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Strength of Silty Soil Treated with Cement and Reinforced with Plastic Water Bottles Waste

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Keywords:
Cement; Plastic waste materials; Silty soil; Soil reinforcement; Strength properties.

Highlights:

- *Improved environmental sustainability by using fly ash waste in composites.*
- *Fly ash reduces the overall cost of polyethylene composites.*
- *Morphological analysis reveals a uniform dispersion of fly ash within the polymer matrix.*
- *Improved thermal stability observed in fly ash-reinforced polyethylene composites.*
- *Fly ash enhances the physical properties of LDPE and HDPE composites.*

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Abstract: The silty soil is subject to significant settlement and a decrease in bearing capacity when subjected to high stresses. Improving the properties of this soil is necessary to achieve the bearing capacity required by buildings. In this study, various percentages of plastic water bottle waste fibers (PET) and cement were used. The effect of these materials on the unconfined compressive strength (UCS), indirect tensile strength (ITS), and punching tensile strength (PTS) of the silty soil was studied. All cemented soil samples were cured for (7, 14, and 28) days at 25 °C. The results of laboratory tests showed that the use of PET fibers in percentages (0.5, 1, and 1.5%) led to an increase in the UCS and the ITS at each percentage. These resistances reached their maximum value at (1%) fiber content and (30) mm length. The use of (1%) PET fibers and (30) mm length with (4%) cement and (28) days as a curing time increased these resistances to 2626 and 7693%, respectively. The PTS of soil reinforced with PET fibers in percentages (0.5, 1, 1.5, and 2%) increased at each percentage. The value of the increase was about 229 % at 1.5 % with a length of (30) mm of fibers, while its value was about 4732 % at 1.5 % of PET and 4 % cement and for a curing time of (28) days compared to soil without additions, i.e., 12kN/m².

مقاومة التربة الغرينية المعاملة بالسمنت والمسلحة بألياف مخلفات قناني الماء البلاستيكية

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الخلاصة
تتعرض التربة الغرينية لاستقرار كبير وانخفاض في قدرتها على التحمل عند تعرضها لإجهادات عالية. إن تحسين خصائص هذه التربة ضروري لتحقيق قدرة التحمل المطلوبة للمباني. في هذه الدراسة، تم استخدام نسب مختلفة من ألياف نفايات زجاجات المياه البلاستيكية (PET) والأسمنت. تمت دراسة تأثير هذه المواد على قوة الضغط غير المحصورة (UCS) وقوة الشد غير المباشرة (ITS) وقوة الشد اللكم (PTS) للتربة الغرينية. تم معالجة جميع عينات التربة الأسمنتية لمدة (٧ و١٤ و٢٨) يومًا عند ٢٥ درجة مئوية. أظهرت نتائج الاختبارات المعملية أن استخدام ألياف PET بنسب مئوية (٠,٥ و١ و١,٥٪) أدى إلى زيادة في UCS وITS عند كل نسبة مئوية. وصلت هذه المقاومات إلى أقصى قيمتها عند محتوى الألياف (١٪) وطول (٣٠) مم. أدى استخدام ألياف PET بنسبة (١٪) وطول (٣٠) مم مع (٤٪) أسمنت ومدة معالجة (٢٨) يومًا إلى زيادة هذه المقاومات إلى ٢٦٢٦ و٧٦٩٣٪ على التوالي. كما زادت قيمة PTS للتربة المسلحة بألياف PET بنسب (٠,٥، ١، ١,٥، و٢٪) عند كل نسبة. وبلغت قيمة الزيادة حوالي ٢٢٩٪ عند ١,٥٪ بطول (٣٠) مم من الألياف، بينما بلغت قيمتها حوالي ٤٧٣٢٪ عند ١,٥٪ من PET و٤٪ أسمنت ومدة معالجة (٢٨) يومًا مقارنة بالتربة بدون إضافات أي ١٢ كيلو نيوتن/م٢.

الكلمات الدالة: تسليح التربة، الياف صناعية، مواد المخلفات البلاستيكية، خصائص المقاومة، تطبيقات هندسية.

1.INTRODUCTION

A silty soil in its natural state, especially submerged in water, is characterized by its feeble resistance to the high stresses applied to it, which can sometimes lead to failure in engineering structures built on it. Failures in these constructions are caused by either a bearing failure or a soil descent failure [1]. Therefore, geotechnical engineers resort to improving the properties of this soil to meet specific engineering requirements through several methods, including replacing the soil with another that has acceptable engineering characteristics, soil stabilization (chemical or physical stabilization), soil compaction of various types, and soil reinforcement [2-5]. The choice of a certain method from the previous methods to improve soil properties depends on the type of soil, the importance of the engineering building, the climatic conditions surrounding the soil, and other (economic) factors. The method of soil reinforcement, using natural or synthetic reinforcement materials, is a crucial technique in geotechnical engineering, which enhances the stability of the soil and increases its ability to bear loads [6-10]. Soil reinforcement has garnered significant attention in recent years, particularly in the implementation of various engineering structures, including roads, retaining walls, embankments, and surface foundations. This method involves adding reinforcing elements, which take various forms, including fibers, strips, and small pieces, to the soil to enhance its resistance to applied loads [11-12]. Soil reinforcement is considered one of the oldest methods used to improve soil properties; the concept of soil reinforcement was introduced more than 5,000 years ago. For example, ancient civilizations, such as the Babylonian civilization and the Chinese civilization, used straw fibers and palm fronds to produce building blocks (clay blocks) in their civilizations. The Chinese used tree branches as reinforcement elements during the construction of the Great Wall. The Babylonians also used palm fronds as mats during the construction of the ziggurats [11, 13]. The principle of soil reinforcement primarily depends on the interaction between the soil and the reinforcing elements, which in turn enhances the stability and resistance of the soil. The efficiency of soil reinforcement also depends significantly on the shear resistance between the fibers and the soil, especially at the interface between them, as any stresses and strains applied to the soil lead to strains in the reinforcing materials inside the soil, which increases the resistance of the soil to the applied loads on it [1]. The bottled water industry is considered one of the fastest-growing industries worldwide. The International Bottled Water Association indicated that sales of bottled water in plastic bottles increased by 500% over the past decade, and 1.5 million tons of plastic are used annually as bottled water [3]. It is also reported that the annual global consumption of bottled water is about 10 million tons, and this figure is increasing by up to 15% annually. The plastic waste disposal process negatively impacts both the economy and the environment, as a significant amount of money is spent on disposing of these materials [1]. It also causes numerous problems, including environmental pollution. The best solution to address the problem is to reuse these plastic wastes for specific purposes, such as using them in engineering applications, especially since they are non-biodegradable materials. Alternatively, plastic waste can be recycled and used as a reinforcing material in most civil engineering applications, such as in concrete, road, and surface foundations [1]. Consoli et al. [14] investigated the characteristics of unconfined compressive strength (UCS), indirect tensile strength (ITS), and friction angle between particles for samples of reinforced sandy soil with waste plastic water bottle fibers and for samples of reinforced sandy soil with these fibers and cement treatment. The lengths of the fibers used were (36, 24, and 12) mm, and the fiber ratios were (0.1, 0.22, 0.5, 0.78, and 0.9%), while the cement ratios ranged from 3 to 7%. The results of the triaxial shear test for the unreinforced and reinforced sandy soil samples treated with cement showed an increase in the friction angle with an increase in the fiber percent, which increased from 37 to 43 and 49 for the reinforced and cement-treated reinforced soil samples, respectively. The ITS and UCS increased by approximately 73% and 40%, respectively, at a cement ratio of 7%, fiber ratio of 0.9%, and fiber length of 36 mm. Changizi and Haddad [15] studied the impact of polyethylene bottle waste and nano-SiO2 on the strength properties of soft clay. The test results showed that at a fiber percent of (0.5%) and a nano-silica ratio of (1%), the direct shear resistance and the unconfined compressive strength increased by about (200%) compared to natural soil samples. Peddaiah et al. [16] conducted a study on reinforced silty-sand soil with plastic waste fibers to determine the effect of these fibers on the soil by direct shear testing and CBR (California Bearing Ratio) testing. The shear modulus for the reinforced soil was found for fiber ratios of (0.2, 0.4, 0.6, and 0.8%) and lengths of (35, 25, and 15 mm). The test results showed an increase in the CBR ratio, cohesion values, and friction angle, as well as an increase in fiber length and percentage compared to natural soil. Gardete et al. [17] investigated the effect of reinforcing sandy-clay soil with plastic waste (polyethylene PE waste and polypropylene PP waste) on the CBR of this soil, studying the soil reinforced with percentages (1, 2, and 3%) of these fibers. When 1% of these fibers was added, the test results showed an increase in the CBR value from 11% to 14% and 19% when penetrated by (2.5 mm and 5 mm), respectively. Hassan et al. [18] experimentally investigated two types of plastic waste: (PET) from water bottles and (PP) from plastic bags. The soil was reinforced with these fibers separately to determine their effect on the unconfined compressive strength and CBR of the clayey soil. The fiber lengths used were 10 mm and 20 mm, and their proportions were)1, 2, 3, and 4% (by dry soil weight. The test results showed an increase in the unconfined compressive strength of the reinforced samples, with the most significant increase observed at a fiber proportion of 1% for both fiber lengths and both types of fibers (PET and PP). The strength increased from 148 kPa to 291 kPa and 256 kPa for PET and PP-reinforced models, respectively. The CBR value increased progressively for the reinforced samples as the fiber length and proportion increased compared to the unreinforced soil models. Eltayeb and Attom [19] investigated the effect of plastic bottle waste fibers on the UCS for two groups of clay soil (high plasticity clay soil (CH) and low plasticity clay soil (CL)). The studied fiber length was 10 mm, and the fiber width ranged from 1 mm to 2 mm with percentages of (0.5, 1, 1.5, 2, 2.5, and 3%). The laboratory test results showed an increase in the unconfined compressive strength for the reinforced soil groups compared to the unreinforced soil group. The optimum fiber percentage was found to be 1.5% for the two reinforced soil groups. The objective of this study is to address the problems associated with a specific type of soil in the city of Mosul, namely silty soil. This soil is considered problematic due to its engineering issues, including settlement and low bearing capacity. One method for treating this soil is to reinforce it with plastic waste from water bottles. Disposing of waste in this manner can achieve economic, environmental, and engineering benefits by improving the resistance and behavior of the soil, as previous studies have revealed.

2.EXPERIMENTAL PROGRAM

2.1.Materials

1- Soil: Silty soil was selected from one of the areas in Nineveh Governorate, specifically from Khwaja Khalil, located in the western part of Mosul City. The soil was dried at 60 °C for 48 hours, then passed through sieve #4 before use. Table 1 shows the physical, engineering, and chemical tests conducted on the silty soil in the laboratories of Mosul University.
2- The PET fibers: The thickness of PET fibers was (0.05 mm). These wastes were converted into fibers (see Fig. 1) by cutting them using a paper-cutting machine. Table 2 presents the physical properties of the PET fibers used in the present study.
3- Cement: Ordinary type cement was used, and it was brought from the Badush cement factory located in Mosul. Table 3 presents the chemical composition of the cement, which meets the global specifications for Portland cement.

2.2.Methodology

In the present study, tests were conducted on the unconfined compressive strength (UCS), indirect tensile strength (ITS), and punching tensile strength (PTS) of natural and reinforced soil samples, as well as soil samples treated with cement and reinforced-cemented samples. Different ratios of PET fibers were studied, i.e., from (0% to 2.0%). The ratio (2%) was used in the PTS test only. Each ratio of the PET fibers was tested at three different lengths (10, 20, and 30 mm) and a width of (2- 4 mm). While the cement ratios in the experiments were (2, 4, and 6%).

Table 1 Physical, Chemical, and Engineering Properties of Natural Soil.

Property		Value	Standard
Gypsum content (%)		5.7	Al-Zubydi [20]
Specific gravity		2.67	ASTM D 854-98
Liquid limit (%)		NP	ASTM D 4318-98
Plastic limit (%)		NP	
Grain size analysis	Gravel (%)	10	ASTM D 422-98
	Sand (%)	29	
	Silt (%)	49	
	Clay (%)	12	
Unified soil classification system (USCS)		ML	ASTM D 2487-98
Standard compaction characteristics	γ_{dmax} (kN/m³)	17	ASTM D 698-98
	OMC (%)	16	
Unconfined compressive strength (kN/m²)		91.7	ASTM D 2166-98
Indirect tensile strength (kN/m²)		6.1	Alkiki et al. [21]
Punching tensile strength (kN/m²)		12	Chen [22]; Fang and Fernandez [23]

Table 2 Physical and Mechanical Properties of PET Fibers.

Property	Value
Length (mm)	10-30
Width (mm)	2-4
Thickness (mm)	0.05
Specific gravity	1.26
Tensile strength (MPa)	354
Resistance to acid and alkaline	Resistant

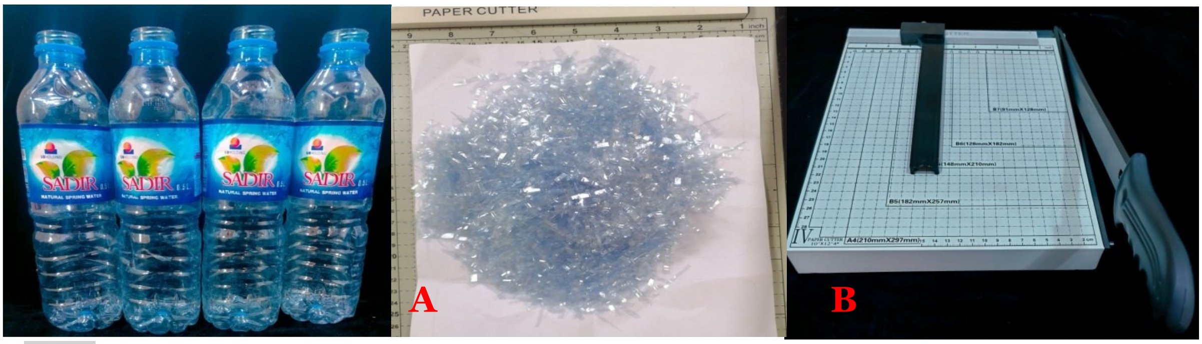

Fig. 1 Preparation of PET Fibers (A) Cutting Plastic Water Bottle Wastes in the Form of Fibers (B) Paper Cutter.

Table 3 Chemical Composition and Components of the Cement.

Chemical Composition	Value	Chemical Composition	Value
SiO2	20.6	C3S	53.64
AL2O3	4.90	C2S	18.59
Fe2O3	2.60	C3A	8.58
CaO	64.64	C4AF	7.92
MgO	3.32	L.S.F	97.37
SO3	1.58	Solid Solution	14.71
Free Lime	2.9		
Loss of ignition	2.61		
Insoluble residue	0.40		

2.3.Laboratory Tests and Preparation of Samples

2.3.1.Laboratory Tests

1- UCS Test

The unconfined compression test was conducted according to the ASTM D 2166-98. This test was conducted on natural soil, soil treated with cement, reinforced soil samples, and reinforced-cement-treated soil. Eq. (1) is used to calculate the UCS:

$$\mathbf{UCS} = \frac{P_{max}}{\mathbf{Area}} \qquad (1)$$

where UCS is the unconfined compressive strength, P is the maximum applied load per unit, and Area is the area of the sample.

2- ITS Test

ITS test was conducted following the test procedure adopted by Alkiki et al. [21] to determine the ITS of natural and reinforced soil samples, as well as treated reinforced soil samples. This test involves using a uniaxial compressive strength tester at a loading rate of 1.27 mm/min. The ITS values were then calculated using Eq. (2):

$$ITS = \frac{2Pmax}{\pi L D} \qquad (2)$$

where ITS represents the indirect tensile strength, P represents the maximum applied load, L represents the length of the sample, and D represents the diameter of the samples.

3- PTS Test

The PTS test, also known as the unconfined penetration test, was used in this research. This test was proposed by Chen [22] and developed by Fang and Fernandez [23]. The PTS test was conducted on all soil samples, as mentioned in

UCS tests. These soil samples were prepared in a Proctor compaction mold, 101.6 mm in diameter and 116.8 mm in height. The PTS test effectively reduced the boundary effects by using smaller loading discs (Kim et al., 2012). To maintain this benefit, it is essential to keep a good alignment between the soil sample and the loading discs. Therefore, a metal frame was used to center the loading discs on the top and bottom surfaces of the soil samples, ensuring that the loading discs and soil samples were perfectly aligned vertically. To facilitate this alignment, the metal frame's bases were provided with two engraved concentric circles, which aid in locating the soil sample and loading discs at the center. After that, a vertical load was applied to the discs at a loading rate of 1.27 mm/min until the sample failed. The PTS of the samples can be calculated using Eq. (3):

$$PTS = \frac{P_{max}}{\pi(kHb - a^2)} \quad (3)$$

where PTS is the punching tensile strength, P is the maximum applied load, H is the height of the samples, b is half of the radius of the sample, a is half of the radius of the solid disc, k is a coefficient that depends on the friction angle, angle of cone failure, and the relation between compressive and tensile stresses. According to Fang and Fernandez [23], the (k) value used in the present investigation was 1.2.

2.3.2. Preparation of samples

To prepare samples for UCS of cement-treated soil, three ratios of Portland cement were used in this study: (2, 4, and 6%) by dry weight of soil. The required cement ratio for the remaining tests will be determined by the UCS test. Firstly, each ratio was mixed with the soil in a plastic sack and shaken until homogeneous. Secondly, a fixed quantity of water corresponding to the optimum moisture content of natural soil was gradually added to the mixture. The mixture was left in the plastic sack for 10 minutes to ensure homogeneity before being placed into a cylindrical mold, 50 mm in diameter and 100 mm in height. The soil samples were statically prepared to achieve the maximum dry unit weight of natural soil, i.e., 17 kN/m^3. After compaction, the samples were wrapped with aluminum foil to maintain mixture moisture and cured at a constant temperature of 25 °C for curing periods of (7, 14, 28, and 56 days). After determining the cement percentage that gives the design strength to use soil as a base layer, the samples of ITS and PTS were also treated with a cement ratio of (4%) and cured for (7, 14, and 28 days) at a temperature of 25 °C. To prepare the reinforced soil samples, the PET fibers were mixed with soil in a dry state in a plastic sack. Thereafter, a desired quantity of water corresponding to the optimum moisture content of natural soil was added. The mixture was remixed to get homogeneity. For reinforced-cemented soil samples, all components, i.e., soil, cement, and PET fibers, were mixed in a dry state in a plastic sack until homogeneity was achieved. Then, the same aforementioned procedure was followed. After the moisture homogeneity process, which took 10 minutes for cemented samples and 24 hours for uncemented ones, the mixture was statically compacted in the desired mold, corresponding to the required test, to achieve the maximum dry unit weight of the natural soil.

3. RESULTS AND DISCUSSION

3.1. Effect of PET Fibers on the UCS and ITS of Natural Soil

Figures 2 and 3 show the impact of fiber length and ratio on the UCS and ITS of natural soil, respectively. It is observed that both strengths were increased with increasing fiber ratio up to a certain limit, then decreased, which agrees with the results of [24], which showed an increase in UCS for reinforced soil samples with increasing fiber length and ratio up to a maximum of (1%), after which UCS decreased. Refs. [24-26] stated that when soil is reinforced with fibers, the fibers transfer the load applied to the soil to the frictional interface between soil particles and the fibers. The fibers make it difficult for the soil particles surrounding them to change position under load, thereby enhancing the friction among the soil particles. This behavior explains why the use of fiber increases soil strength. As can be shown in Figs. 2 and 3, the highest values of UCS and ITS were obtained at a fiber ratio of (1%). However, after that point, these resistances decreased. Nevertheless, the resistance values remained higher than those of the unreinforced soil. According to the results of Refs. [27, 28], increasing the fiber content above a specific ratio leads to the sliding of fibers on top of each other, forming a weak plane that causes soil particles to slide over these surfaces instead of relying on soil-fiber cohesion. In the present study, the best strength value was obtained using fibers with a length of (30 mm). According to Ref. [29], the optimal fiber length was the length that achieved the best interlocking with soil particles. Figure 4 illustrates the typical stress-strain curves of reinforced soil samples with different ratios of PET fibers 30 mm in length. It is observed that the inclusion of PET fibers improved the strain values at peak stress. Furthermore, the strain values increased as the fiber content increased. The larger values of strain were noticed for soil samples having longer fibers. It is worth noting that the axial stress increased up to the peak stress and then decreased gradually. Whereas the stress-strain curve of the reinforced samples was flatter than those of natural soil samples. Ref. [30] showed that the stress-strain behavior of reinforced soil samples enhanced significantly due to the increase in plastic ratio.

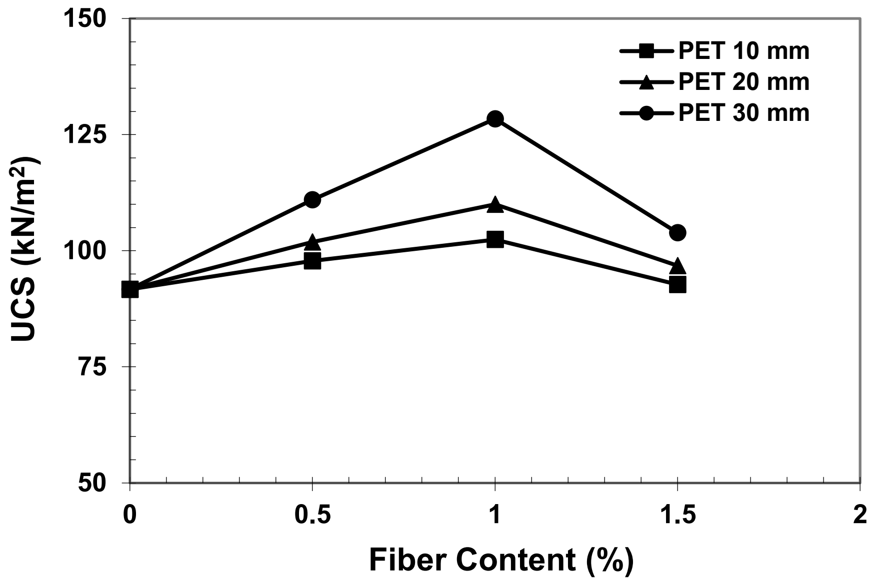

Fig. 2 UCS Variations with the Fiber Length and Ratio.

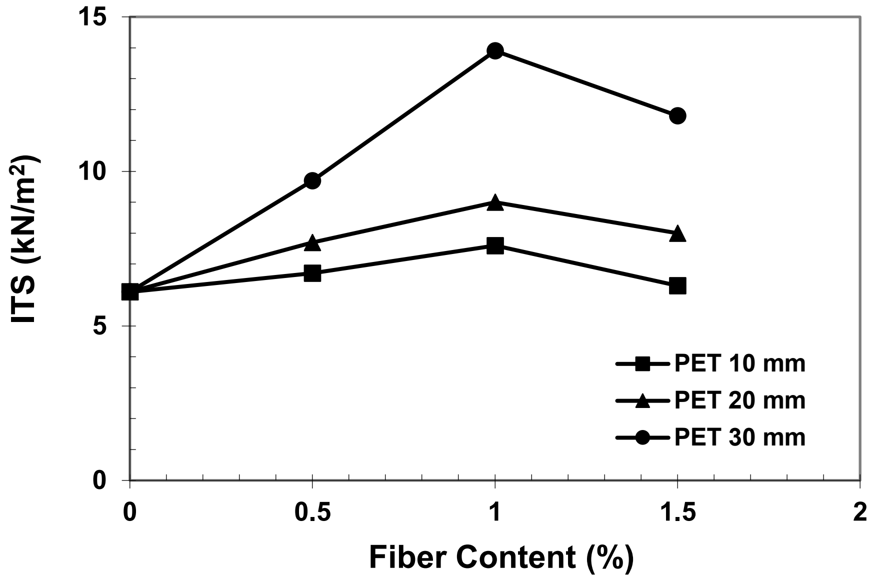

Fig. 3 ITS Variations with the Fiber Length and Ratio.

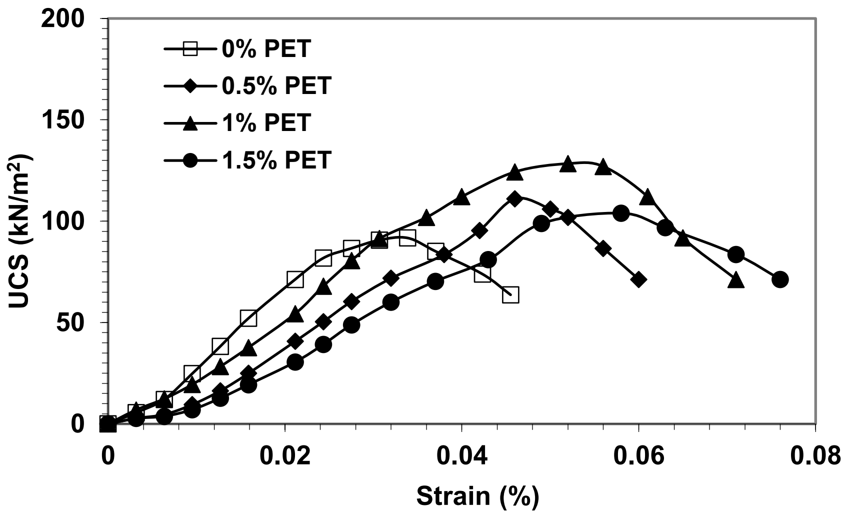

Fig. 4 Typical Stress-Strain Curves of Unreinforced and PET-Reinforced Soil Samples with 30 mm in Length.

Figure 5 presents a typical failure mode of natural and reinforced soil samples. In general, both natural and reinforced samples fail in shear, and different failure modes can be attained. The natural soil samples showed a brittle failure mode in the UCS test. While the reinforced samples showed a propagation of cracks along the soil samples. The propagation of these cracks increased with PET fiber content, resulting in a practically irregular sample shape. For ITS samples, the addition of fiber slightly affected the modes of failure. The natural soil samples failed in the middle area where stress was applied, i.e., splitting failure. The reinforced soil samples did not present a defined rupture plane, and the sample remained coherent.

Fig. 5 Typical Failure Mode of Natural and Reinforced Soil Samples (A) UCS Samples (B) ITS Samples.

3.2.Effect of PET Fibers on the PTS of Natural Soil

Figure 6 illustrates the variation PTS with PET fibers. This test showed the same behavior as both UCS and ITS tests. An increase in the PTS of the reinforced soil was observed compared to natural soil samples, where its value reached approximately (39.57 kN/m^2) at a fiber length of (30 mm) and a ratio of (1.5%). After this ratio, the (PTS) values decreased. The increase in PET fiber ratio, i.e., 1.5%, resulted in a larger value of PTS than with (1.0%) PET fiber that gave larger values of UCS. ITS could be attributed to the larger mold size used for this test than the sizes of molds used for the UCS and ITS tests. Mishra and Gupta [31] concluded that samples with different volumes (of the same test type) and reinforced with a constant fiber ratio had different strength values. The highest strength was achieved when the fiber ratio was sufficient to ensure optimal interlocking with the quantity and mass of the soil compared to other models of different sizes.

3.3.Effect of Cement Ratio and Curing Periods on the UCS of Natural Soil

The cement was mixed with soil in proportions of (2, 4, and 6%); the method of preparing cement-treated specimens for this test was explained in section 2.3.2. Figure 7 shows the impact of cement ratios and curing periods on the UCS compared to natural soil samples. The UCS of soil samples increased approximately linearly with increasing both cement ratios and curing periods. This behavior is with expectation. This increase can be attributed to the combined action of several factors. The first process was cement hydration, which provided the calcium ions necessary for ion exchange. The second one was the pozzolanic components, i.e. CSH and CAH. These components act as filler materials that fill the pore spaces of soil samples, resulting in a denser structure. Similar explanations were observed by Refs. [10, 21, 32]. Moreover, the cement treatment is a time-dependent process. Thus, the soil–cement reactions increased the bonding among soil grains as the curing periods increased.

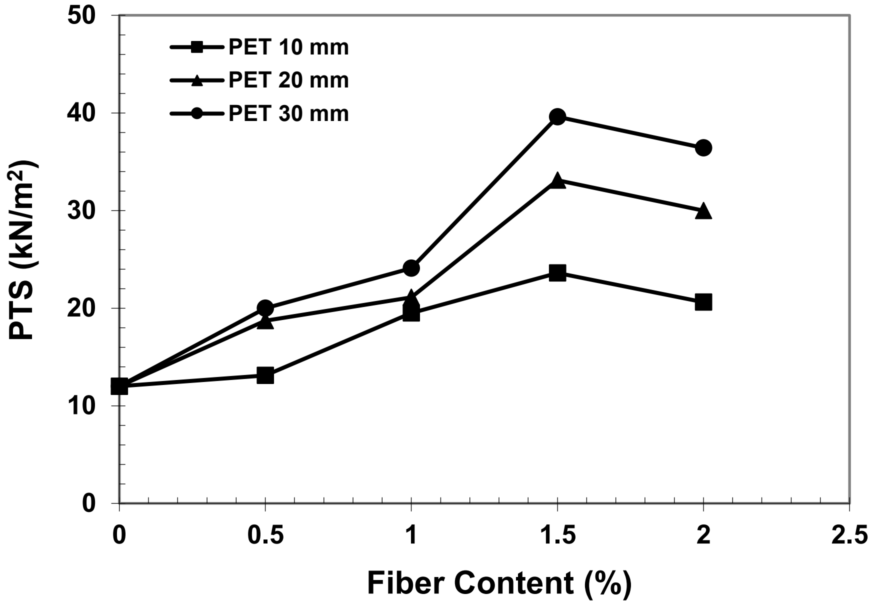

Fig. 6 PTS Variations with the Fiber Length and Ratio.

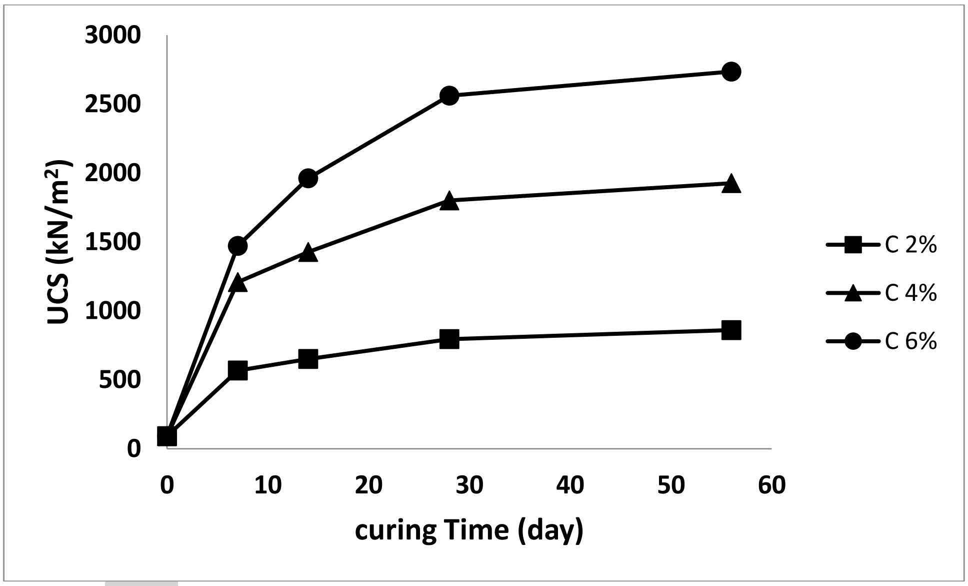

Fig. 7 UCS Variations with Cement Content and Curing Periods.

3.4.Effect of Curing Periods on the ITS and PTS of natural Soil

A ratio of (4%) cement was used in the ITS and PTS tests, as mentioned previously. Figure 8 shows the variations of ITS and PTS with curing periods. These tests followed the same trend as the UCS test. It is observed that the ITS of natural soil samples increased from (6.1 kN/m²) to (113, 245, and 312 kN/m²) for soil samples cured for (7, 14, and 28) days, respectively. In the same manner, the PTS increased from (12 kN/m²) to (125, 258, and 371 kN/m²) for soil samples cured for (7, 14, and 28 days), respectively. The increase in ITS and PTS could be attributed to the same factors mentioned in section 3.3.

3.5.Effect of Cement and PET Fibers on UCS and ITS

Figures 9 and 10 show the influence of fiber ratios and curing periods on the UCS and ITS, respectively. An increase in the UCS and ITS was observed when fibers were added. These values increased with more extended curing periods, which is consistent with Ref. [14]. The highest value for these strengths was noticed at (1%) of PET and all curing periods. After this percentage, the strength values decreased with increasing fiber ratios. These results were similar to what was found by Ref. [30] through their practical study on treated reinforced clay soil samples with plastic fiber ratios (0.4, 0.8, 1.2, and 1.6%), where the ratio of (1.2%) fibers showed the best results. The increase in soil strength with PET fibers and cement addition could be attributed to (1) adding PET fibers to stabilized soil is responsible for reducing deformations and cracks due to the bridging effect of the fibers, as shown in Fig. 11, and (2) adding stabilizing materials such as cement will fill the voids between soil particles and increase the contact area with PET fibers in this mixture, increasing interfacial friction between them. These factors contributed to the increased strength of reinforced cement-treated soil samples compared to either reinforced soil samples or cement-treated soil samples alone. The UCS and ITS of soil samples cured for (7, 14, and 28 days), reinforced by (1%) PET fiber, and treated with (4%) cement increased compared to natural soil. It is worth noting that, despite the increase in values of UCS and ITS for only reinforced soil samples and/or only cemented soil samples, they are still lower than those of cemented reinforced soil samples, which corresponds with what was found by Ref. [14] through their study on reinforced and cement-treated soil.

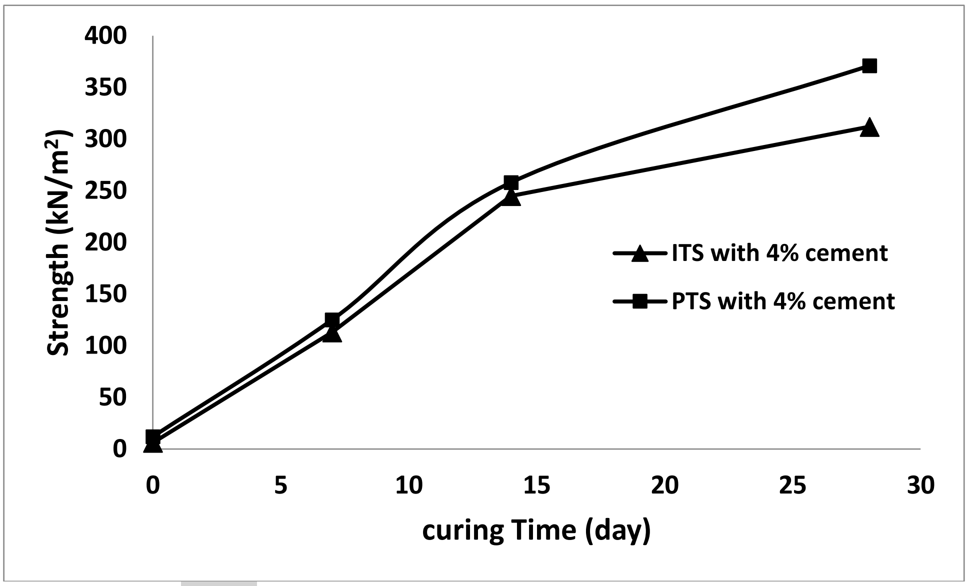

Fig. 8 ITS and PTS Variations with Curing Periods.

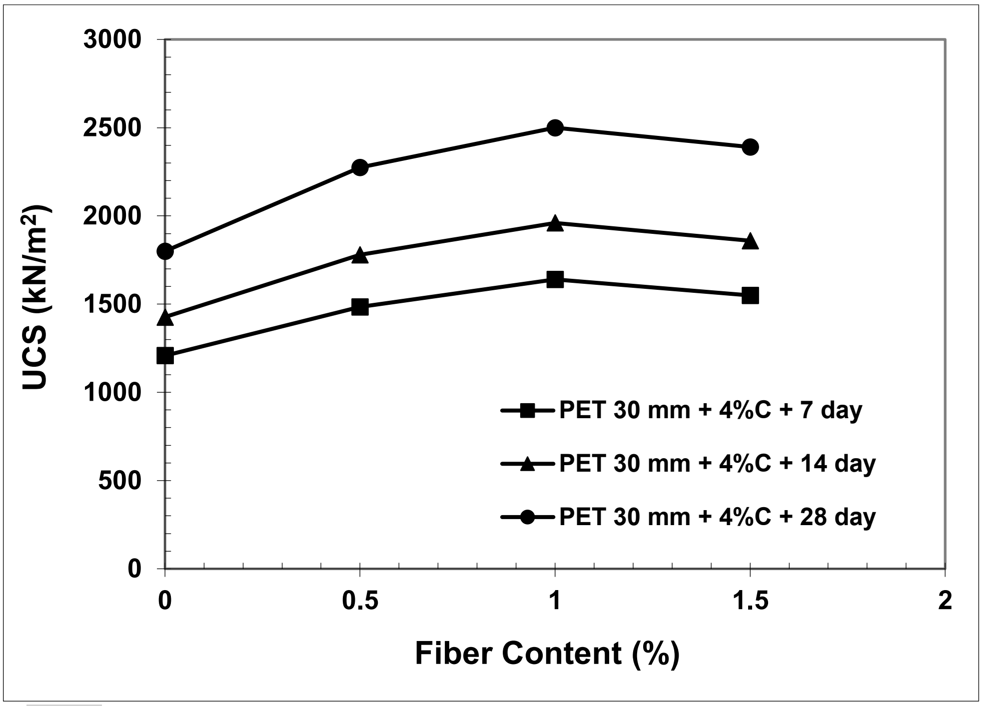

Fig. 9 UCS of Cemented Reinforced Soil Samples with Varying Curing Periods.

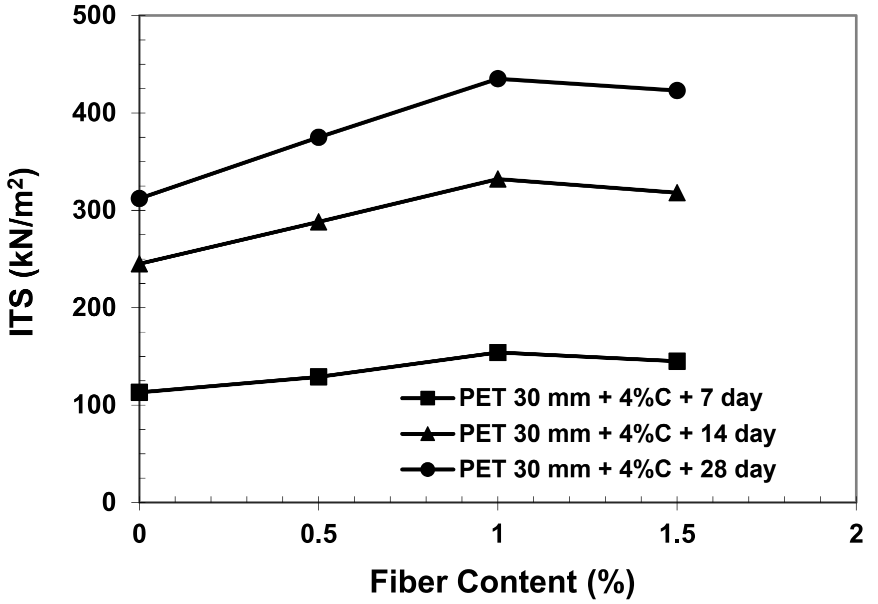

Fig. 10 ITS of Cemented Reinforced Soil Samples with Varying Curing Periods.

3.6.Effect of Cement and PET Fibers on PTS

Figure 12 shows the variations of PTS with both PET fiber ratio and curing periods. It is noted that the increase in PTS of cemented reinforced soil samples was greater than that of natural soil, reinforced soil alone, and cement-treated soil. The PTS value increased with fiber ratios and curing periods, and its value reached approximately (188 kN/m^2), (400 kN/m^2), and (2579 kN/m^2) for curing periods of (7, 14, and 28 days), respectively. As natural reinforced soil samples, the maximum values of PTS were recorded for soil samples reinforced with (1.5%) PET fibers, indicating that the cement addition insignificantly affected the optimum PET fiber ratio that gives the maximum PTS. Finally, for all PET fiber ratios and cement percentages, curing periods play a significant role in increasing the strength values of the cemented reinforced soil samples.

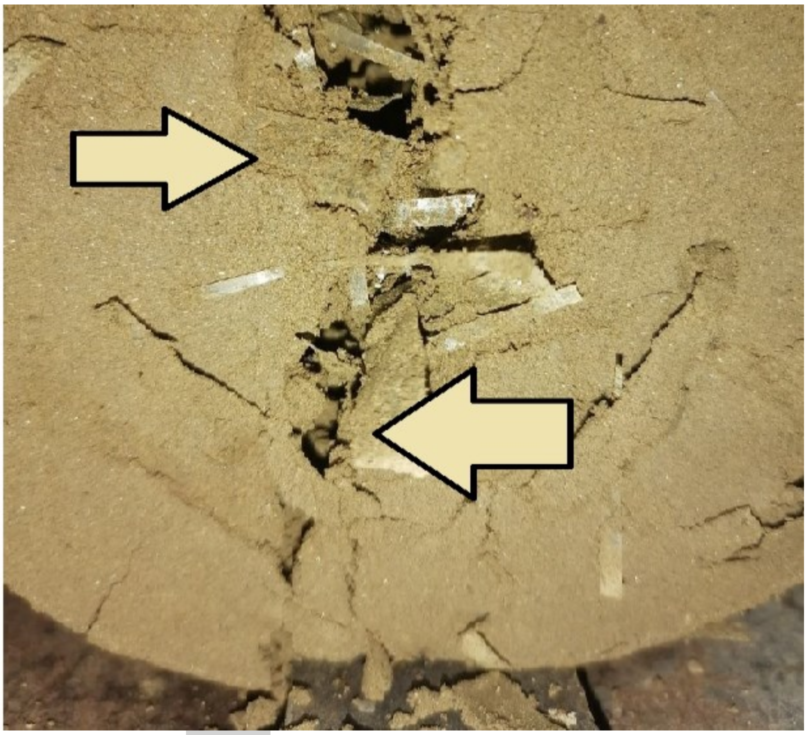

Fig. 11 Bridging Effect of the Fibers.

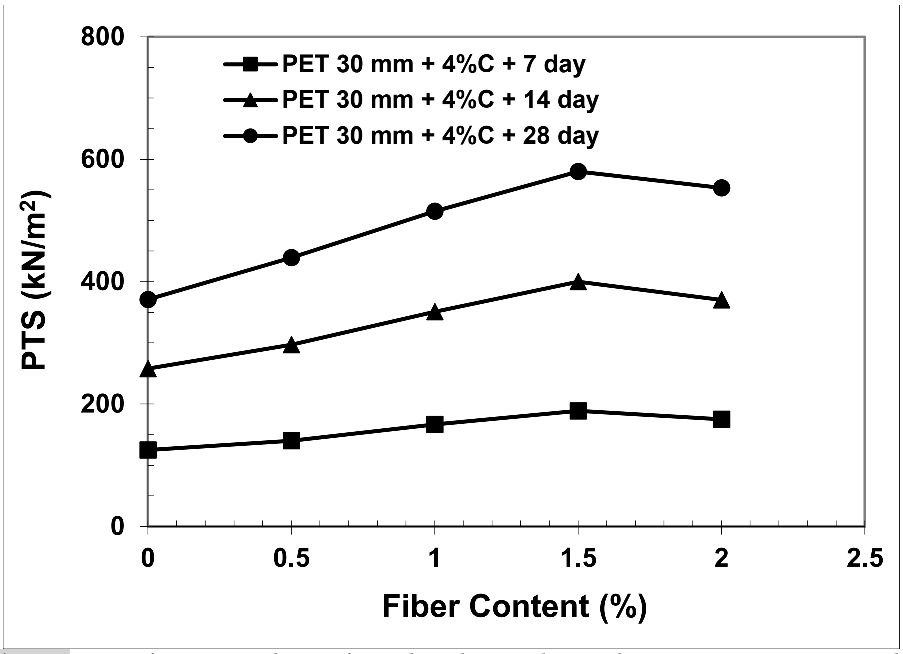

Fig. 12 PTS of Cemented Reinforced Soil Samples with Varying Curing Periods.

4.CONCLUSIONS

Based on the present investigation, the following points can be drawn:

1- The use of recycled plastic water bottle fibers as reinforcement fibers for silty soil increased compressive and punching strength, as well as the soil's ability to withstand tensile forces.

2- The most significant values for resisting tension and compression were found at a fiber ratio of (1%), indicating that this ratio achieved the best contact with the soil mass. However, for samples of punching strength, the greatest value was found at (1.5%). This behavior may be attributed to the larger size of the soil samples compared to those used in UCS and ITS tests.

3- For all lengths of fiber used, there was an increase in resistance. The maximum increase in strength was recorded in soil samples reinforced with fibers having (30 mm) in length. This behavior is attributed to the increase in the tensile strength of the long fibers, resulting in a corresponding increase in strength.

4- Adding cement to reinforced soil increased the soil's resistance by a greater degree, e.g., 32 times in UCS, compared to the resistances of soil samples treated with cement alone (19 times) or reinforced soil alone (1.5 times).

5- Curing periods have played a crucial role in enhancing the strength of cemented and reinforced cemented soil samples.

ABBREVIATIONS

C	Cement
D	Curing time (days)
ITS	Indirect tensile strength
PFL	Plastic fibers length
PFP	Plastic fibers percent (%)
PTS	Punching tensile strength
PWF	Plastic waste fibers
UCS	Unconfined compressive strength

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