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Effect of Water Content and Degree of Compaction of Clay Subgrade Soil on the Interface Shear Strength Using Geogrid

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ABSTRACT

Pavement performance in clay soil roads can be enhanced with the help of the geogrid concept by increasing lateral confinement, bearing capacity, and overall rigidity of the pavement. Also, geogrid is useful in minimizing vertical and lateral pavement deformations. In this study, 65 tests are performed without and with two types of geogrid, and the aim behind it is to investigate the effect of the moisture content and degree of compaction of clay soil on the interface shear strength. The number of materials used to conduct this study, included subbase granular (type B), clay subgrade soil, the Biaxial and SS2 geogrid which is used as a reinforcing material. Testing the direct shear is conducted by a large-scale direct shear manufactured device contains an upper box with side lengths of (20×20×10) cm, and a lower box with side lengths of (20×25×10) cm. Results show that for all tests the normal applied stresses are 25, 50, 75 and 100 kPa, the shear stress displacement curves for all cases follow similar trends and they are affected by normal stress, density and water content of subgrade soil and type of geogrid. Also, it is obvious that the shear stress increases by increasing the normal applied stress and degree of compaction of clay subgrade soil reaching its maximum value at 95% degree of compaction while it decreases by increasing the water content of subgrade soil. The maximum value of shear strength is observed when water content is equal to 8% (dry side) and finally, the Biaxial geogrid BX1100 (G1) is more efficient in reinforcing clay-subbase interface as compared with SS2 geogrid (G2).

1. Introduction

Geosynthetic reinforcement of soil structures was first conducted in the 1970s [1]. After that, it has been applied broadly in many transportation and geotechnical engineering uses. Most uses of geosynthetic reinforcement of soil are confined to granular soils (noncohesive) such as sand and gravel, because of their high frictional resistance, lower water susceptibility and good drainage and because of these advantages many researchers turned to reinforcing clay soil (cohesive soils) with

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this technique. When high-quality backfill is hard to come by, geosynthetic soil reinforcement of locally accessible soils can effectively offer a workable and cost-effective option for pavement embankments, shallow foundations, and mechanically stabilized earth walls (MSE walls). Cohesive soils were employed as reinforced backfill material in a number of cases reported in the literature [2-4].

There are eight commonly known kinds of geosynthetic products represented geotextile, geonets, geogrid, geofoams, geomembrances, geosynthetic clay liner, geopipes and geocomposities. Each type of the previous product is used to cover certain engineering categories. In pavement works, geogrid is the best selected choice for subgrade stabilization in flexible pavement. The main components of geogrids may include polypropylene, polyester, polyethylene, and coated polyester materials. On the other hand, many steps of standard manufacturing processes. Heating, extruding, plasticizing, perforating, flattening, directional drawing and cooling etc. are performed when geogrids are produced. Geogrids have a higher tensile strength and rigidity to resist more tensile stresses, as compared with other kinds of geosynthetic products [5]. Geogrids are divided to three groups according to the direction of the resistance (uniaxial, biaxial and triaxial). The uniaxial geogrids are used in the slopes, embankments and retaining walls, while the triaxial and biaxial geogrids are used for subgrade stabilization and base reinforcement [6,7].

Using soil reinforcement (geogrid) in road pavements can increase the lateral confinement, overall rigidity of the pavement and bearing capacity, on the other hand, it reduces the lateral and vertical deformations. Therefore, this would improve road performance [8,9]. For improving weak subgrade soil, geogrid synthetic reinforcement is the best, most effective and easiest solution compared with traditional alternative soils in the design of pavement. Interface parameters (cohesion of soil and angle of friction) between geogrid and road base materials are considered key factors in the design of a reinforced pavement. There are two modes of failure in the designing of soil reinforcing structure, pullout failure caused by sufficient anchorage and the direct shear failure mode occurring in the interface area between the soil and geosynthetic reinforcement [10-17]. In this paper, only the direct shear failure mode will be discussed because the direct shear test is the suitable method to simulate the interaction between soil and synthetic reinforcement [18,19]. Many experimental studies to assess the shear properties of soil-geogrid interface have been conducted [20-24] but, few researchers have studied the shear resistance for soil-geosynthetic interfaces for different conditions of density and soil moisture of subgrade soil therefore, the interface shear properties for soil- G1- subbase and soil- G2- subbase are analyzed and derived with different cases of density and water content of clay subgrade soil. Therefore, the aim of this study is to explain the effect of water content and degree of compaction of cohesive soil on the shear strength interaction between subbase and subgrade soil with two types of geogrid using a manually manufactured direct shear device.

2. Material Used

2.1 Subbase Material

Subbase granular materials are taken from Sabeaa Al-Bour location within Baghdad city with Type B (SGM). Table 1 states the gradation of (SGM) subbase granular materials. The chemical analysis and physical properties of subbase granular materials are listed in Table 2.

Table 1
Gradation of the (SGM) subbase granular materials [4]

Passing by the weight%		
Size of the Sieve (mm)	**Passing (%)**	**Limits of SCRB/R6,2003**
75	100	-
50	100	100
25	88.5	75-95
9.5	74.5	40-75
4.75	51.2	30-60
2.36	41.4	21-47
0.3	27	14-28
0.075	14.30	5-15

Table 2
The physical properties and chemical analysis [4]

Characteristics	Results	Limits of SCRB/R6,2003
Maximum dry density (gm/cm^3)	2.240	Not limited
% Optimum moisture content	7	Not limited
% Organic matter	0.84	Maximum = 2
% T.S.S	7.58	Maximum =10
% (SO_3) content	2.60	Maximum = 5
% Gypsum content	5.59	Maximum = 10.75

2.2 Clay Subgrade Soil Layer

The clay subgrade soil is obtained from Al-Muthanaa Airport area within Baghdad city. Table 3 illustrates the properties of clay subgrade soil. Figure 1 shows the compaction curve.

Table 3
Properties of clay subgrade soil type

Characteristics	Results	Specification requirement
Maximum dry density (gm/cm^3)	1.88	AASHTO T99 – 95
% Optimum moisture content	10	AASHTO T99 – 95
% Liquid limit	34.5	AASHTO T89 – 96
% Plastic limit	21.8	AASHTO T90 – 96

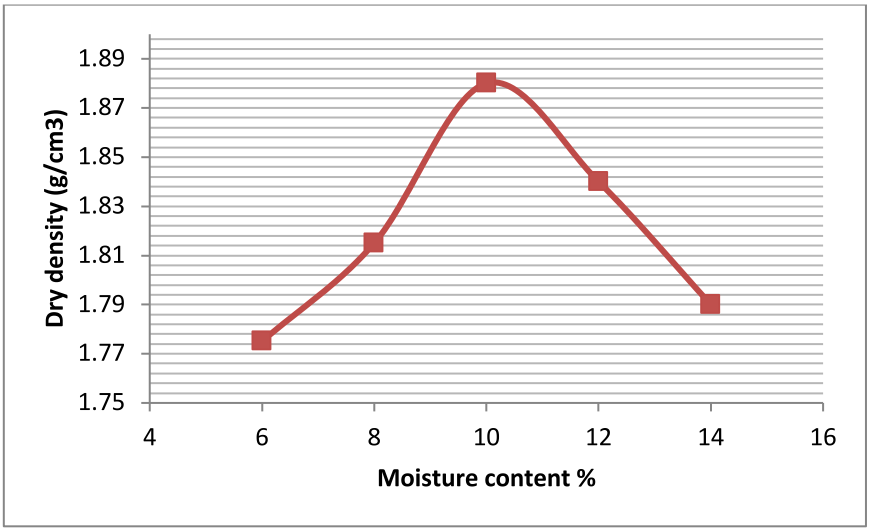

Fig. 1. Compaction curve of the clay subgrade soil

2.3 Geosynthetic Reinforcement
2.3.1 (G1) Biaxial geogrid BX1100

The first type of geogrid reinforcement material used in this study is the Biaxial Geogrid BX1100, produced by Tensar International Company as shown in Figures 2 and 3. The physical and mechanical characteristics of the G1 are listed in Table (4).

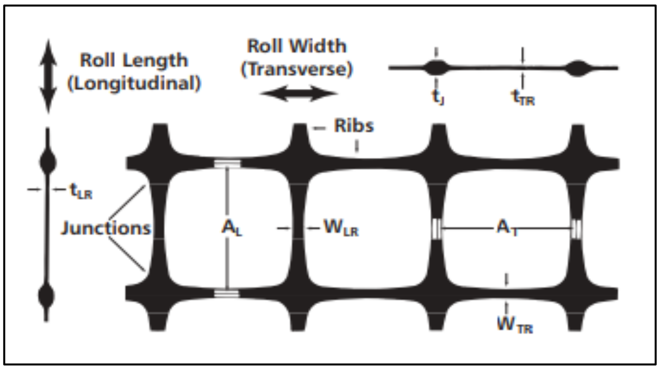

Fig. 2. Details of geogrid reinforcement SS2 **(**Tensar international company's**)**

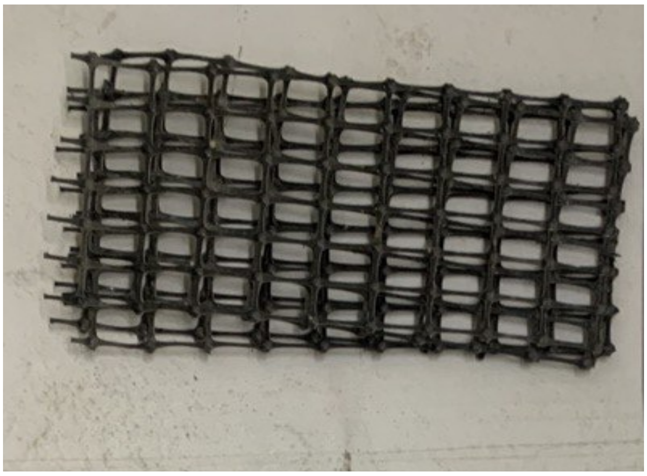

Fig. 3. Geogrid reinforcement (BX1100)

Table 4
Dimensional and Physical properties of the Biaxial geogrid (Tensar Co.)

The physical properties	Data		
Polymer type	Biaxial geogrid		
Color	Black		
Polymer	PP		
Rib shape	Rectangular		
Index properties	**Units**	**MD Values**	**XMD Values**
Rib Thickness	mm	0.76	0.76
Aperture Dimensions	mm	25	33
Ultimate Tensile Strength	kN/m	12.4	19.0
Tensile Strength @ 5% Strain	kN/m	8.5	13.4
Tensile Strength @ 2% Strain	kN/m	4.1	6.6

2.3.2 (G2) SS2 Geogrid:

The SS2 geogrid is the second type of reinforcement material used in study (Tensar international company's) as shown in Figures 4. Table (5) shows the physical and mechanical characteristics of the SS2 geogrid's.

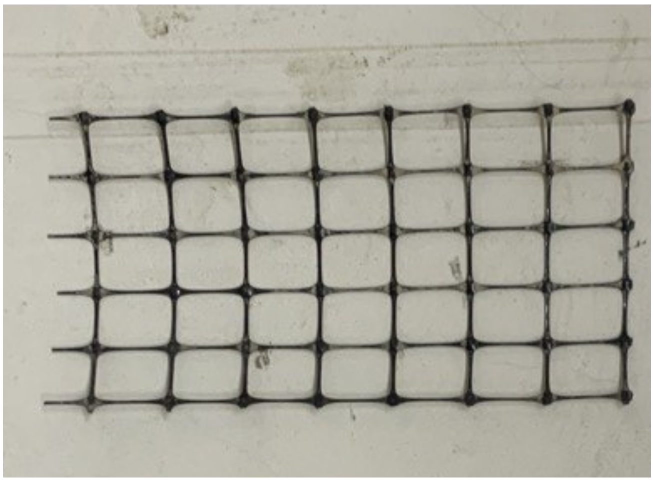

Fig. 4. Geogrid reinforcement (SS2)

Table 5
Dimensional and Physical properties of the SS2 geogrid (Tensar Co.)

Physical properties	Data	
Rib shape	Rectangular	
Color	Black	
Polymer type	SS2	
Polymer	PP	
Dimensional properties	**Unit**	**Data**
Roll length	M	50
Roll width	M	4
Unit weight	Kg/m^2	0.29
Aperture size	mm	28*40
WTR	mm	3
WLR	mm	3
tLR thickness of longitudinal ribs	mm	1.2
tLR thickness of transvers ribs	mm	0.9
(Transversal) Quality control Strength		
Load at 2% strain (3)	KN/m	12
Load at 5% strain (3)	KN/m	23
(longitudinal) Quality control Strength		
Load at 2% strain (3)	KN/m	7
Load at 5% strain (3)	KN/m	14

3. Laboratory Testing Program
3.1 Direct Shear Test

The main purpose of using the direct shear test is to evaluate the shear parameters of the interface surface between clay subgrade and subbase soil with and without geogrid at four different levels of normal applied stresses with different values of water content and degrees of compaction of clay subgrade soil.

The shear parameters are cohesion (C) between clay and subbase soil and angle of friction (φ) in the case without geogrid, while in the case of soil reinforcement by geogrid the parameters are adhesion (Ca) between soil and geogrid and (δ) angle of friction. The shear strength is calculated using equations 1 and 2 without and with geogrid respectively.

$$\tau = c + \sigma\,(\tan\varphi) \tag{1}$$

$$\tau = c_a + \sigma\,(\tan\delta) \tag{2}$$

3.2 Large Size Direct Shear Device

The study uses a large-size direct shear device that is made locally. It is composed of two boxes: the upper half, measuring 20 cm by 20 cm by 10 cm, and the lower part, measuring 20 cm by 25 cm by 10 cm. Throughout the model experiment, the lower part's size is kept greater than the upper part's in order to maintain a constant shearing area.

3.3 Interface Testing Program

A total of 40 tests are performed in a large-scale direct shear device with two types of geogrid for five moisture content (6,8,10,12 and 14%) with maximum dry density (100% degree of compaction), where the normally applied stresses are 25, 50, 75 and 100 kPa respectively for all tests [25]. Also, 24 interface tests are performed with optimum water content and different degrees of compaction (90%, 95% and 98%) with Biaxial and SS2 geogrid. For comparison purposes, the soil was tested at optimum conditions without geogrid.

3.4 Test Setup and Procedure

Components of the used device are horizontal load cells which are used to measure the shear stresses with a maximum capacity equal to 50 kN and two LVDTs (linear variable differential transducers) with a range of ±50 mm. The vertical and horizontal displacement of the sample during the test are measured by the LVDTs. The measurements are automated through a Data Acquisition System (DAQ). During the test, the geogrid is placed between the clay subgrade soil and the subbase. The details of the device are explained in Figure 5. Figure 6 shows some of the photos during the test.

3.5 Failure Criterion

The ASTM D3080 [26] stated that at least a 10% horizontal displacement of the box size should be used to shear the specimen where this would be equal to 20 mm. Shear stress can be obtained either from the peak shear stress value or the shear stress value at the end of the test, while the ASTM D5321 [27], mentioned that the horizontal displacement might be across a 75 mm or any other values reached by the user or the test can be finished as the shear stress is reached. Failure criteria used in this study are based on the peak shear stress [28].

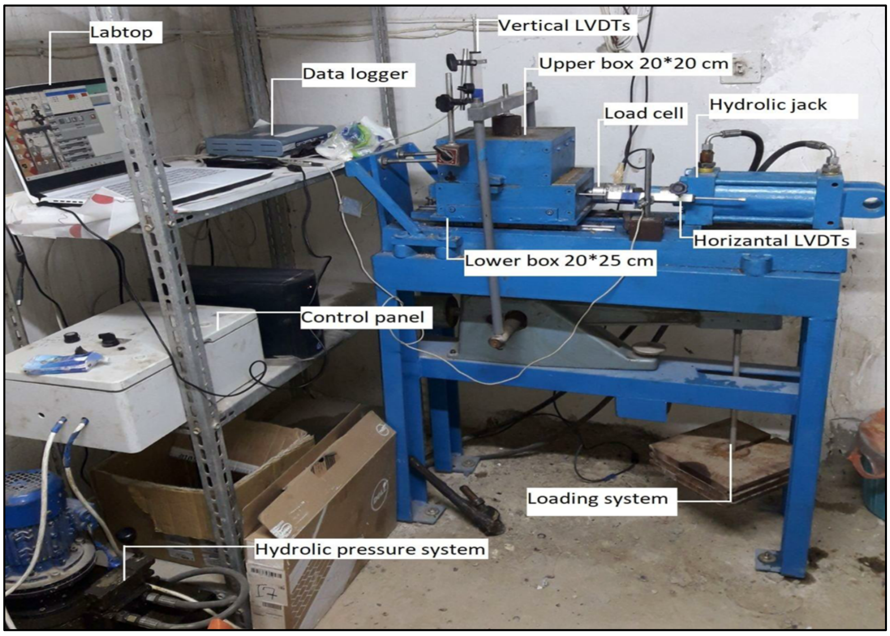

Fig. 5. Large-scale direct shear apparatus

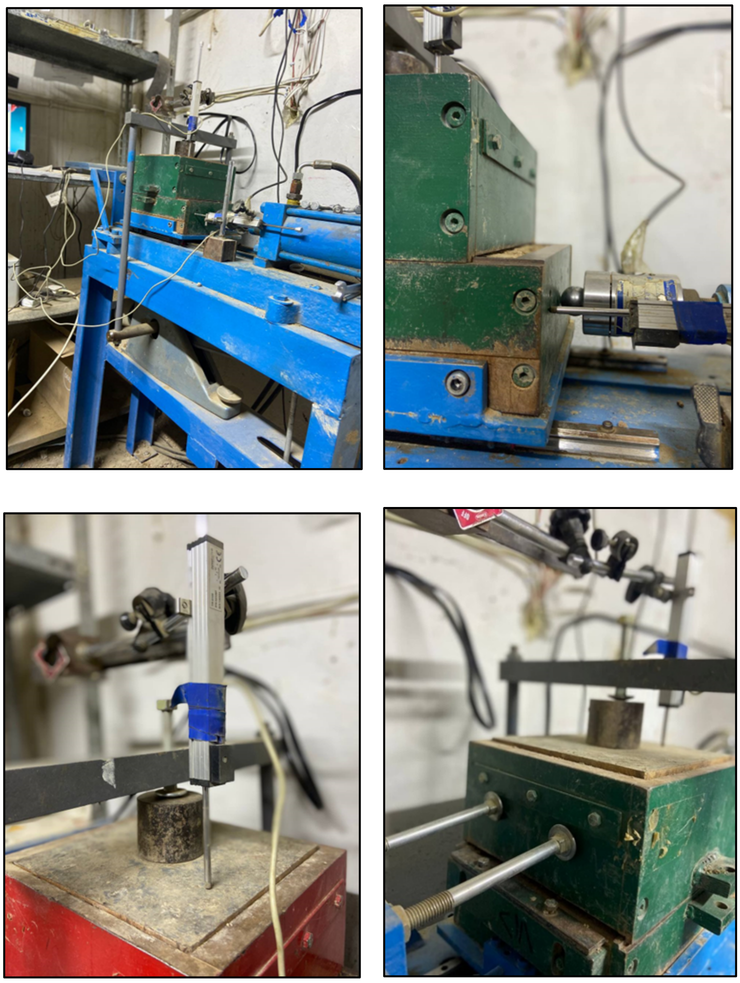

Fig. 6. Experimental setup

Journal of Advanced Research in Applied Sciences and Engineering Technology
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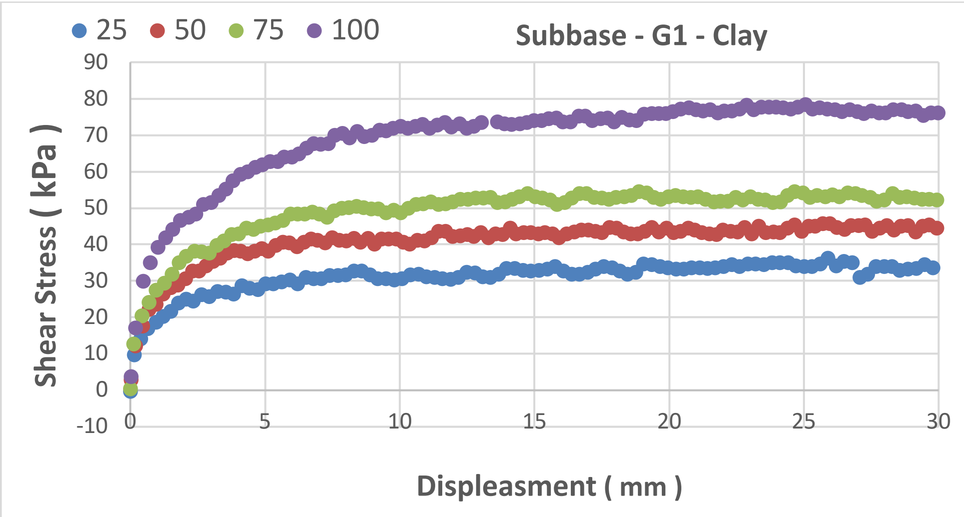
4. Results and Discussion

4.1 Effect of Water Content

The effect of the water content of clay subgrade soil on the interface shear strength is shown in Figures 7 and 8. The soil sample is prepared with maximum dry density (100% degree of compaction) and with different water content (6,8,10,12 and 14%). Maximum dry density and optimum water content are predetermined by the standard protector test and equal to 1.88 gm/cm^3 and 10% respectively. Figures 7 and 8 explain the relationship between the shear stress and displacement for clay subgrade and subbase soil with two types of geogrid (G1 and G2). For each test, the normal stresses are (25, 50, 75 and 100) kPa. The shear strength parameters (angle of friction and adhesion) are shown in Tables 6 and 7.



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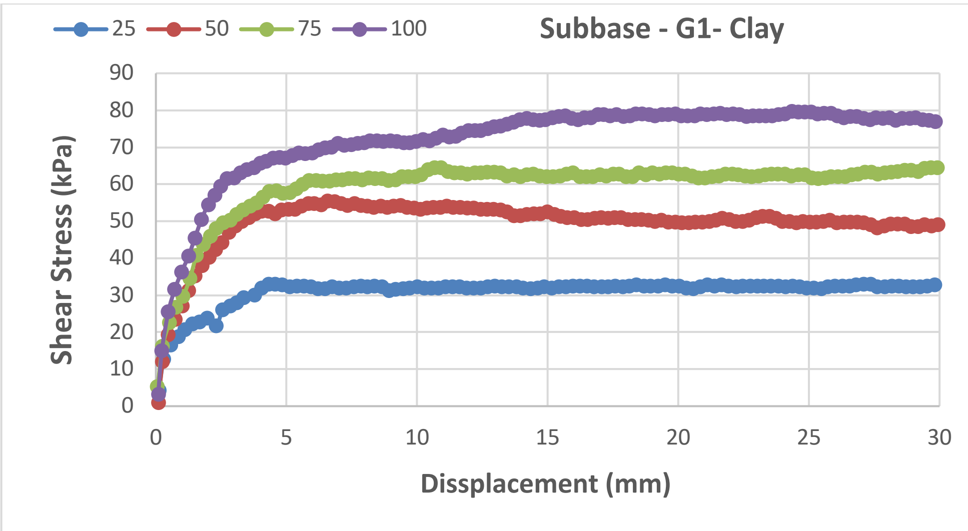

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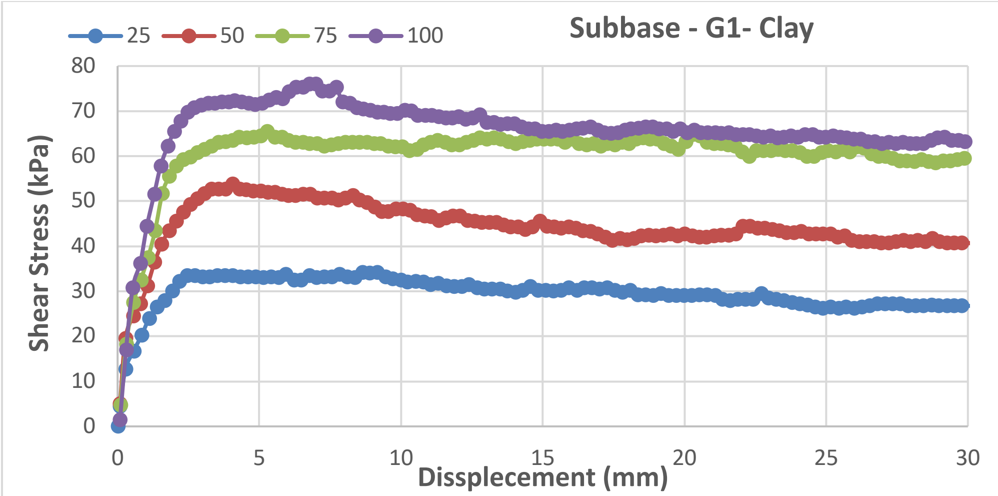

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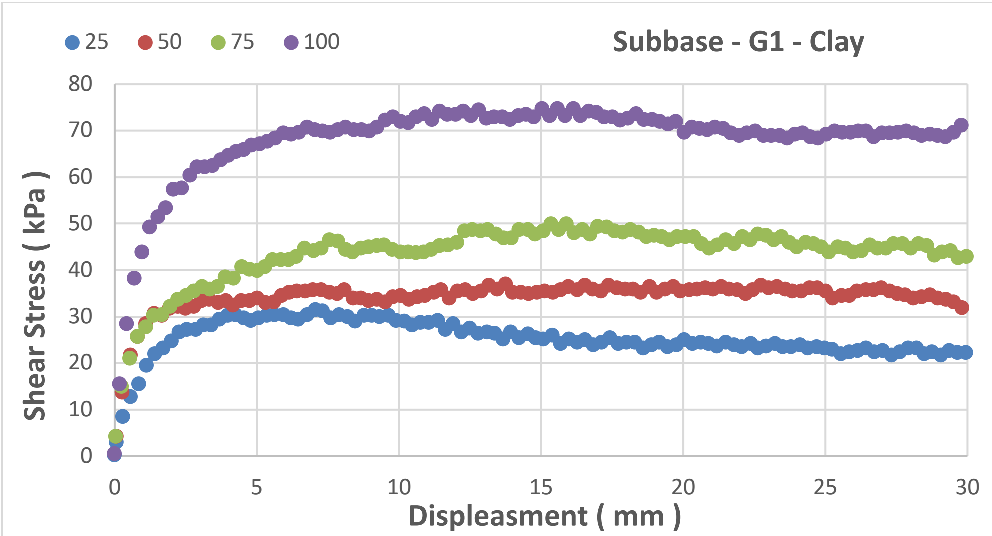

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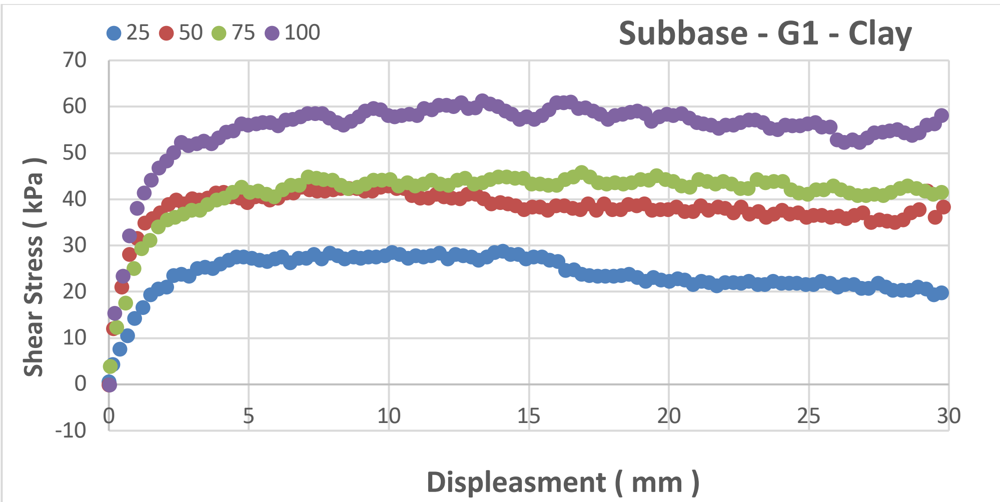

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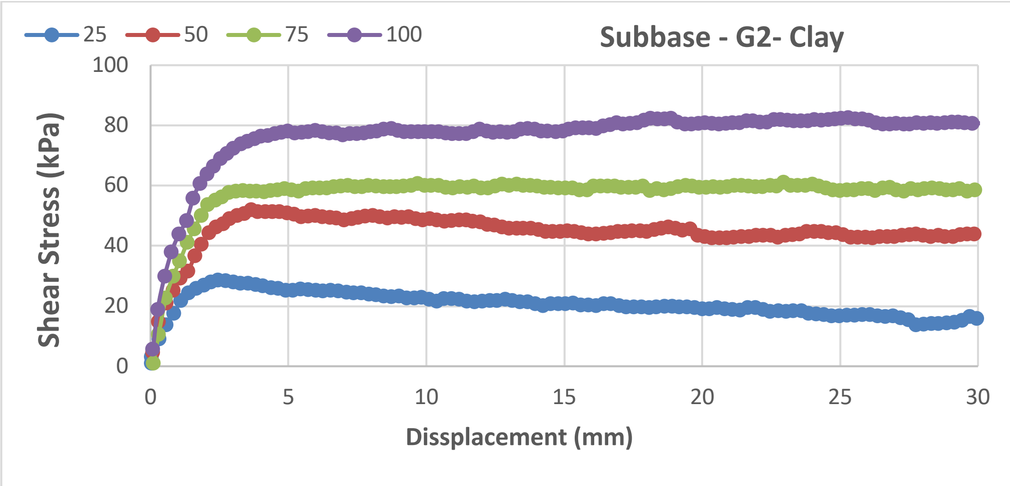
Fig. 7. Shear stress with displacement for 100% degree of compaction and water content (6,8,10,12 and 14% respectively) with G1

From the above results, the values of shear strength increase with increasing normal stress and decrease with increasing water content for all tests. The maximum value of shear strength is observed in the dry side optimum water content specifically at water content equal to 8% after this value the shear strength trends to drop until reaching the minimum value at water content equal to 14%. The reduction in the values of shear strength (difference between the upper and lower value of shear strength at 8% and 14% water content respectively) for 100 kPa normal stress equals 25% for clay-G1-subbase and 21% for clay-G2-subbase. This is attributed to the development of excess pore water pressure and decreasing the matric suction of clay soil [29-32].



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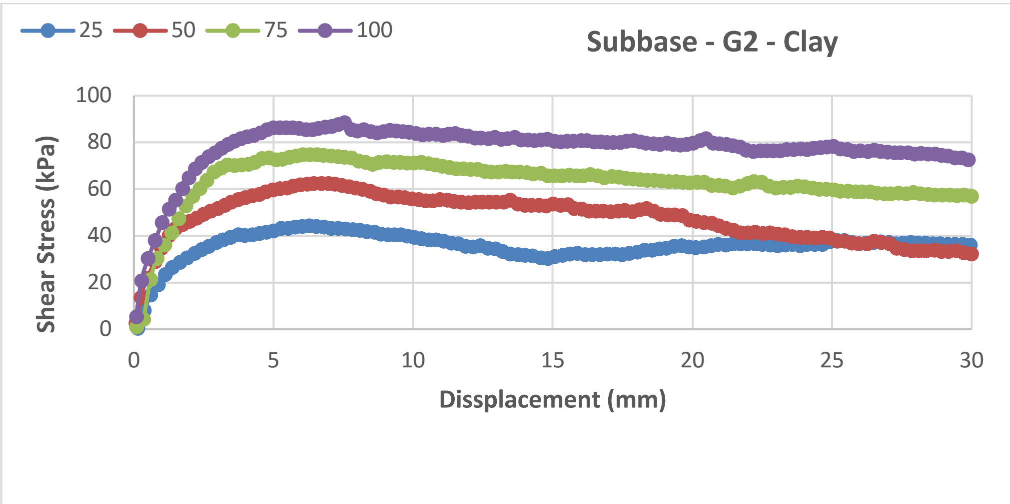

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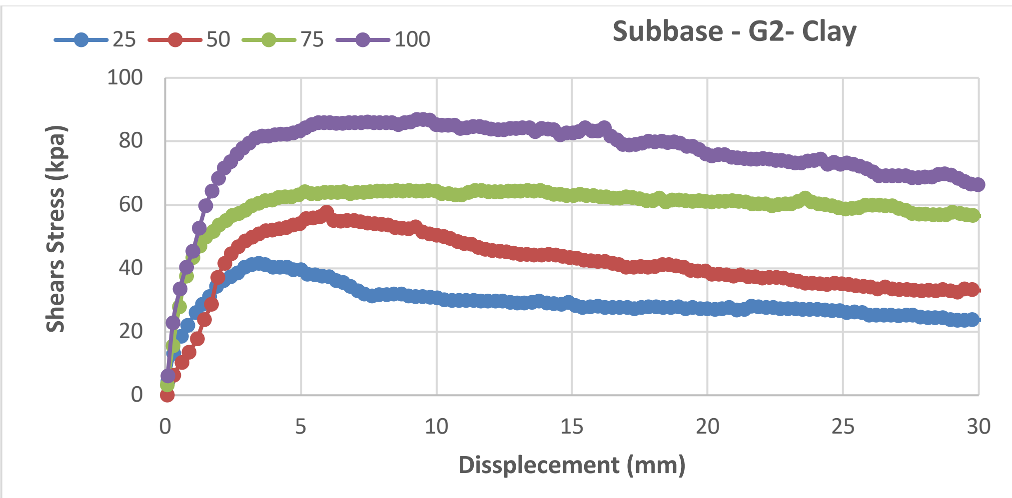

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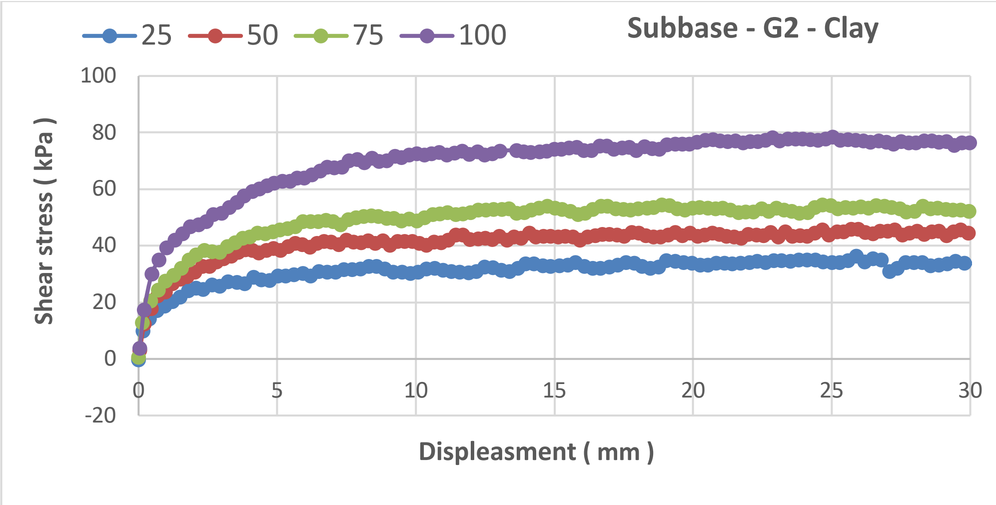

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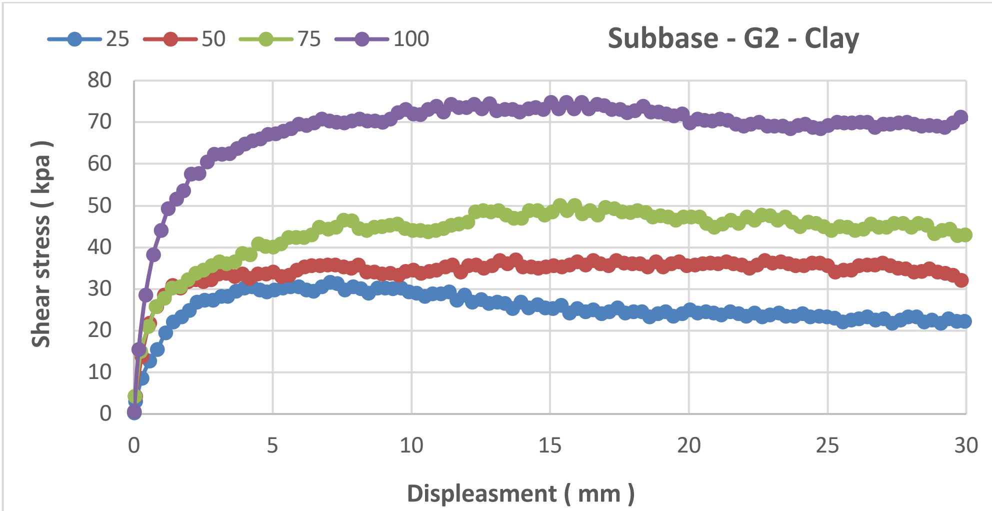

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Fig. 8. Shear stress with displacement for 100% degree of compaction and water content (6,8,10,12 and 14% respectively) with G2

4.2 Effect of Degree of Compaction

Figures 9 and 10 show the effect of the degree of compaction of clay subgrade soil on the interface shear strength. Soil sample is prepared with optimum water content and with different degrees of compaction of clay soil (90%,95% and 98%). For each test, the applied normal stresses are (25, 50, 75 and 100) kPa. The shear strength parameters are shown in Tables 8 and 9 with G1 and G2. The obtained results illustrate that the behaviour of shear stress failure envelopes is similar for both cases clay-G1-subbase and clay-G2-subbase. The shear strength increases by increasing the degree of compaction of clay soil, where, when the last one reaches 95% the shear strength starts to decrease after this value. The significant variance in the interface shear resistance value resulting from changes in soil density demonstrated the significance of quality control in reinforced soil to guarantee the intended interface behaviour.

Table 6
Shear properties with different water content and 100% degree of compaction with G1

State	Density	W%	σ	τ	c	δ
Clay-G1-Subbase	1.88	6%	25	25	12	28
			50	39		
			75	52		
			100	65		
		8%	25	36	21	32
			50	52		
			75	68		
			100	83		
		10%	25	37	23	29
			50	51		
			75	65		
			100	79		
		12%	25	27	12.5	30
			50	41		
			75	56		
			100	70		
		14%	25	30	19.5	23.4
			50	41		
			75	52		
			100	62		

Table 7: Shear properties with different water content and 100% degree of compaction with G2

State	Density	W%	σ	τ	c	δ
Clay-G2-Subbase	1.88	6%	25	31	13	35.7
			50	49		
			75	67		
			100	85		
		8%	25	46	31	30.5
			50	61		
			75	75		
			100	90		
		10%	25	42	27	31.1
			50	57		
			75	72		
			100	87		
		12%	25	34	20	29.4
			50	48		
			75	62		
			100	76		
		14%	25	27	13	30
			50	42		
			75	56		
			100	71		

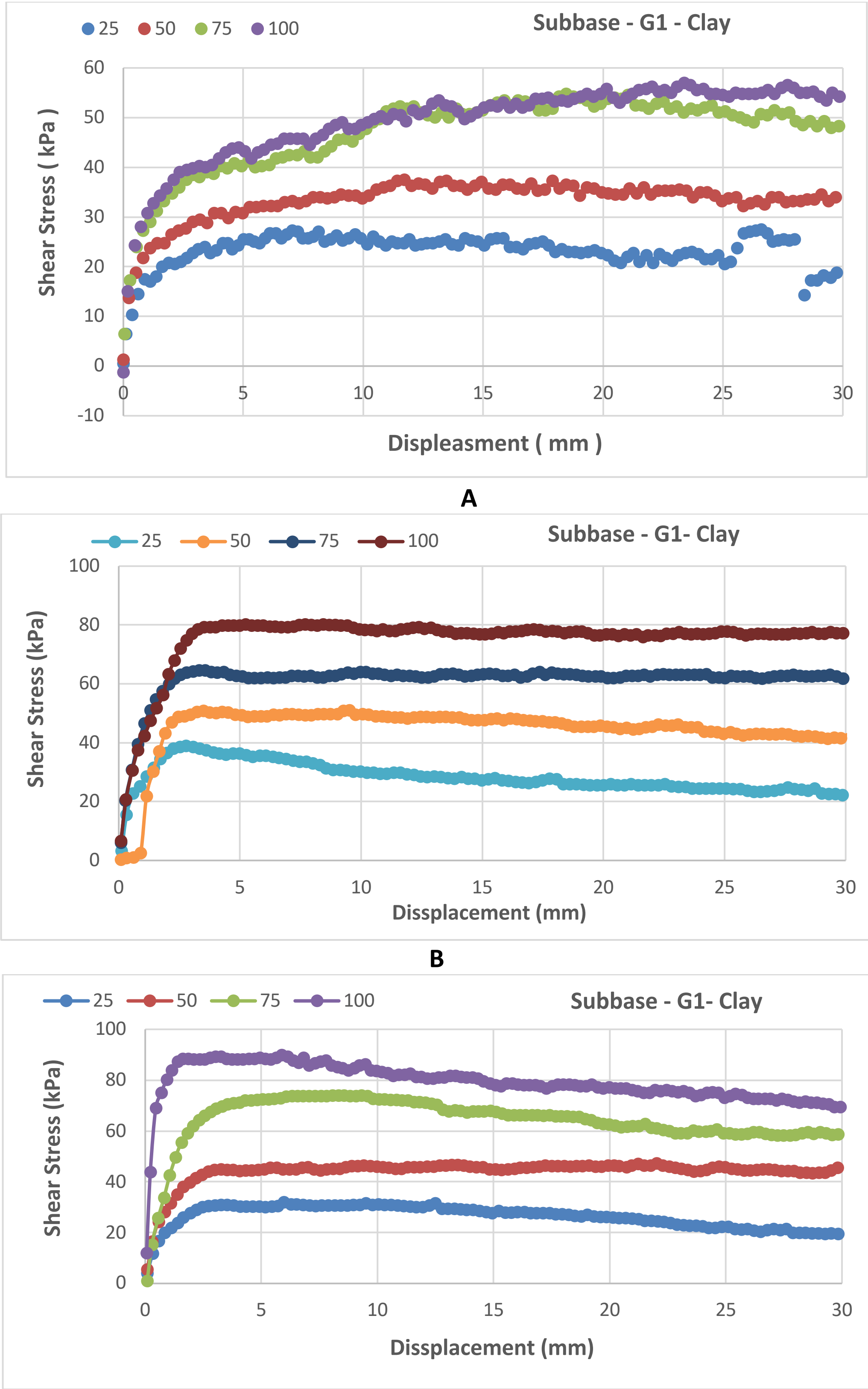

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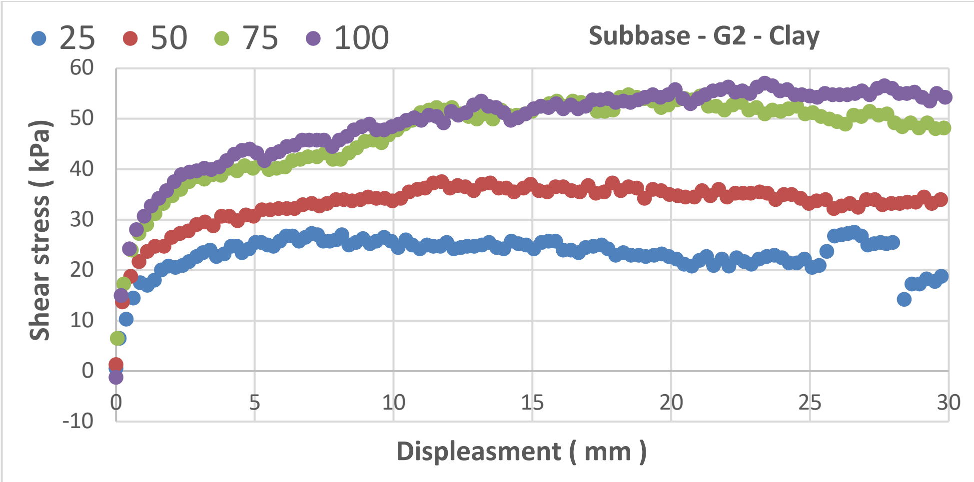
Fig. 9. Shear stress with displacement for 10% water content and degree of compaction (90%, 95% and 98 respectively) with G1



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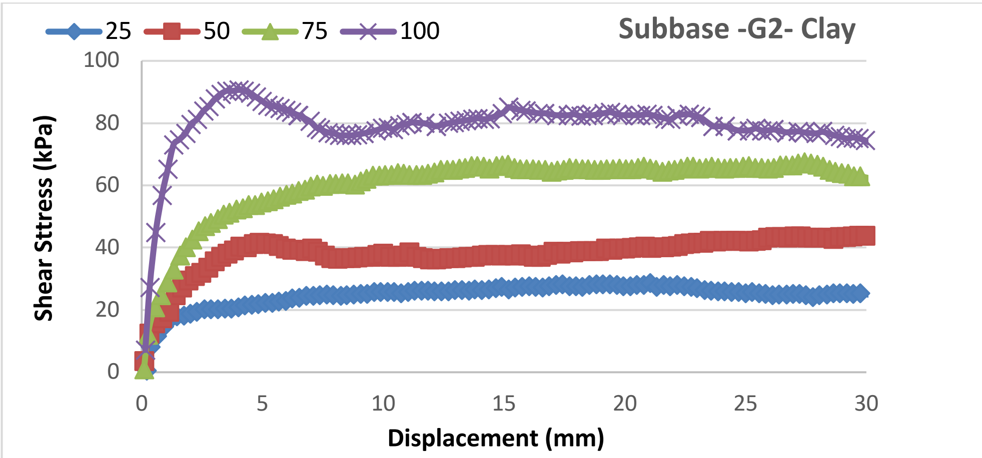

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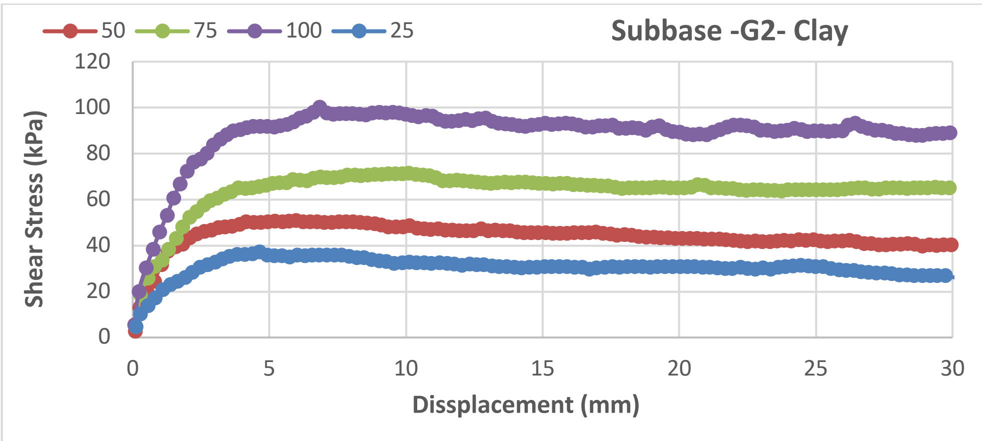

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Fig. 10. shear stress with displacement for 10% water content and degree of compaction (90%, 95% and 98% respectively) with G2

Table 8
Shear properties with different degrees of compaction and optimum water content with G1

Sate	W%	Degree of Compaction	σ	τ	c	δ
Clay -G1- Subbase	10%	90%	25	28	18	21.5
			50	37		
			75	48		
			100	57		
		95%	25	40	22	36
			50	58		
			75	77		
			100	95		
		98%	25	30	11	37.7
			50	50		
			75	69		
			100	88		

Table 9
Shear properties with different degrees of compaction and optimum water content with G2

Sate	W%	Degree of Compaction	σ	τ	c	δ
Clay –G2- Subbase	10%	90%	25	29	18	22
			50	38		
			75	49		
			100	58		
		95%	25	41	20	39.7
			50	62		
			75	82		
			100	103		
		98%	25	34	13	40
			50	55		
			75	76		
			100	97		

4.3 Effect of Types of Geogrid

The effect of types of geogrid used in this study is shown in Figure 11 which shows the relationship between normal stress and shear stress for different states (clay-subbase, clay-G1-subbase and clay-G2-subbase) at optimum water content and maximum dry density. From the results of Figure 11, the shear strength of clay- G1- subbase is higher than the shear strength of clay- G2-subbase and this is explained further in Table 10. The average value of the shear interaction coefficient for the clay-G1- subbase equals 0.77 while it is 0.86 for the clay-G2- subbase. This means that the Biaxial geogrid BX1100 (G1) is more efficient in reinforcing this type of soil because it has a percent open area higher than the SS2 geogrid (G2). It is widely accepted that when the soil is reinforced by a geogrid, the development of the internal soil resistance in the apertures of the geogrid leads to an increase in the overall interface resistance in direct shear mode [6,14,15].

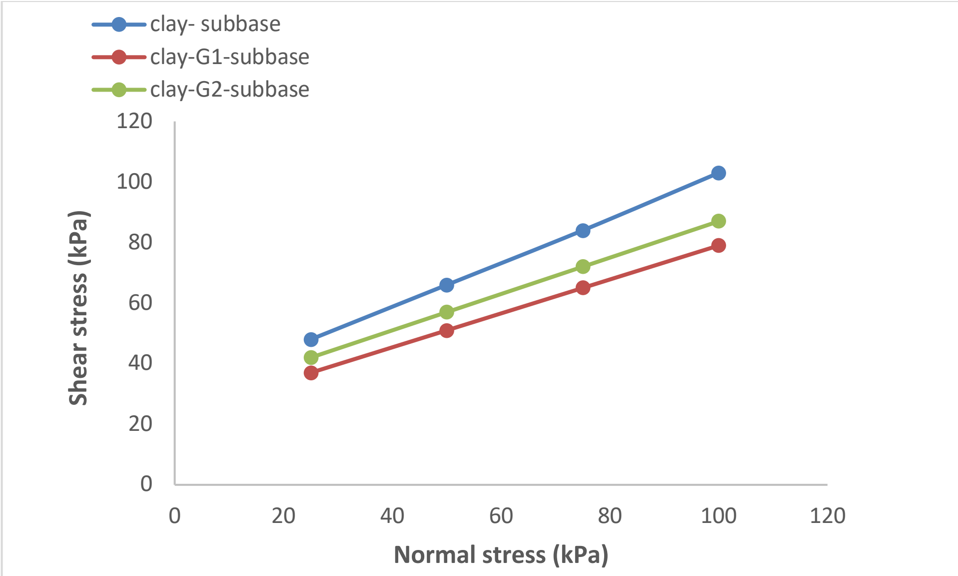

Fig. 11. Peak shear envelope of the soil at optimum state

4.4 Interaction Coefficient of Reinforcement

The relationship between the interface shear strength of reinforced soil (τ reinforced) and the shear strength of unreinforced soil (τ unreinforced) at the same normal applied stress is known as the interaction coefficient (`). Equation three is used to get the reinforcement's interaction coefficient.

$$\eta = \tau_{reinforced} / \tau_{unreinforced} \tag{3}$$

when the interface efficiency (η >1) value is higher than unity, it indicates that the soil and geogrid have a strong enough link, meaning that the interface shear strength between them is higher than the soil's shear strength in the absence of the geogrid. In 1998, according to Tatlisoz *et al*. [33], when the interface efficiency value is greater than 1, soil-geosynthetic interlocking must mobilize a significant bearing capacity resistance; conversely, when the interface efficiency value is less than 0.5, a weak bonding between the soil and geogrid forms. Table (10) shows the values of the shear interaction coefficient (interface efficiency) for clay -G1-subbase soil and clay–G2-subbase soil with optimum water content and maximum dry density (for comparison purposes) at normal applied stresses equal to (25, 50, 75 and 100) kPa. The value of the shear interaction coefficient varies from 0.761 to 0.787 for the Biaxial Geogrid BX1100 (G1) while it varies from 0.844 to 0.875 for the SS2 geogrid (G2) and this means that there is a good bonding between clay subgrade soil and geogrid. The shear interaction coefficient varies with the level of normal stress and type of geogrid. These results agree with the observation by Koutsourais *et al*. [34].

As a result, the interface shear strength increases by increasing the density and it reaches to the maximum value at degree compaction of 95% and then starts to drop gradually after this value, while its value decreases by increasing water content. This reduction in the value of shear strength is due to the decrease in soil suction (clay subgrade soil) that concurrently occurs with increasing water contents, and the possible development of excess pore water pressure in near saturated clays. These results illustrate that the soil-geogrid interface shear strength is improved considerably when the backfill material compacted at the dry side of the optimum moisture content as compared with that when the optimum value is adopted.

Table 10
Shear interaction coefficient for clay subbase soil with and without G1 and G2 at optimum state

State	Density	W%	σ	τ	c	δ	η
Clay – Subbase	1.88	10%	25	48	30	36	---
			50	66			
			75	84			
			100	103			
Clay – G1- Subbase			25	37	23	29	0.770
			50	52			0.787
			75	64			0.761
			100	79			0.769
Clay – G2- Subbase			25	42	27	31	0.875
			50	57			0.863
			75	72			0.857
			100	87			0.844

5. Conclusions

This study presents a testing large direct shear program to explain the effect of water content and degree of compaction of clay subgrade soil on the shear properties interaction between subgrade and subbase soil using two types of geogrid at different conditions. The following conclusions of this study are found below.

1. A direct relationship between normal stresses and interface shear strength is formed where the last one increases by increasing the normal applied stresses following a similar trend.
2. The interface shear properties are affected by the water content of subgrade soil, where the shear strength increases with water content decreasing. The maximum value of shear strength is observed in the dry side optimum water content specifically at water content equal to 8% after this value the shear strength trends to drop until reaches to minimum value at water content equal to 14%.
3. The reduction in the value of shear strength due to increasing water content from 8% to 14% for 100 kPa normal stress equals 25% for clay-G1-subbase and 21% for clay-G2-subbase.
4. The increase in moisture content of clay soil causes the reinforcement efficiency to be lesser due to the development of excess pore water pressure and decreasing the matric suction of clay soil, which reduces the effective normal stress and the interface shear strength.
5. The interface shear strength is obviously affected by the degree of compaction of clay subgrade soil, with a maximum value obtained at a 95% compaction degree.
6. The value of the shear interaction coefficient varies from 0.761 to 0.787 for the Biaxial geogrid BX1100 (G1) while it varies from 0.844 to 0.875 for the SS2 geogrid (G2). The Biaxial geogrid BX1100 is more efficient than the SS2 geogrid to reinforce clay subgrade and subbase soil for all conditions of water content and degree of compaction of clay soil as well as normal applied stresses.
7. To enhance the pavement performance, it suggests that the compaction of clay subgrade soil at 95% maximum dry density (dry side) and the optimum moisture content 2% lower than the optimum value for biaxial and SS2 geogrid.

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