Behavior of Soils Strengthened By Plastic Waste Materials

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Abstract :

The amount of wastes has increased year by year and the disposal becomes a serious problem. Particularly, recycling ratio of the plastic wastes in life and industry is low and many of them have been reclaimed for the reason of unsuitable ones for incineration. It is necessary to utilize the wastes effectively with technical development in each field.

This study presents a simple way of recycling plastic waste in the field of civil engineering as reinforcing material. Reinforced soil construction is an efficient and reliable technique for improving the strength and stability of soils. The technique is used in a variety of applications, ranging from retaining structures and embankments to subgrade stabilization beneath footings and pavements.

This paper describes an experimental study on mixing plastic waste pieces with two types of soil (clayey soil and sandy soil) at different mixing ratios (0,2,4,6,8)% by weight respectively. For the two types of soils, the shear strength parameters (cohesion value and angle of internal friction) of reinforced and unreinforced samples were investigated by the direct shear test. In addition, a series of compaction tests were performed on clayey soil mixed with different percentages of waste pieces. It was found that, there is significant improvement in the strength of soils due to increase in internal friction. The percentage of increase in the angle of internal friction for sandy soil is slightly more than that in clayey soil, but there is no significant increase in cohesion for the two types of soils. Also, it was concluded that the plastic pieces decreases the maximum dry density of the soil due to their low specific gravity and decreases the optimum moisture content.

Keywords: soil improvement, plastic waste, shear, compaction.

سلوك الترب المقواة بمخلفات المواد البلاستكية

المدرس المساعد مها حاتم نصيف
الجامعة التكنولوجية – قسم هندسة البناء والانشاءات

الخلاصة :

ان كمية المخلفات في تزايد مستمر سنة تلو الأخرى ورميها أصبح مشكلة جدية. خصوصا وان نسبة أعادة التدوير للمخلفات البلاستيكية في الحياة والصناعة واطئة والكثير منها أصبح يسترد بسبب عدم ملائمتها للحرق. من الضروري استخدام المخلفات بصورة كفؤة مع تطور التقنيات في كل حقل. تعرض هذه الدراسة طريقة بسيطة لأعادة استخدام المخلفات البلاستيكية في مجال الهندسة المدنية كمادة تسليح. انشاء الترب المسلحة تقنية كفوءة وموثوق بها

لتحسين مقاومة واستقراريه الترب. استخدمت هذه التقنية في تطبيقات مختلفة مثل المنشآت الساندة والسدود الترابية والطبقات تحت الاسس والارصفة.

يصف هذا البحث دراسة تجريبية لخلط قطع مخلفات بلاستيكية مع نوعين من الترب (تربة طينية وتربة رملية) وبنسب وزنية مختلفة (0,2,4,6,8) %. ولنوعين من الترب تم دراسة معاملات مقاومة القص (التماسك وزاوية الاحتكاك الداخلي) للترب المسلحة وغير المسلحة بواسطة فحص القص المباشر. وبالإضافة لذلك تم أنجاز سلسلة من فحوصات الرص القياسي على التربة الطينية مع نسب مختلفة من المخلفات البلاستيكية.

لقد وجد ان هناك تحسن ملحوظ في مقاومة الترب نتيجة زيادة زاوية الاحتكاك الداخلي . ان نسبة الزيادة في زاوية الاحتكاك الداخلي للتربة الرملية أكبربقليل من نسبة الزيادة في زاوية الاحتكاك الداخلي للتربة الطينية ولكن لا توجد زيادة ملحوظة في قيمة تماسك التربة لكلا النوعين من التربة. استنتج ان المواد البلاستيكية قللت قيمة الكثافة الجافة العظمى نتيجة الكثافة الواطئة للمادة البلاستيكية و قللت ايضا محتوى الرطوبة الامثل.

1. Introduction :

For the construction of any kind of structure resting on weak soil, there are many available methods used to improve the bearing capacity and reduce the settlement of such soils. One of these methods is using reinforcement.

Reinforced soil is a construction material that consists of soil fill strengthened by a variety of tensile inclusions ranging from low-modulus, polymeric materials to relatively stiff, high-strength metallic inclusions. These tensile inclusions come in many forms ranging from strips and grids to discrete fibers and woven and non-woven fabrics. The soil and reinforcing element will interact by means of frictional resistance. Appropriate selection of the type and location of the reinforcement material is necessary in order to achieve optimum improvement.

In the recent years, several researchers are trying to develop solutions for the reuse of different types of wastes generated which has become one of the major challenges for the environmental issues in many countries. Wastes such as plastic waste mixed with soil behave similar to fiber-reinforced soils and several researchers presented technique of using discrete fibers to enhance the strength of soil.

Gray and Al-Refeai (1986) [1] described testing carried out on fabric-reinforced and fiber-reinforced soil. The fibers used included reed fibers and glass synthetic fibers and the fabrics included commercially available geotextiles. The results showed that the strength increase in the soil was generally proportional to the amount of reinforcement, but the strength increase eventually reached a limiting value.

Maher and Gray (1990) [2] described how the type of fiber and sand properties affected the strength and deformation of the fiber-reinforced sand. A model developed by the authors was compared with results from triaxial tests, and it was shown that the strength and deformation of the fiber-reinforced sand was predictable. The results showed that an increase in the size of the particles lowered the fiber contribution to strength.

Consoli et. al. (2002) [3] performed unconfined compression tests, splitting tensile tests, and saturated drained triaxial tests in order to determine the effects of adding randomly distributed polyethylene terephthalate fiber (from waste plastic bottles) to uniform fine sand.

The results indicated that the addition of the fibers increases the peak and ultimate strength of the soil.

Naeini and Sadjadi (2008) [4] investigated the effect of plasticity index and fiber content on the shear strength parameters (c and Φ) of randomly distributed fiber-reinforced soil by performing direct shear tests .The results have clearly shown a significant improvement in the shear strength parameters (c and Φ) of the treated soils. The reinforcement benefit increased with an increase in fiber contents

Choudhary et al. (2010) [5] studied the feasibility of reinforcing soil with strips of reclaimed high density polyethylene (HDPE). Strips of HDPE were mixed with local sand and tested to determine CBR values and secant modulus. The tests showed that reinforced sand with waste HDPE strips enhances its resistance to deformation and its strength.

Babu and Chouksey (2011) [6] investigated the effects of plastic waste from waste water bottles as reinforcing material mixed with soil. Series of triaxial compression (UCC & CU) and one dimensional compression tests have been performed with various percentages of plastic waste. The experimental results are presented in the form of stress–strain-pore water pressure response and compression paths. The experimental results showed that there is a significant improvement in the strength of soil with inclusion of plastic waste and significant reduction in compression parameters.

Rao and Dutta (2004) [7] assessed the overall influence of waste plastic as a reinforced material on the bearing capacity improvement of granular trench. The results of conventional drained triaxial compression tests conducted on 100 mm diameter x 200 mm high specimens of sand with two types of waste plastics were presented. It was concluded that inclusion of waste plastic strips in sand improves the bearing capacity of granular trench.

2. Materials Used :

Three materials are used in this study,

- Sandy soil
- Clayey soil
- Plastic waste material

2.1. Sandy Soil

Standard tests are conducted to obtain the physical properties of sandy soil:

Grain size distribution :

Standard test for grain size analysis of soil particles was performed according to **(ASTM D422–02)** [8] procedure. The grain size distribution curve of the soil sample is shown in Figure (1). The sand is classified according to the Unified Soil Classification System (USCS), as poorly graded sand (SP) with coefficients of uniformity (Cu) and curvature (Cc) 3.92 and 1.43, respectively.

Specific gravity :

The standard test for specific gravity of soil particles is performed according to (**ASTM D854-02)**[9] procedure by using water pycnometer method. The specific gravity (Gs) of the sand is (2.66).

Maximum and minimum dry unit weights :

The standard test for maximum unit weight of soil is performed according to **(ASTM D4253-00)**[10] procedure by using a vibratory table method. The maximum dry unit weight of sand ($\gamma_{d\ max}$) is found to be (19) kN/m^3.

The standard test for minimum unit weight of soil is performed according to **(ASTM D4254-00)**[11] procedure, where the minimum dry unit weight of sand ($\gamma_{d\ min}$) is found to be (15.6) kN/m^3. Maximum and minimum void ratio (e_{max} & e_{min}) of the sand can be estimated from the minimum and maximum dry unit weights which are found to be (0.67) and (0.37) respectively.

Direct shear test :

The angle of internal friction (Φ) for the sand is obtained from the direct shear test according to **ASTM (D3080)**[12] procedure and found to be (36.7°).

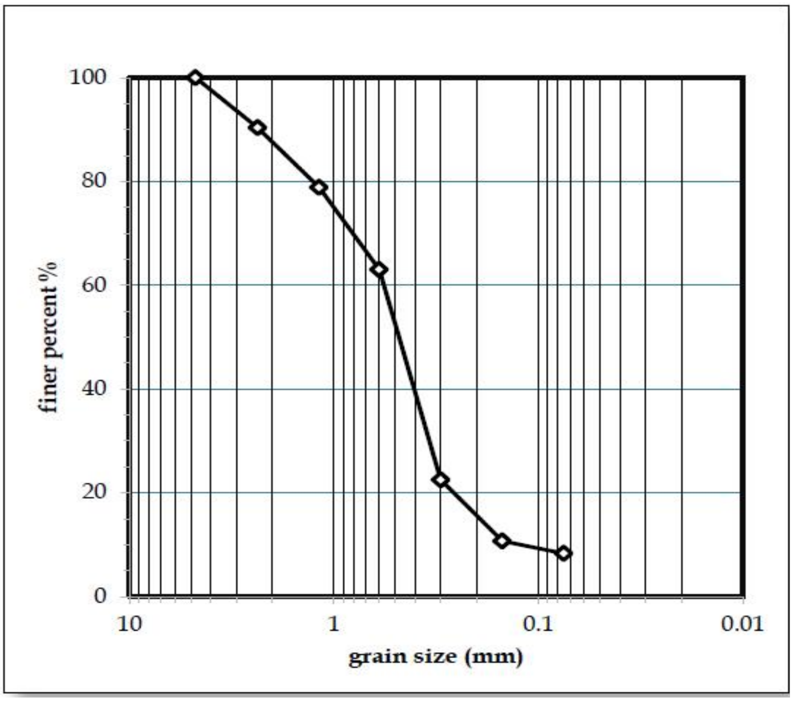

Fig.(1). Grain size distribution for the sandy soil.

2.2. Clayey Soil

In this study, a disturbed sample was taken from Al-Nahrawan site, located at 35 kilometers southeast of Baghdad, Table (1) shows the physical properties results of the clayey soil.

2.3. Plastic Waste Material

The material used throughout this study as plastic waste is brought from the General Company for Plastic Industries in Baghdad. This material is one of bad products, and it is cut in the same company. The type of this material is polyethylene with specific gravity of 0.93. The plastic is cut into circular pieces (1-2)mm diameter and 5mm thick.

Table(1): Physical Properties of the Clayey Soil.

Physical properties	Index value	Standards
Specific gravity (Gs)	2.7	ASTM: D 854 -02
Liquid Limit (L.L. %)	41	ASTM: D 4318-00
Plastic Limit (P.L. %)	22	ASTM: D 4318-00
Plasticity Index (P.I. %)	19	ASTM: D 4318-00
Sand(%)	16	
Silt(%)	34	
Clay(%)	50	
Maximum dry unit weight (kN/m^3)	17.8	ASTM: D698
Optimum moisture content (%)	16.68	ASTM: D698
Soil Classification (USCS)	CL	ASTM: D2487-00

3. Test Procedure :

3.1 Direct shear test

The experimental study involved performing a series of laboratory direct shear tests on the two types of soil with different percentages of plastic waste materials. A calibrated proving ring of (2 kN) capacity and (0.01) dial gauge for horizontal deformation is used. The rate of strain is (1 mm/min); all specimens are prepared with a size of (60 *60 *20) mm. The test was conducted with various normal stress of 27, 55 and 111 kPa, so that the cohesion and angle of internal friction could be obtained.

For sandy soil, all the samples were prepared at a density of 17 kN/m^3.

The clayey soil was dried before using in the mixtures. At first the required amounts of clayey soils and waste reinforcement material were blended together under dry conditions. As the fibers tended to lump together, considerable care and time were spent to get a homogeneous distribution of the plastic pieces in the mixtures. Then all the test specimens were compacted at their respective maximum dry unit weight and optimum moisture content (OMC), corresponding to the values obtained in the Standard Proctor Compaction Tests.

3.2 Compaction test

A series of laboratory compaction tests were performed on clayey soil according to (ASTM D698) procedure. This test was performed for two purposes, first to obtain the clayey soil samples on the optimum moisture content that shall be used in direct shear test and the second to investigate the effect of inclusion of plastic waste pieces in the soil on the maximum dry density and optimum moisture content.

4. Results and Discussion :

Figures (2 to 11) show the plots obtained from direct shear test represented by shear stress versus normal stress from which the shear strength parameters are obtained. Table (2) summarizes the results of direct shear test on the soil mixes.

From the results, it can be found that the cohesion of sandy soil is ranging from (0 kPa) of unreinforced soil to (4 kPa) of a soil reinforced by (8%) plastic pieces while the cohesion of clayey soil ranging from (53) of unreinforced soil to (54 kPa) of a soil reinforced by (8%) plastic pieces. It can be noticed that the addition of plastic pieces to two types of soils does not increase the cohesion of soils significantly, this may be due to the separation of clay particles by plastic pieces. This conclusion disagrees with the findings of Naeini and Sadjadi 2008, this may be attributed to the difference in the material properties which are used in the two works.

The angle of internal friction (**Φ**) increases considerably with inclusion of different percentages of plastic pieces for sandy and clayey soils, this may be attributed to the increase in the friction surfaces between the plastic pieces and the soil particles where the surface area of plastic pieces is greater than of that of the soil particles.

The percentage of increase in friction angle for sandy soil which ranges from (13.5%) to (48.6%) is slightly more than that in clayey soil which ranges from (14.2%) to (52.3%). This behavior may be belong to the different shapes of particles between clay and sand.

From **figure (12)** , it can be noticed that the variation of friction of clayey soil with percentage of plastic content is a nonlinear variation and similar trend is found in sandy soil as shown in **figure(13).** The non linear behavior may be due to distribution of plastic pieces at different directions to shear surface.

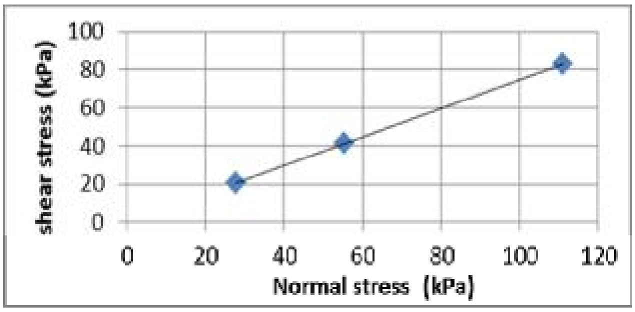

Fig.(2) shear stress-normal stress relationship of unreinforced sandy soil.

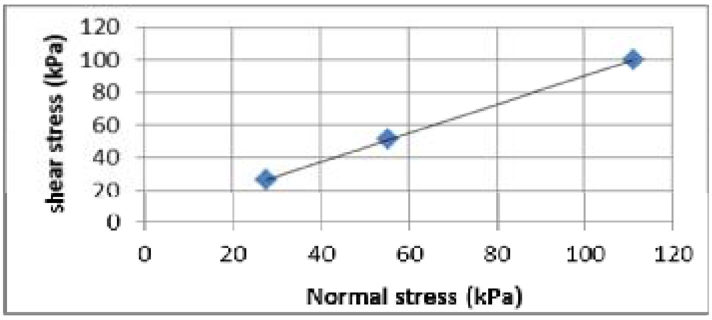

Fig.(3) shear stress-normal stress relationship of a sandy soil reinforced by 2% waste plastic.

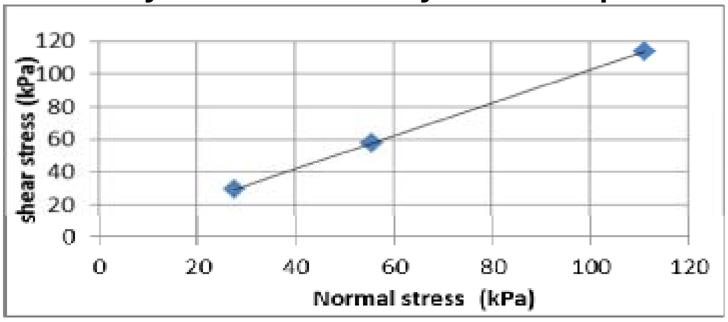

Fig.(4) shear stress-normal stress relationship of a sandy soil reinforced by 4% waste plastic.

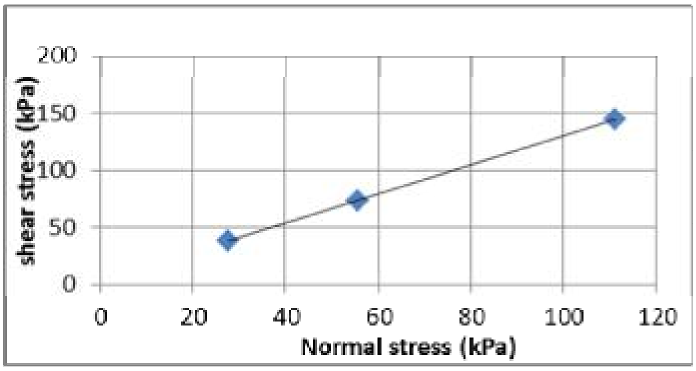

Fig.(5) shear stress-normal stress relationship of a sandy soil reinforced by 6% waste plastic.

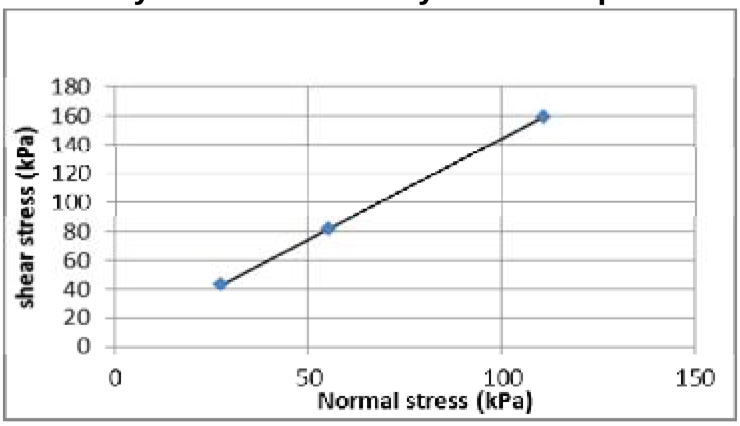

Fig.(6) shear stress-normal stress relationship of a sandy soil reinforced by 8% waste plastic.

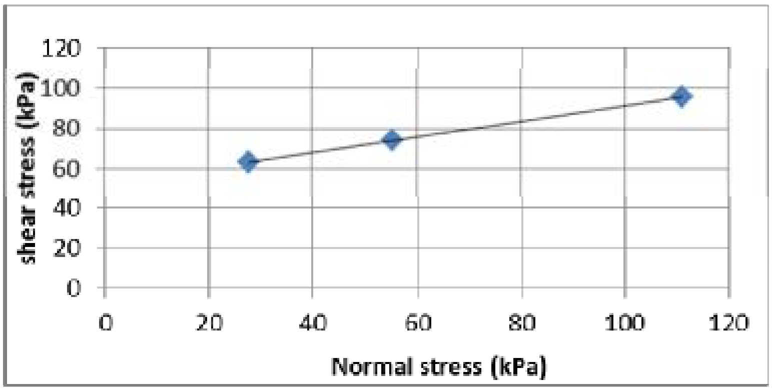

Fig.(7) shear stress-normal stress relationship of unreinforced clayey soil.

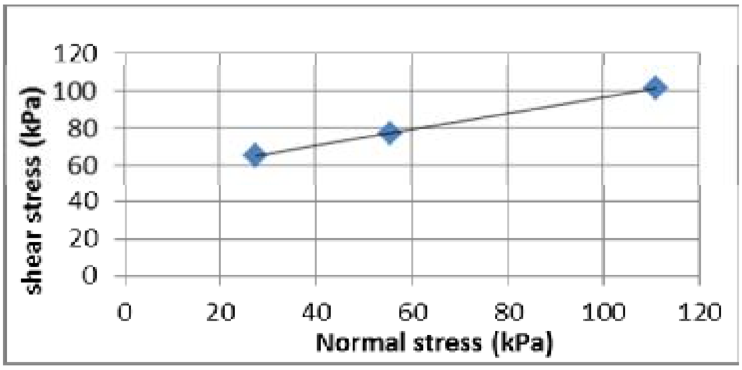

Fig.(8) shear stress-normal stress relationship of a clayey soil reinforced by 2% waste plastic

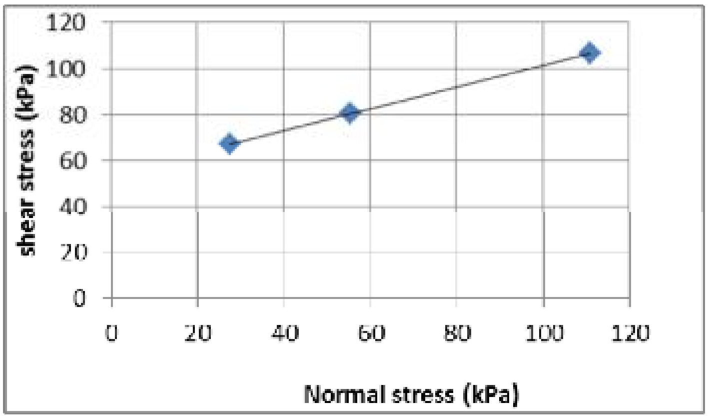

Fig.(9) shear stress-normal stress relationship of a clayey soil reinforced by 4% waste plastic.

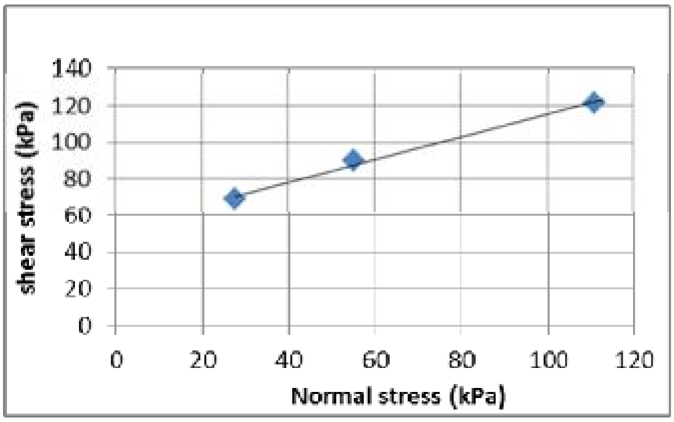

Fig.(10) shear stress-normal stress relationship of a clayey soil reinforced by 6% waste plastic.

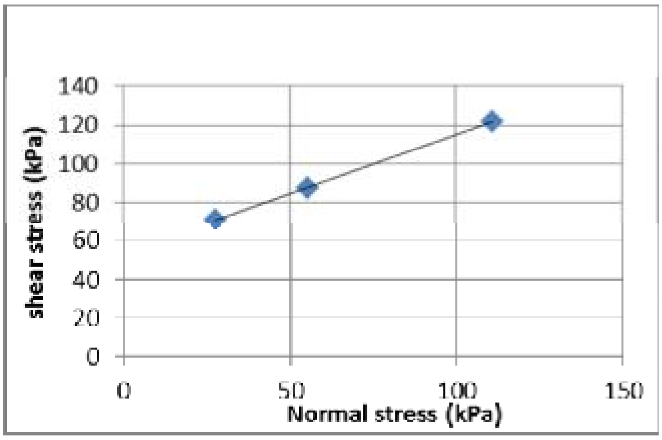

Fig.(11) shear stress-normal stress relationship of a clayey soil reinforced by 8% waste plastic.

Table (2): Results of Direct Shear Test on the Soil Mixes

Type of soil	Plastic waste content (%)	Cohesion (kPa)	friction angle Φ(degrees)
Sandy soil	0	0	37
	2	2	42
	4	2	45
	6	3	52
	8	4	55
Clayey soil	0	53	21
	2	53	24
	4	54	25
	6	54	30
	8	54	32

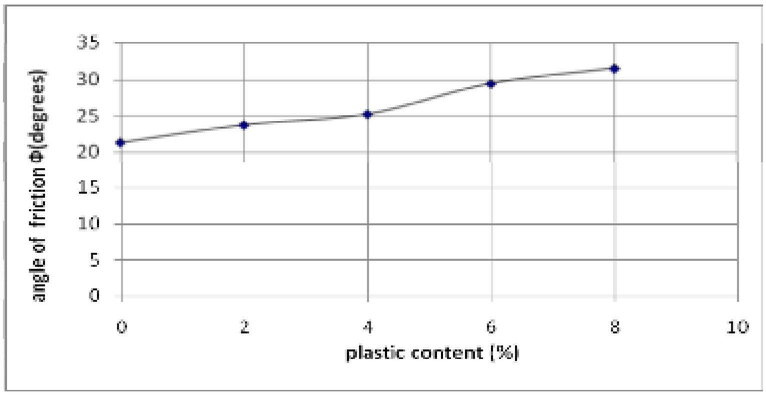

Fig.(12) Effect of plastic waste content on friction angle of clayey soil.

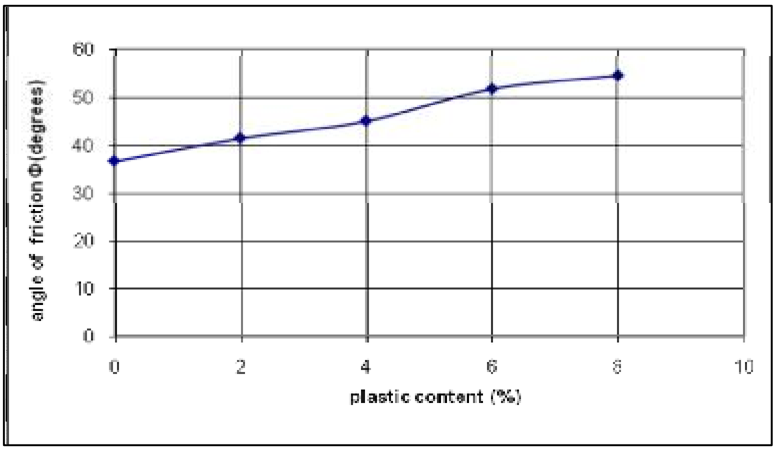

Fig.(13) Effect of plastic waste content on friction angle of sandy soil.

For compaction tests, **Figure.(14).** shows the results of compaction test and **Table (3)** summarizes the results of compaction test of clayey soil.

It can be concluded that the plastic pieces decreases the maximum dry density of the soil due to their low specific gravity. This point can be beneficial in the construction of embankments of light weight materials. Also, it can be noticed that the addition of plastic pieces decreases the optimum moisture content, this may be attributed to that the plastic pieces does not absorb water which that different to clay behavior which it have a tension surface water.

The variation of optimum water content and maximum dry unit weight with plastic pieces content is linear as shown in **figure (15)** and **figure (16).**

Also, it can be noticed that the shape of the compaction curves are similar to those of unreinforced samples. These conclusions agree with the findings of Naeini and Sadjadi **(**2008).

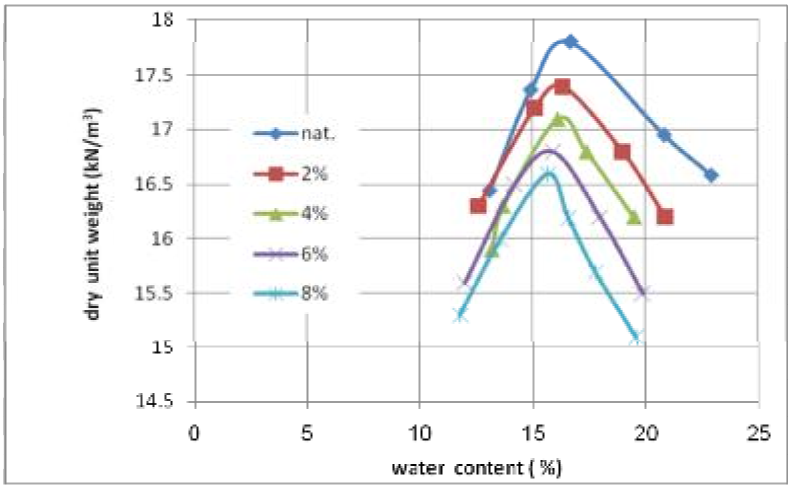

Fig.(14) Dry unit weight-water content relationship of clayey soil with different percentages of plastic waste.

Table (3) : Results of Compaction Test of Clayey Soil.

Plastic waste content (%)	Optimum moisture content (%)	Maximum dry unit weight (kN/m^3)
0	16.68	17.8
2	16.33	17.4
4	16.11	17.1
6	15.92	16.8
8	15.69	16.6

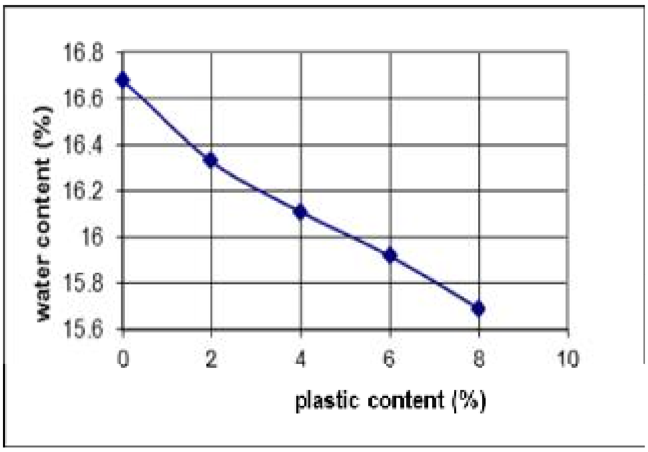

Fig.(15) Effect of plastic waste content on optimum moisture content of clayey soil.

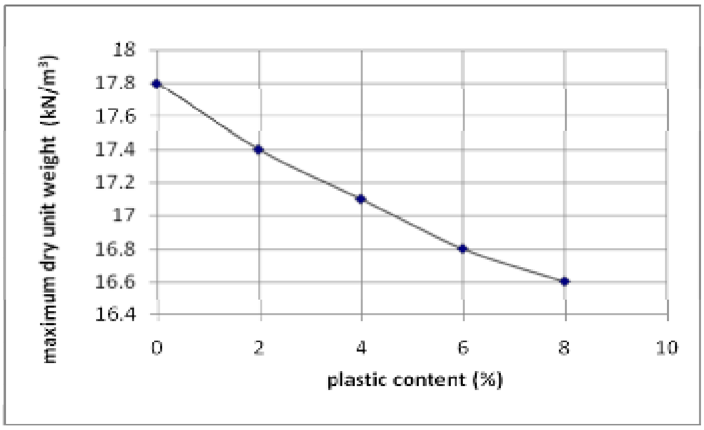

Fig. (16) Effect of plastic waste content on maximum dry unit weight of clayey soil.

5. Conclusions :

1. The effect of plastic waste pieces on soil is influenced by various factors such as soil type and plastic waste content.
2. The addition of plastic pieces to the two types of soils does not increase the cohesion of soils significantly.
3. The angle of internal friction (**Φ**) increases considerably with inclusion of different percentages of plastic pieces for sandy and clayey soils but the percentage of increase in the angle of internal friction for sandy soil is slightly more than that for clayey soil.
4. The variation of the friction angle of clayey soil with percentage of plastic content is a nonlinear variation and similar trend is found in sandy soil.
5. The plastic pieces decrease the maximum dry unit weight of the soil and optimum moisture content. The variation of optimum water content and maximum dry unit weight with plastic pieces content is linear, the shape of the compaction curves are similar to those of unreinforced samples.

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