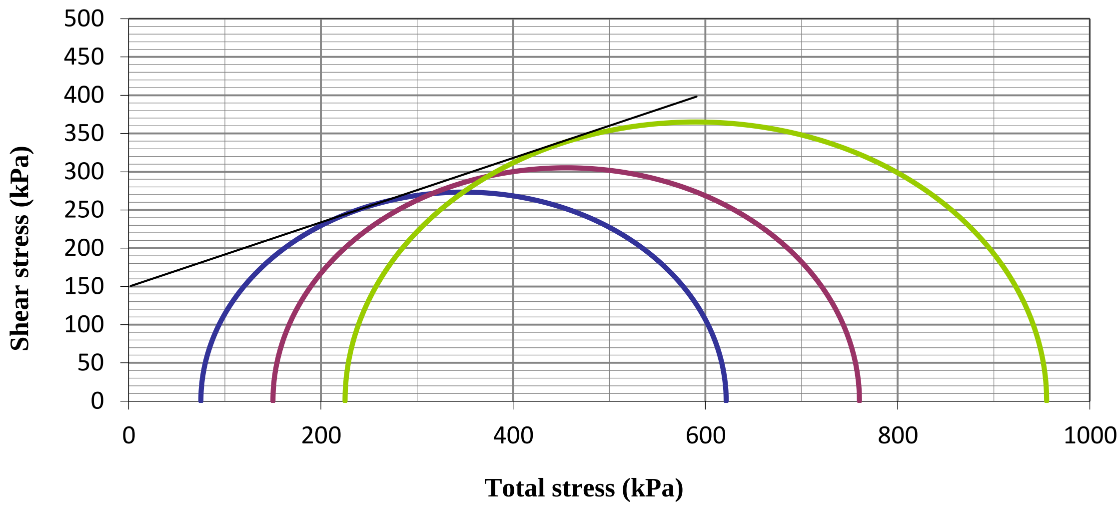


Fig 4.76 Relation between shear and total stress (clay Soil +3% PET waste)

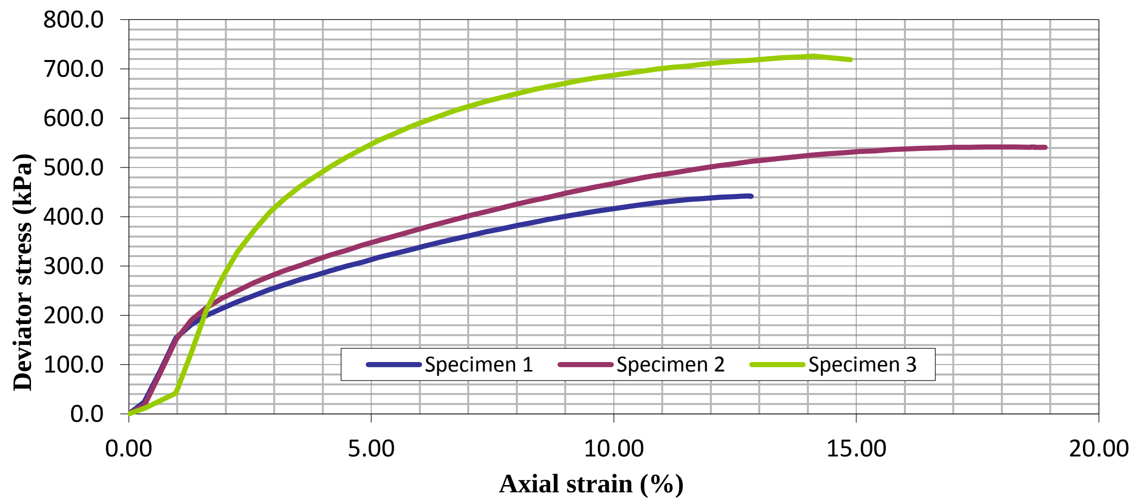


Fig 4.77 Relation between stress and strain (clay soil +6 %PET waste)

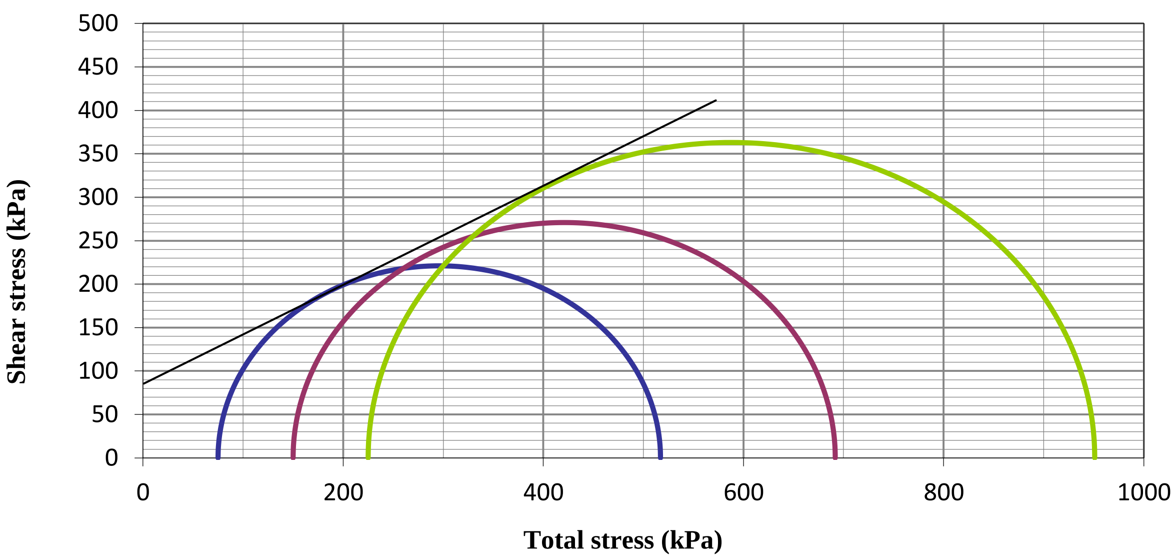


Fig 4.78 Relation between shear and total stress (clay Soil +6% PET waste)

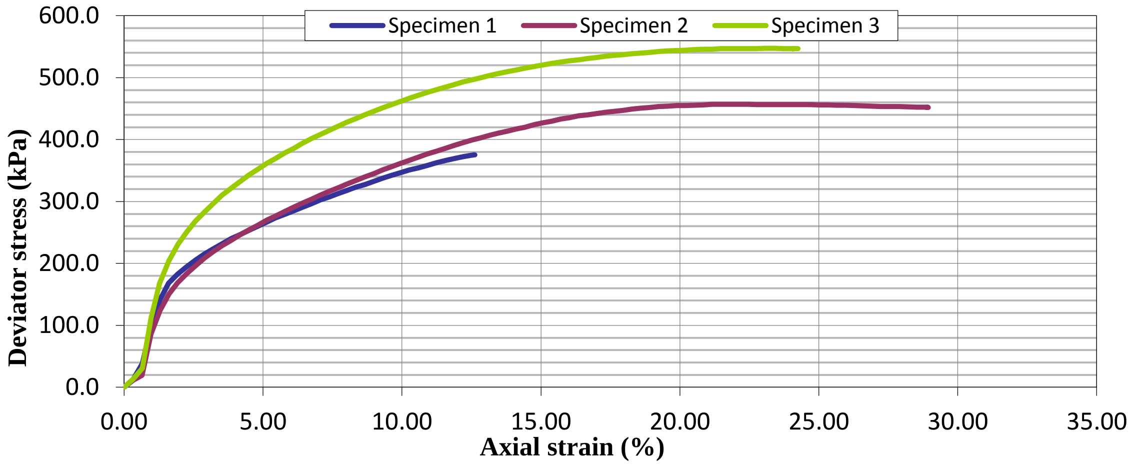


Fig 4.79 Relation between stress and strain (clay soil+9% PET waste)

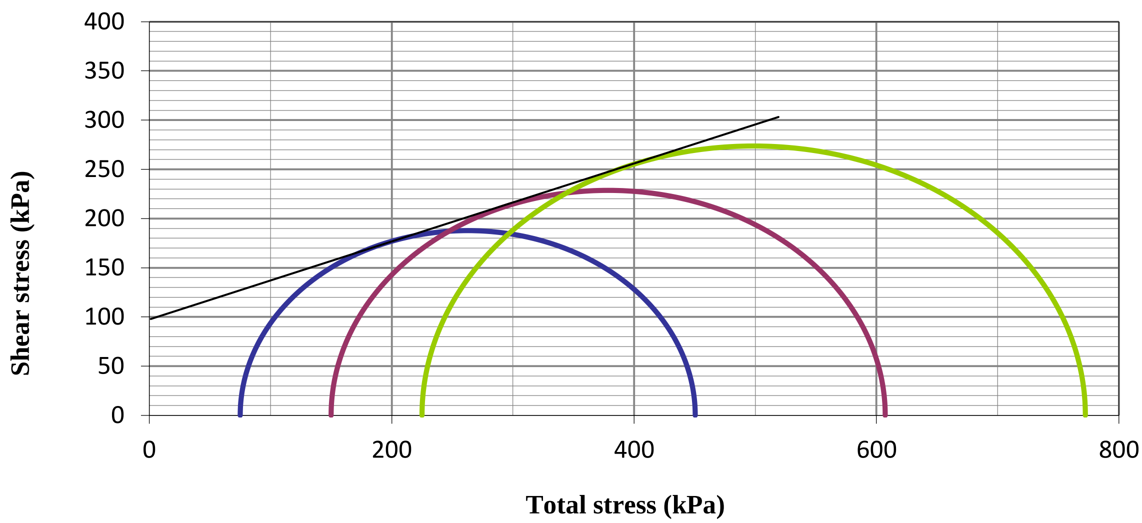


Fig 4.80 Relation between shear and total stress (clay Soil+9%PET waste)

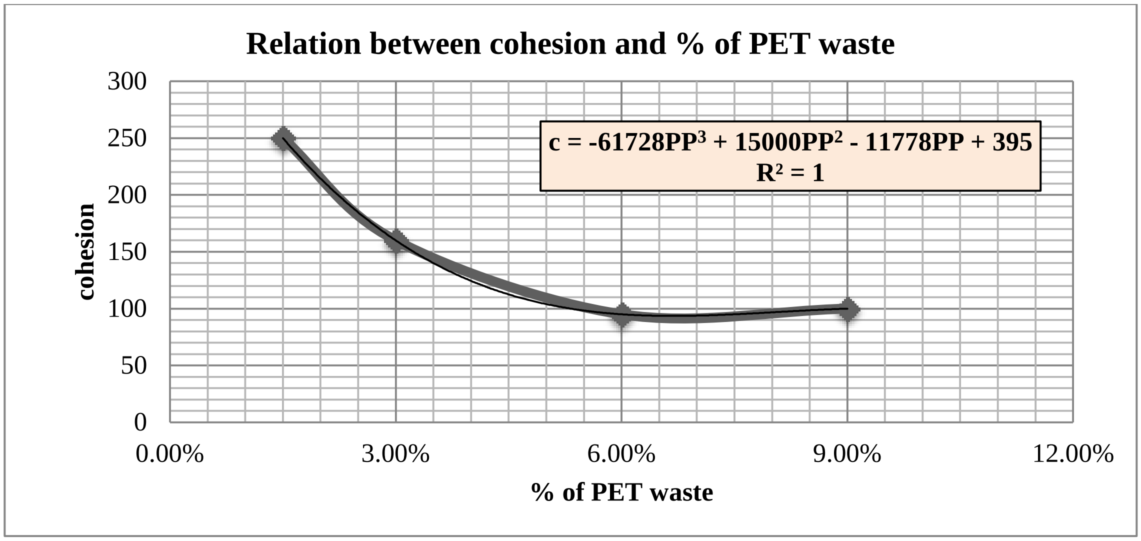


Fig 4.81 Relation between cohesion and % of PET waste

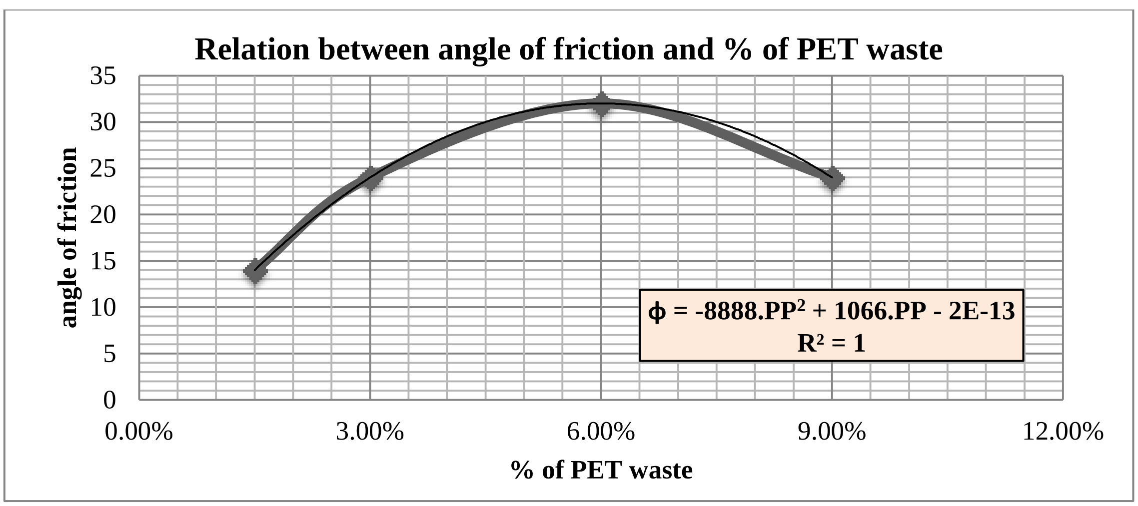


Fig 4.82 Relation between angle of friction and % of PET waste

The results of shear stress of three specimens for various percentages of plastic PET bottles waste are tabulated in Table (4.10) and plotted in Fig (4.84). Also the shear strength is presented in Fig (4.85) and it indicate that the highest value of shear strength achieved at the addition of plastic PET bottles waste equal to 3 % of dry weight of clay soil.

A new formula was obtained by excel sheet to determine the shear strength based on the added percentages of plastic PET bottles waste as follow:

$SS_P = 2EPP^3 - 32035PP^2 + 8979PP + 215.9$ (R^2=0.995)……………(4.15)

Table 4.12: Results of shear stress of 3 specimens (PET waste)

% of PET waste	Specimen 1	Specimen 2	Specimen 3
0 %	*245*	*275*	*297*
0.5 %	*332*	*377*	*431*
1.5 %	*347*	*377*	*390*
3 %	*273*	*305*	*365*
6 %	*221*	*271*	*363*
9 %	*188*	*229*	*274*

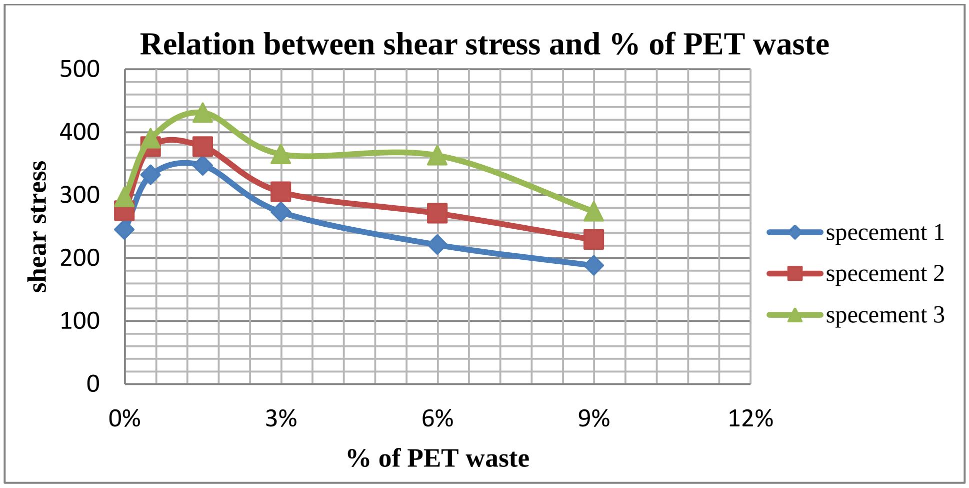


Fig 4.83Relation between shear stress and % of PET waste

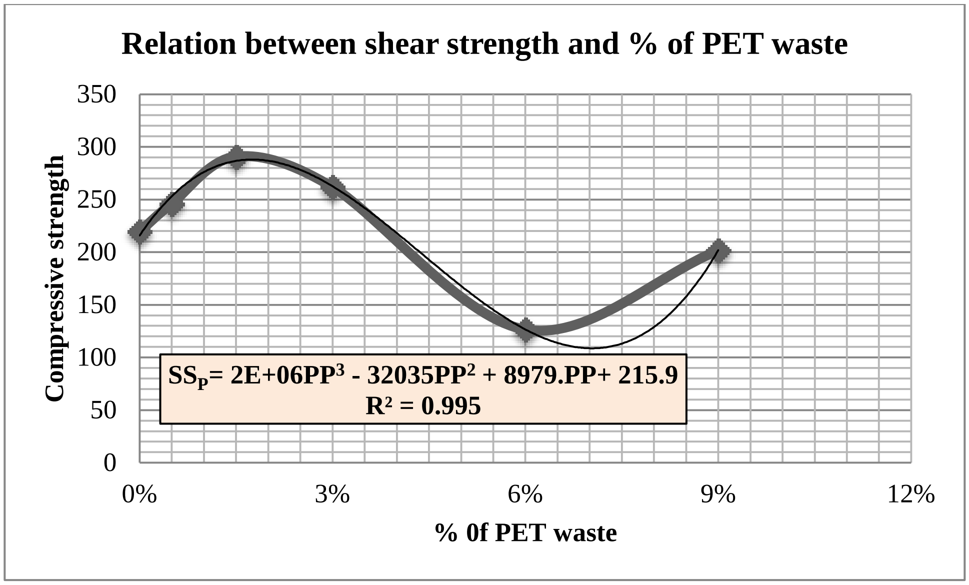


Fig 4.84 Relation between compressive strength and % of PET waste

The shear strength for soil treated by cement waste and soil reinforced by fiber glass and plastic PET bottle wastes is plotted in Fig (4.86) and it indicates that the highest increase in shear strength value was achieved when adding, 9% cement, 3.0% of fiber glass or 1.5 % of PET bottle wastes. The values of compressive strength are (385.38, 386.82 and 386 *mPa*) respectively.

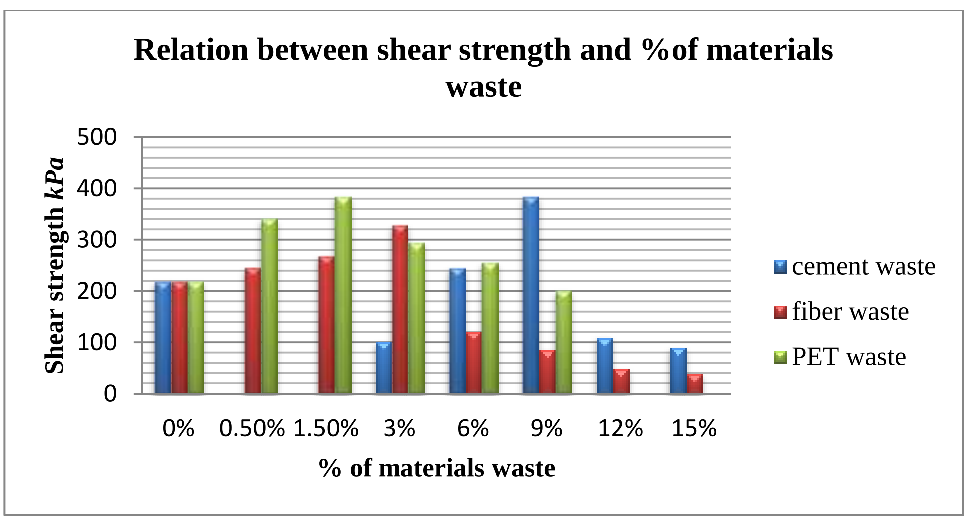


Fig 4.85 Relation between shear strength and % of materials waste

4.7 Results of California Bearing Ratio Test:

A serious of CBR test were performed to investigate the effect of addition of cement waste as chemical stabilizer and fiber glass and plastic (PET) wastes as soil reinforcement on CBR. The results obtained and their analysis and discussion is presented in the following sections.

4.7.1Clay Soil without materials waste:

The relation between penetration and bearing for natural soil is presented in Fig (4.87) and the relation between CBR values and dry density is presented in Fig (4.88) and the CBR of natural clay soil was found to be equal to 3%.

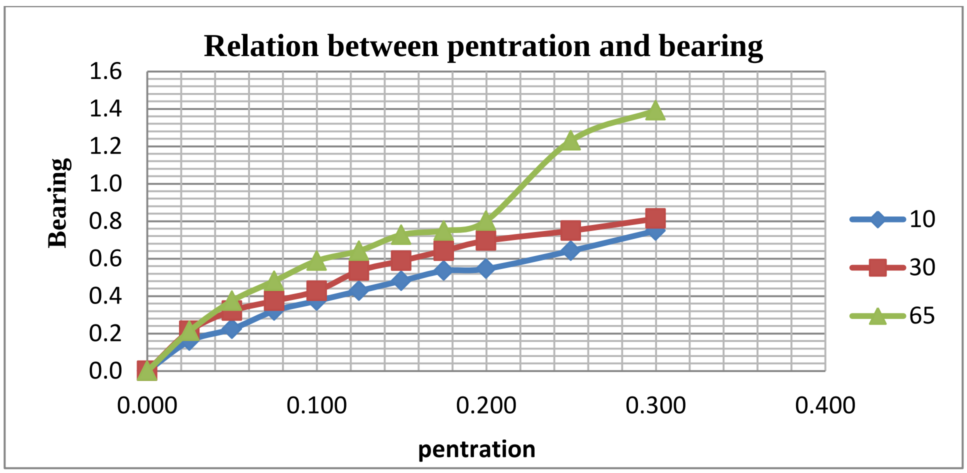


Fig 4.86Relation between penetration and bearing (clay soil)

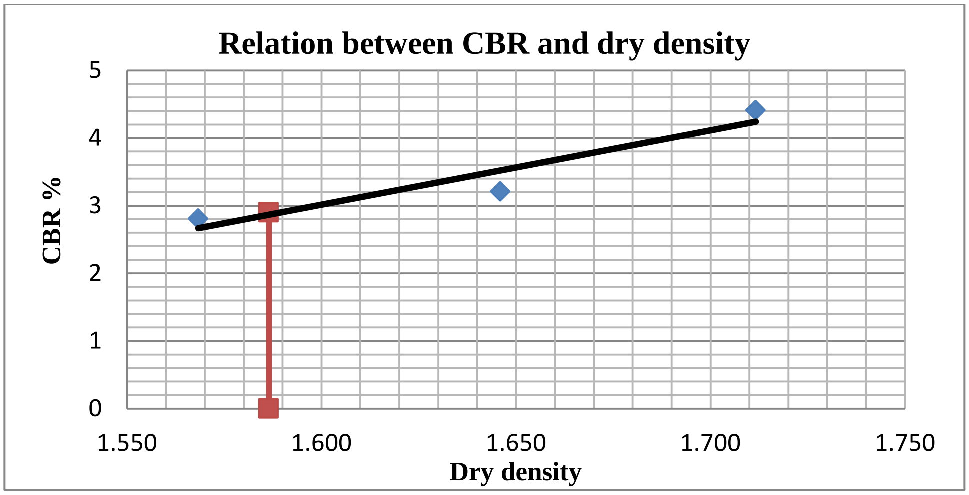


Fig 4.87 Relation between CBR and dry density (clay soil)

4.7.2 Clay Soil Treated by Cement Waste:

Similar relations between penetration and bearing for soil treated by 3, 6, 9, 12 and 15% of cement waste as chemical stabilizers are presented in Fig (4.89), Fig (4.91), Fig (4.93), Fig (4.95), Fig (4.97) and Fig (4.99). Also, the relations between CBR values and dry density are presented in Fig (4.88), Fig (4.90), Fig (4.92), Fig (4.94), Fig (4.96) and Fig (4.98) and the CBR values reported in Table (4.14) and plotted in Fig (4.99).

The results indicate that an increasing of cement waste increases the CBR values up to 9% added waste. Addition of more than 9% of waste decreases the CBR value. The highest value was found to be equal to 29%.

Table 4.14 Results of CBR test of soil treated by cement waste

% of cement waste	CBR %
00	2.9
3	6
6	10
9	29
12	26.5
15	23

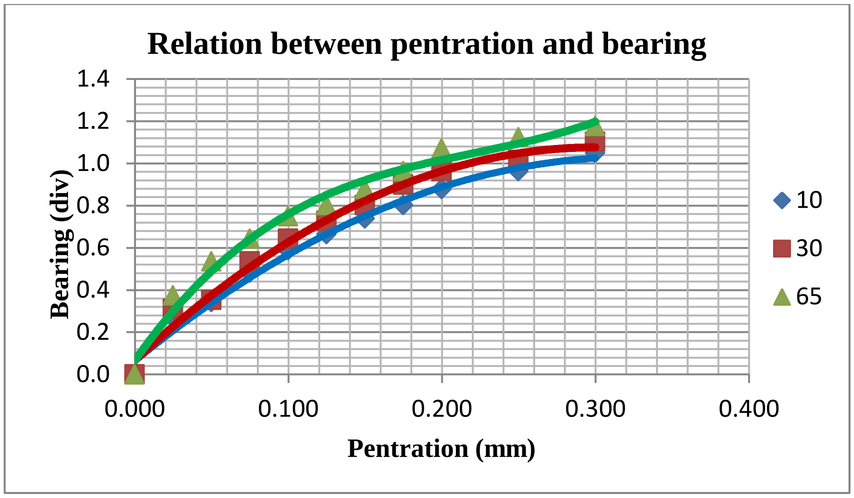


Fig 4.89 Relation between penetration and bearing (clay soil + 3% cement waste)

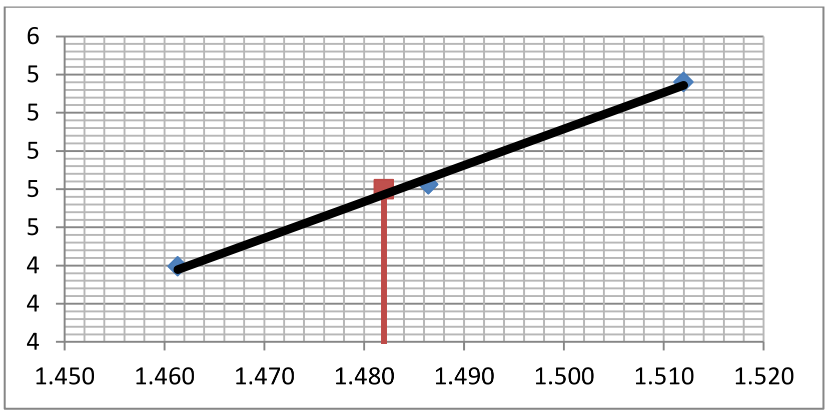


Fig 4.90 Relation between CBR and dry density (clay soil + 3% cement waste)

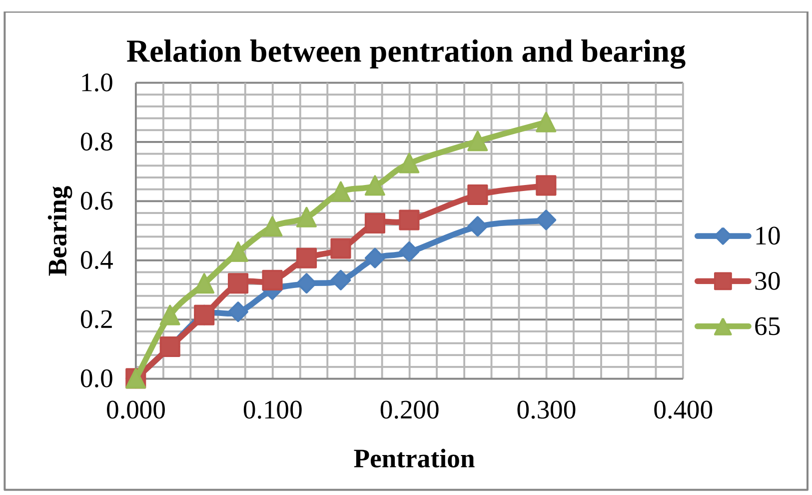


Fig 4.91 Relation between penetration and bearing (clay soil + 6% cement waste)

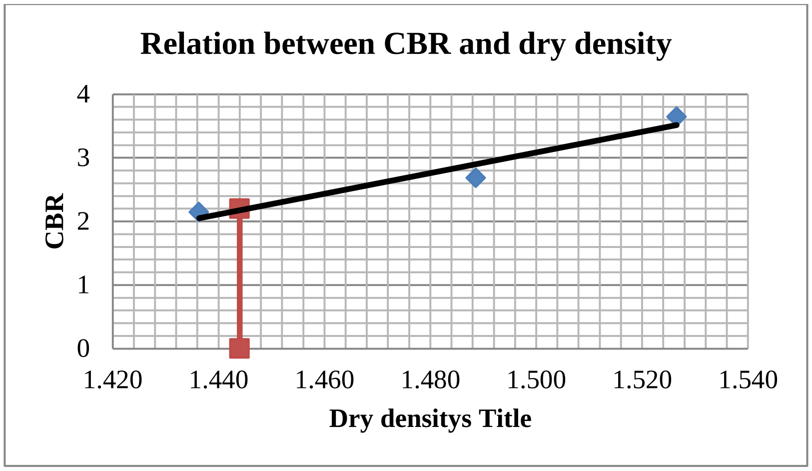


Fig 4.92 Relation between CBR and dry density (clay soil + 6 cement waste)

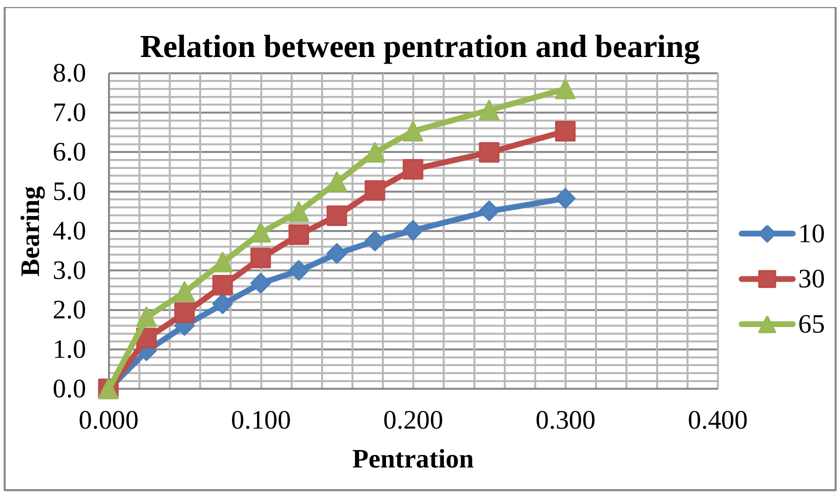


Fig 4.93 Relation between penetration and bearing (clay soil + 9% cement waste)

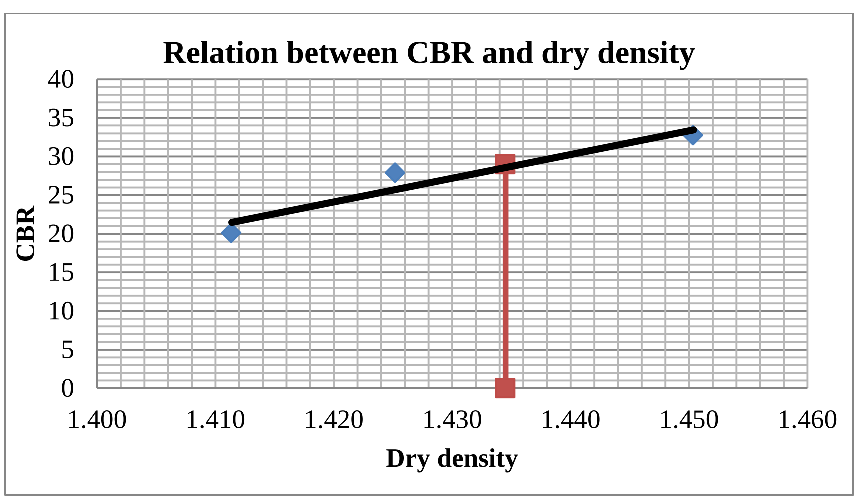


Fig 4.94 Relation between CBR and dry density (clay soil + 9% cement waste)

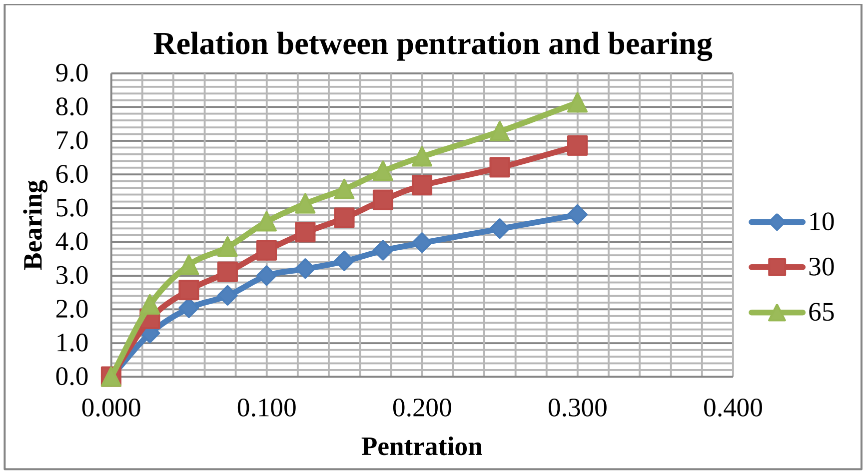


Fig 4.95 Relation between penetration and bearing (clay soil + 12% cement waste)

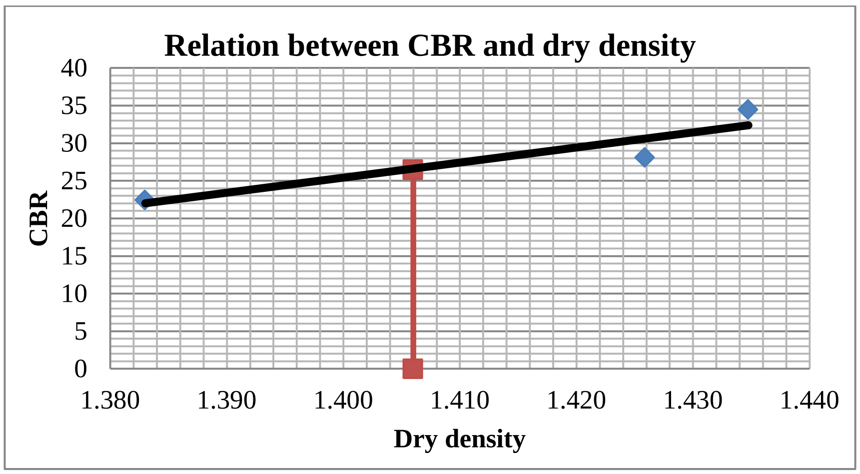


Fig 4.96 Relation between CBR and dry density (clay soil + 12% cement waste)

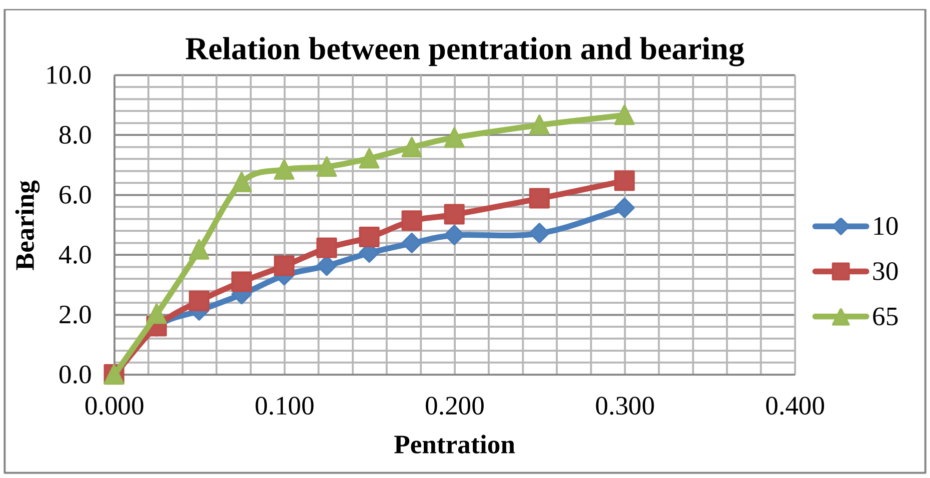


Fig 4.97 Relation between penetration and bearing (clay soil + 15% cement waste)

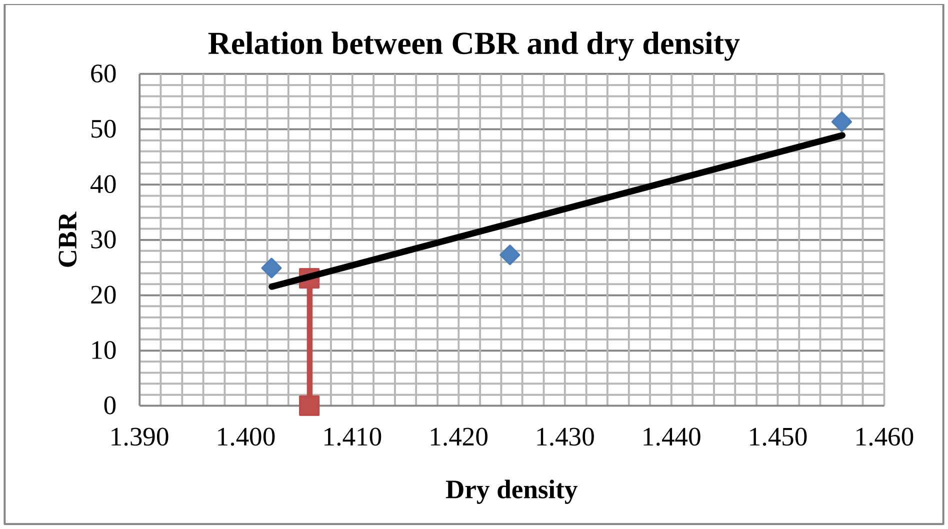


Fig 4.98 Relation between CBR and dry density (clay soil+ 15% cement waste)

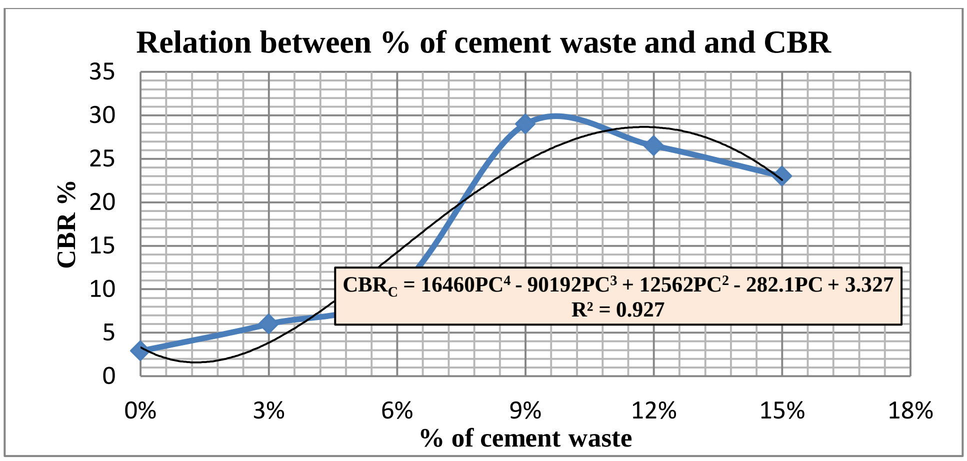


Fig 4.99 Relation between CBR and % cement waste)

4.7.3 Clay Soil Reinforced by Fiber Glass Waste:

Similar results were obtained from the CBR test for soil reinforced by, 1.5%, 3%, 6% and 9% of fiber glass waste. These are presented in Fig (4.100) to Fig (4.103). The CBR values obtained are tabulated in Table (4.15) and presented in Fig (4.104). The results indicate that an increasing of fiber glass waste increases the CBR value up to 3% of added fiber waste content, and then it decreases. The highest CBR value was 10.69% achieved when adding 3% of fiber glass waste.

Table 4.15 Results of CBR test of soil reinforced by fiber glass waste

% of fiber glass waste	CBR %
00	2.9
1.5	7.03
3	10.69
6	5.73
9	3.5

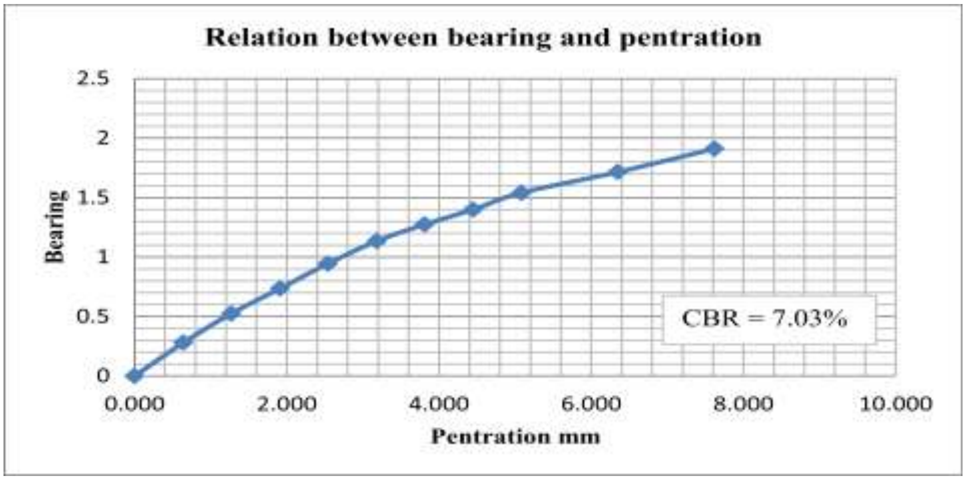


Fig 4.100 Relation between Penetration and Bearing (clay soil+ 1.5% fiber glass waste)

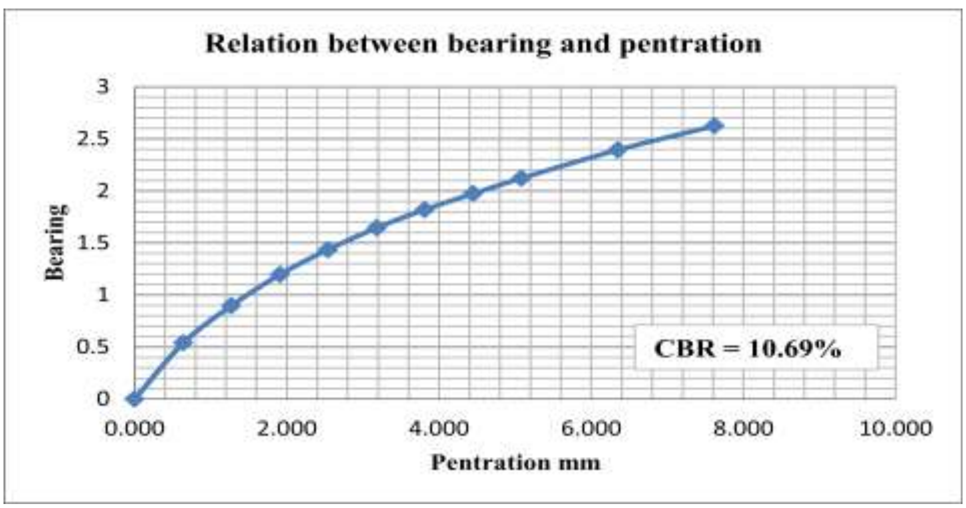


Fig 4.101 Relation between Penetration and Bearing (clay soil+ 3% fiber glass waste)

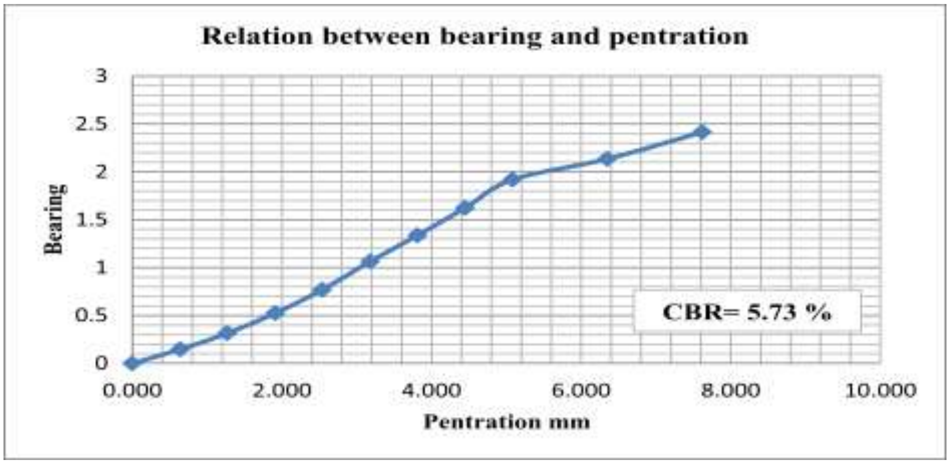


Fig 4.102 Relation between Penetration and Bearing (clay soil+ 6% fiber glass waste)

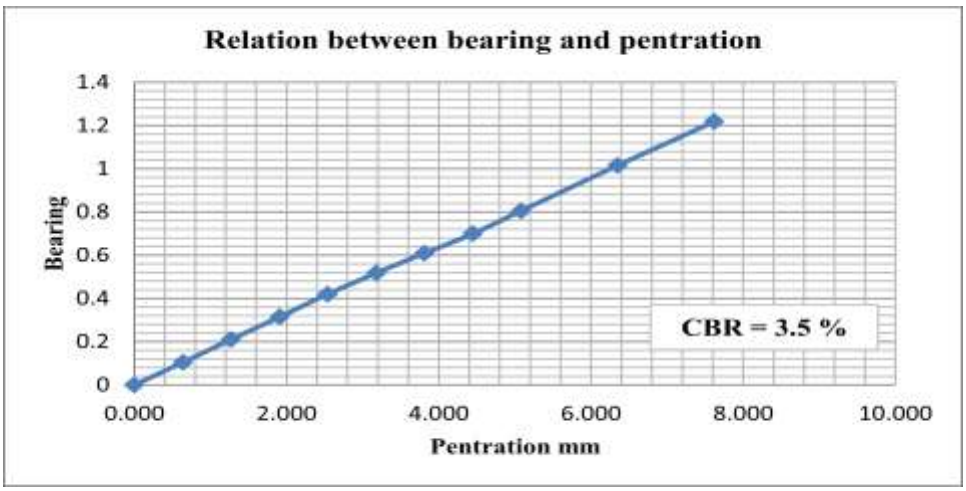


Fig 4.103 Relation between Penetration and Bearing (clay soil+ 9% fiber glass waste)

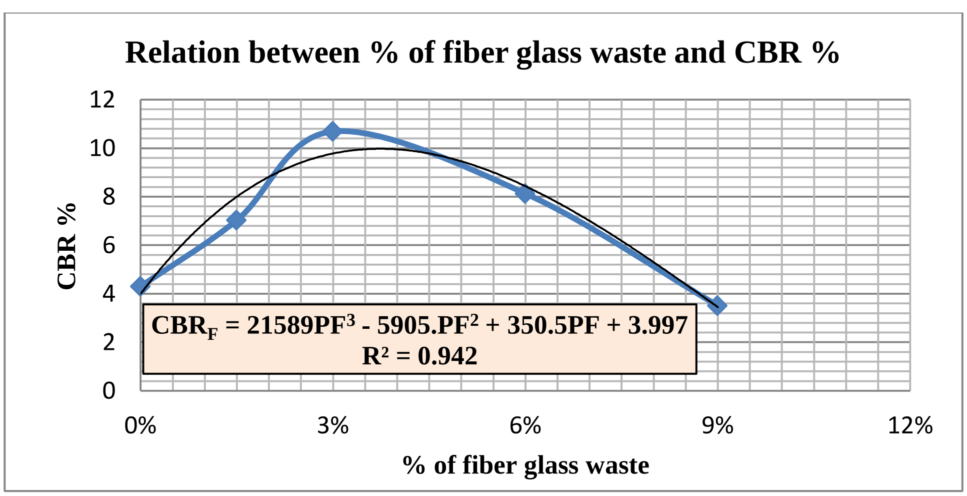


Fig 4.104 Relation between CBR and % fiber glass waste)

4.7.4 Clay Soil Reinforced by Plastic PET Waste:

Similar results were, also, obtained from the CBR test for soil reinforced by 1.5%, 3%, 6% and 9% of PET bottle waste. These present in Fig (4.105) to Fig (4.108). The CBR values are summarized in Table (4.16) and presented in Fig (4.109). These indicate that an increasing of PET bottle waste increased the CBR up to a maximum for 3% added waste content.

Table 4.16 Results of CBR test of soil reinforced by PET waste

% of PET waste	CBR %
00	2.9
1.5	5.6
3	6.15
6	4.06
9	3.49

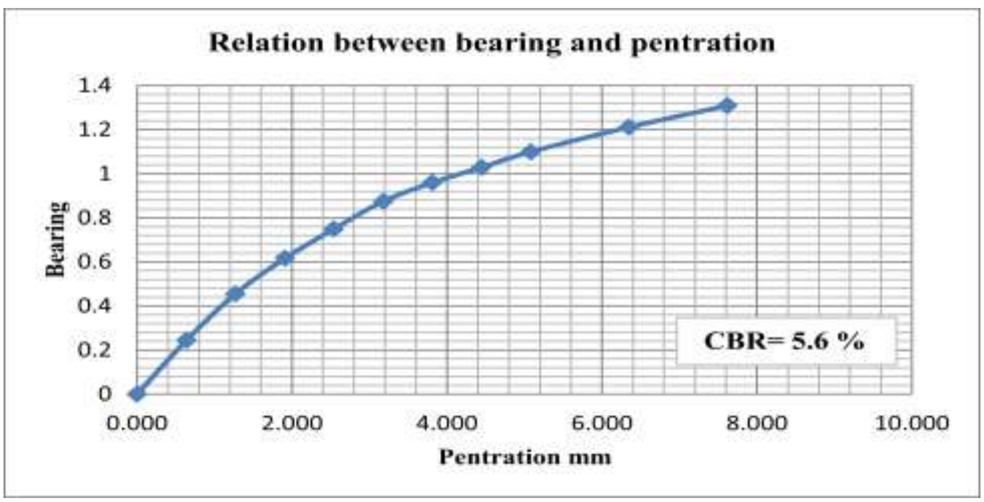


Fig 4.105 Relation between Penetration and Bearing (clay soil+ 1.5% PET waste)

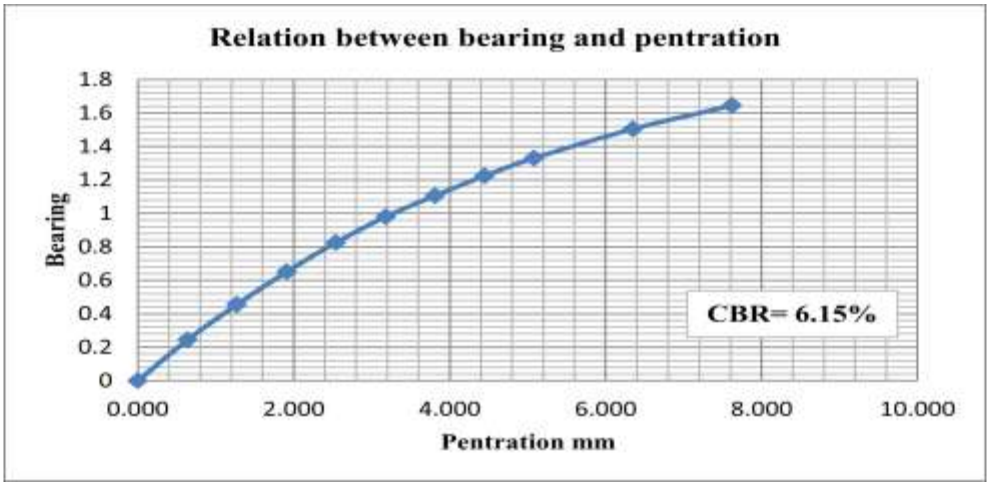


Fig 4.106 Relation between Penetration and Bearing (clay soil+ 3% PET waste)

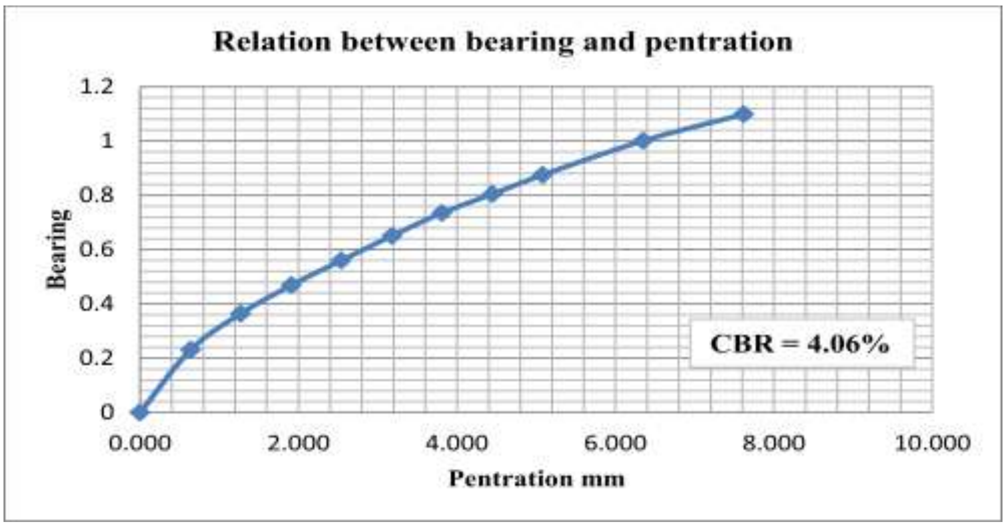


Fig 4.107 Relation between Penetration and Bearing (clay soil+ 6% PET waste)

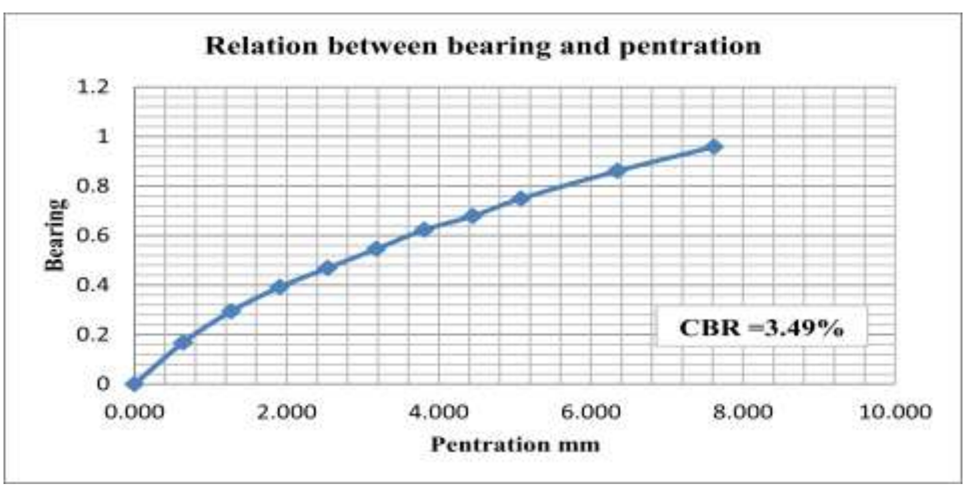


Fig 4.108 Relation between Penetration and Bearing (clay soil+ 9% PET waste)

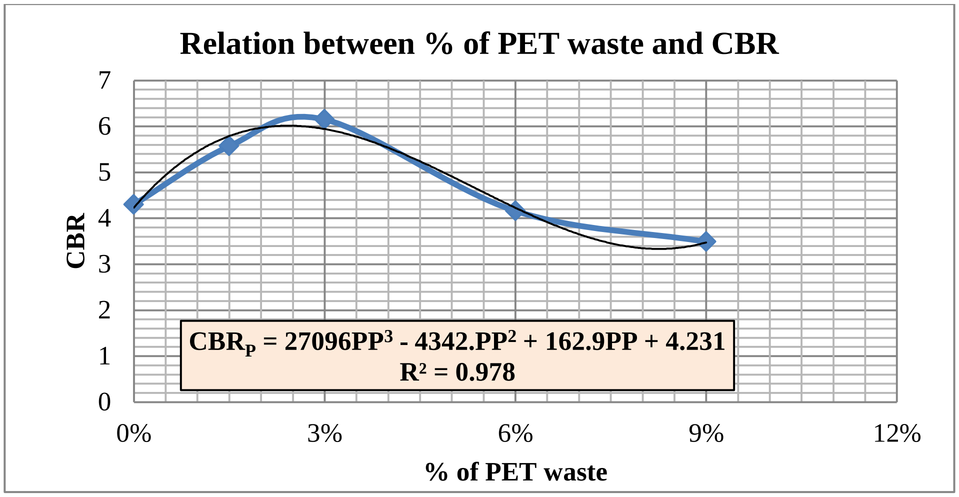


Fig 4.109Relation between CBR and % PET waste

From the results presented in Fig (4.99), Fig (4.104) and Fig (4.109) the following equations were obtained to determine the CBR values for soil treated and reinforced by cement, fiber glass and PET bottle:

$CBR_C = 16460PC^4 - 90192PC^3 + 12562PC^2 - 282.1PC + 3.327$ ($R^2 = 0.927$).....(4.15)

$CBR_f = 21589PF^3 - 5905.PF^2 + 350.5PF + 3.997$ ($R^2 = 0.942$)………………...(4.16)

$CBR_p = 27096PP^3 - 4342.PP^2 + 162.9PP + 4.231$ ($R^2 = 0.978$)……….……..... (4.17)

Where CBR_c , CBR_f and CBR_P are the CBR values for soil treated by cement waste and soil reinforced by fiber glass and PET bottle respectively.

The CBR values for soil treated by cement waste and soil reinforced by fiber glass or plastic PET bottle wastes are presented in Fig (4.110). It indicates that the highest increase in strength value was achieved when adding, 9% cement, 3.0% of fiber glass or 3.0 % of PET bottle wastes respectively. The values of CBR are (29, 10.69 and 6.15%) respectively.

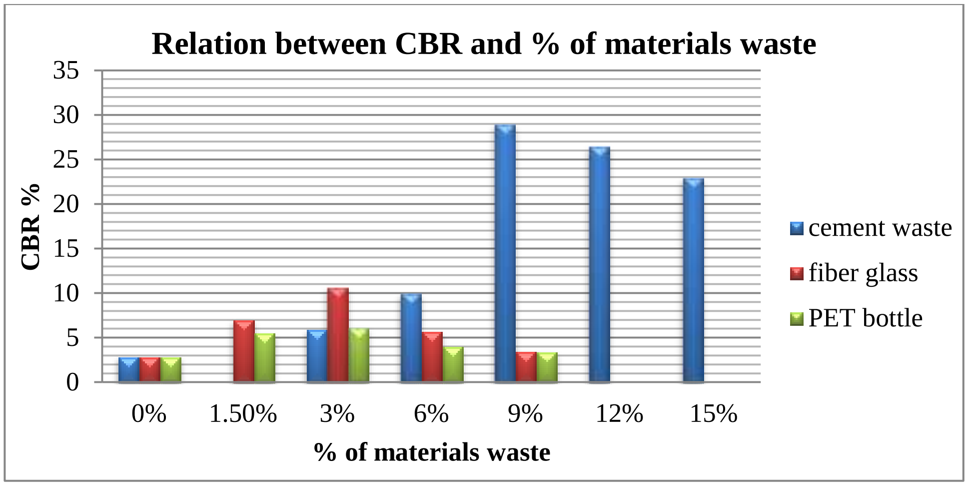


Fig 4.110 Relation between CBR and % of materials waste

4.8 Results of Swelling:

The results obtained from swelling test for natural clay soil and soil treated by various percentages of cement waste and soil reinforced by various percentages of fiber glass or PET wastes are tabulated in Table (4.17) and presented in Fig (4.111). The results indicate that an addition of cement, fiber glass or PET wastes reduces the swelling that occurs in the clay soil.

The following equations were obtained to determine the swelling that occurs in soil reinforced by fiber glass or PET bottles wastes:

$$S_f = 2911.PF^2 - 605.8PF + 35.36 \qquad (R^2 = 0.986) \ldots\ldots\ldots\ldots\ldots\ldots (4.18)$$

$$S_P = 4721.PP^2 - 801.6PP + 33.95 \qquad (R^2 = 0.999) \ldots\ldots\ldots\ldots\ldots\ldots (4.19)$$

Where: S_f and S_p are the swelling value for soil reinforced by fiber glass or PET wastes respectively.

Table 4.17 Results of swelling test of soil and soil stabilized by waste materials

Percentage of waste materiales	Cemenet waste	Fiber glass waste	PET waste
00%	**34**	34	34
1.5%	-	23	29
3%	0	14	20
6%	0	3	8
9%	0	0	5

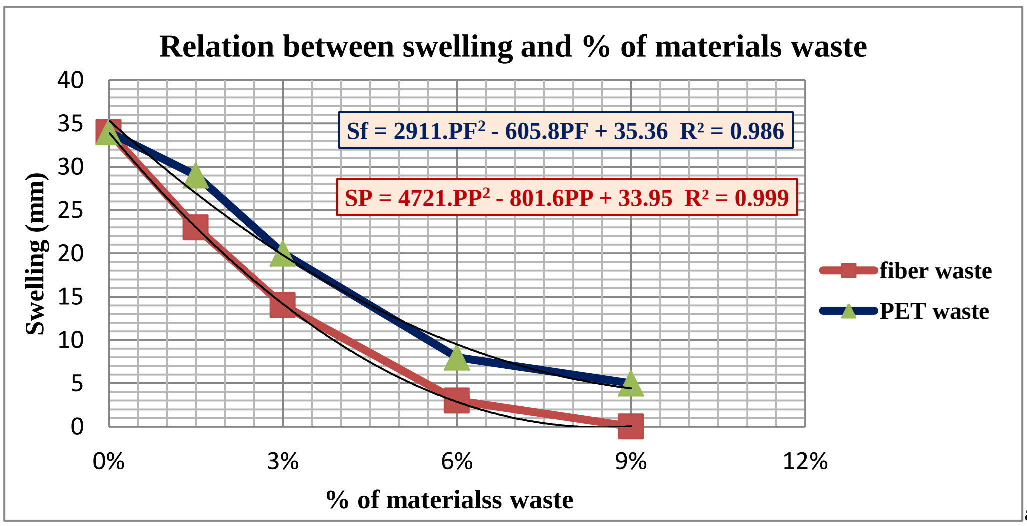


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Fig 4.111 Relation between swelling and % of materials waste