Enhancing the Strength of Clay-Sand Mixture by Discrete Waste Plastic Strips

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The addition of waste plastic bottle strips to soil as a reinforcing material is widely used nowadays to enhance the engineering properties of soils. In this study, series of unconfined compression tests were conducted on clayey sand soil with and without adding strips of waste plastic bottle to investigate the effect of adding plastic strips on the shear strength of soil. Two types of plastic strips were used in this research depending on the nature of the strip surface whether plain or corrugated. Different sizes of plain strips (BxL) were used namely (1x5), (1x10), (1x15), (2x5), (2x10), (2x15), (3x5), (3x10) and (3x15) mm, while one size of corrugated strips was used namely; (1x15) mm, where B and L are the width and length of a strip, respectively. All the plastic strips are of the same thickness of 0.4mm. Both the plain and corrugated plastic strips were added with different percentage ratios of 0.25, 0.5, 0.75 and 1.0 % by the dry weight of soil sample. For a particular ratio, a significant increase in unconfined compressive strength q_u of soil was observed when adding plain plastic strip of size (1x15) mm for addition ratio of 1.0 % while more increase in unconfined compressive strength q_u was deducted when adding corrugated plastic strips of the same size and addition ratio.

Keywords: Soil improvement, plastic reinforced clayey sand soil, unconfined compressive strength, plain strip, corrugated strip.

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1. Introduction

The use of plastics is increasing more and more in recent years. The problem of waste plastic disposal is; it is considered as a non-biodegradable and non-renewable sources. These sustainable plastic wastes cause a pollution to the environment. Therefore, recycling of the waste plastic and reuse them into useful processes become a very necessary demand. Many studies are performed to use the waste plastic as a soil reinforcing material to address the problem of waste disposal and it is as well an economic method of reinforcing since the soil stabilizer such as cement, lime and ash etc. become more expensive. Park (2009), investigated the effect of sand reinforcement by polyvinyl alcohol (PVA) fiber and its distribution through the sample on the strength of fiber reinforced cemented sand (FRCS) by conducted series of unconfined compression tests. It is concluded that the strength of the FRCS increases as the number of layers of fiber inclusion increases. The strength of a reinforced specimen where fibers were uniformly distributed throughout all layers of the specimen was twice a non-reinforced specimen. The fiber reinforcement and its distribution throughout the entire specimen lead to a remarkably increase in the strength of the FRCS [1]. Consoli et al (2007) found that the effect of fiber reinforcement of sandy soil was found to be more efficient for longer fibers and higher fiber contents. They also measured the length of fibers after completion of the shear tests on fiber reinforced sandy soil and found that, the length of fibers had been elongated and some of them had broken [2]. Consoli et. al. (2011), reported that fiber reinforcing the cemented soil results in increasing its unconfined compressive strength [3]. Shao et al. (2014), stated that the sand reinforced with fiber shows more ductile behavior and limited decrease in post peak shearing resistance [4]. Peddaiah et al (2018), investigated the effect of reinforcing silty sand soil with corrugated plastic bottle strips. Series of compaction, direct shear and California bearing ratio (CBR) tests had been conducted with varying percentages of plastic strips. From the results of these tests, it was found that the maximum dry unit weight, cohesion, angle of internal friction and CBR values increased up at 0.4 % plastic content by dry weight of soil for size of strip (15 x 15) mm. Beyond that limit of 0.4 % plastic content and for other strip sizes, these tested soil properties had found to be lesser [5]. The authors stated that the nature of plastic strip surface has a great influence on increasing the cohesion and angle on internal friction of soil. They observed higher shear strength parameters when reinforcing soil by corrugated surface plastic strips. The reinforced soil using plastic strips behaves like a reinforced soil using fiber. Plastic reinforcement can be used for stabilization of pavement sub-grade, embankments and any other fields of civil engineering [5]. Salami and Ghazavib (2019) had conducted series of triaxial compression test on sandy soil unreinforced and reinforced with circular plastic sheet of thickness 0.4 mm and diameter less than 5 cm. The results showed that a good improvement in the angle on internal friction and cohesion of sandy soil because of the plastic sheet increases the interlocking between the soil particle by shorting the path of failure and reducing the lateral deformation of soil sample. Numerical analysis using finite element software ABAQUS were performed to modeling a reinforced slop with plastic sheets. The analysis showed that improvement in factor of safety and stability of the slope were gained when reinforcing the sandy soil with plastic sheets because of their high tensile strength [6].

The scope of this work is to study the effect of adding strips of waste plastic bottle to a soil mixture which is consisting of 60 % sand and 40 % kaolin. The plastic strips are uniformly distributed throughout the soil mixture with different percentages of 0.25, 0.5, 0.75 and 1.0 % by dry weight of the soil sample mixture. Series of unconfined compression tests were performed on the soil mixture samples with and without plastic strips to investigate the percent improvement in ultimate shear strength of the soil mixture.

2. The Used Materials and Methodology

2.1. The Soil

The soil used in this work was prepared in the laboratory by mixing 60 % sand finer than 1.18 mm with 40 % kaolin. Other ratios of 30, 33, 35 and 38 % kaolin were not suitable since the prepared samples with these percentages were collapsed when extracted from the unconfined compression test mold and failed to test. The prepared soil mixture is classified as clayey sand SC according to the unified soil classification system USCS. The grain size distribution and physical properties of the soil mixture are shown in Fig. 1 and Table 1 respectively.

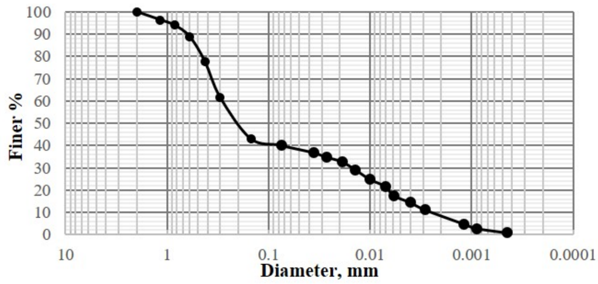


Fig. 1. The grain size distribution of the soil mixture.

2.2. The Plastic strip

The plastic strips which were used as a reinforcing material were cut out from waste plastic water bottles. Two types of strips were used depending on the nature of the plastic surface; plain and corrugated as shown in Fig. 2. The plain plastic strips were cut out with different widths (B) namely; 1, 2 and 3 mm and of different lengths (L) of 5, 10 and 15 mm. The plain strip sizes (BxL) are: (1x5), (1x10), (1x15), (2x5), (2x10), (2x15), (3x5), (3x10) and (3x15) mm, while one size of corrugated strips was used namely; (1x15) mm. All the plastic strips are of the same thickness of 0.4 mm. The axial stress- strain relationship of the plastic strip is shown in Fig. 3. The yield stress and the stiffness of the plastic strips is 45 MPa and 2380 MPa respectively. Both plain and corrugated waste plastic bottle strips were used with different addition percentage ratios **(WP%)**. The percent addition ratio WP% is based on the dry weight of the soil mixture and defined as follows:

$$WP\% = \frac{w_{ps}}{w_s} 100\% \tag{1}$$

where w_{ps} is the weight of the waste bottle plastic strips and ws is the dry weight of the soil mixture. Four different percentage ratios WP% were used in this study namely; 0.25, 0.5, 0.75 and 1.0 % to study the effect of the strip amount on the soil shear strength. Several unconfined compression tests were conducted; one test on soil without any reinforcement, 36 tests on reinforced soil with plain plastic strips to cover all percentages ratio WP% with all different strip sizes and 4 tests were performed on soil reinforced with corrugated plastic strip for different percentage ratios WP%.

2.3. Samples preparation

The soil was first prepared without adding any reinforcement by thoroughly mixing 60 % sand finer than 1.18 mm

Table 1. Properties of soil mixture without adding plastic strips.

Properties	Value	Standard
Specific gravity, G_s	2.68	ASTM D854 [7]
Liquid limit, LL	19 %	(BS 1377) [8]
Plastic limit, PL	11 %	ASTM D4318 [9]
Plasticity index, PI	8 %	
Maximum dry unit weight γ_{dmax}	19.23 kN/m^3	ASTM D1557 [10]
Optimum moisture content, OMC	12.3 %	
unconfined compressive strength, q_u	62.67 kN/m^2	ASTM D2166/D2166M [11]

with 40 % kaolin. The mixed soil was prepared to perform the Unconfined Compression Tests on soil samples with and without reinforcement. To study the influence of adding strips of waste plastic bottle as a reinforcing material on the shear strength of soil; different surface types, sizes and percentage ratios of the plastic strips were added to the soil mixture. All the samples prepared to perform the unconfined compression test were compacted to the maximum dry unit weight and optimum moisture content of the soil mixture without reinforcement namely; 19.23 kN/m^3 and 12.3 %, respectively. All the samples are compacted in the standard unconfined compression mold to produce samples with initial length and diameter of 80 mm and 38 mm, respectively. To prepare the reinforced soil samples and after having a uniform dry soil mixture, a predetermined amount of plastic strip according to the described addition percentage ratios WP% was added to the mixture and mixed together thoroughly by hand to obtain a uniform distribution of plastic strips through the soil mixture. Then a calculated amount of water at optimum moisture content was added to the mixture. The mixture then was divided into three parts. Each part was compacted in the standard mold of the unconfined compression test at a dry unit weight of 19.23 kN/m^3. Then the sample was extracted from the mold and placed in the unconfined compression machine. The test was strain controlled at rate of 1 mm/min. This procedure was followed also without adding any plastic strips to obtain soil sample without reinforcement to perform the unconfined compression test.

3. Results and Discussions

Series of unconfined compression tests were conducted on the soil mixture samples without reinforcement and on soil samples reinforced by waste plastic bottle strips uniformly distributed throughout the samples with different sizes, addition percentage ratios WP% and different type of plastic strip surface whether plain or corrugated.

3.1. Results of adding plain waste plastic bottle strips reinforcement

The stress-strain relationship is very important to better understand the mechanical behavior of modified soils [12]. Therefore, studying this relationship help to investigate how the plastic strip reinforcement affects the behavior of the reinforced soil.

Fig. 4 shows the relationship between the axial stress vs. the axial strain of the samples with and without plain plastic strips for different addition percentage ratios WP% and for different sizes of strips. It is shown that for all percentage ratios WP% and for a particular width of strip, the unconfined compressive strength q_u increases significantly as the length of the plastic strip increases. This increase is due to that the plastic strips act like a tensile member through the reinforced soil sample during the shearing process and that increases the shearing resistance of that samples.

It is also noticed from Fig. 4 that for small strains there is no appreciable effect of adding plastic strips on the shear stress of soil. The shear stress increases considerably for larger strain more than about 2.0 %. This behavior is also observed by Shao et al in (2014) [4] when studying the effect of reinforcing sandy soil by adding fiber with different ratios. It is predicted that at small strains the plastic strips are slipping and yielding. Then, all strips throughout the specimen start being stretched at large strains. This finding is in good agreement with Consoli et. al. (2007) [2].

All the soil samples generally exhibit a strain softening behavior with the same trends irrespective of the ratio or the dimensions of the plastic strips. The reinforced soil specimen starts to upgrade its strength until it reaches a certain constant value with further strain. It is well recognized that the plastic strips can offer a good strength for the soil which is appeared from the direct relation between the WP% and q_u. A continuous development in the compressive strength is shown in Fig. 4 with increasing the plastic ratio from WP%= 0.25 % to 1 %. Although these plastic strips contribute in increasing the unconfined compressive

(a)

(b)

Fig. 2. Waste plastic bottle strip : (a) plain strips (b) corrugated strips.

strength by sharing the applied axial load with the soil particles, both the random distribution and the orientation

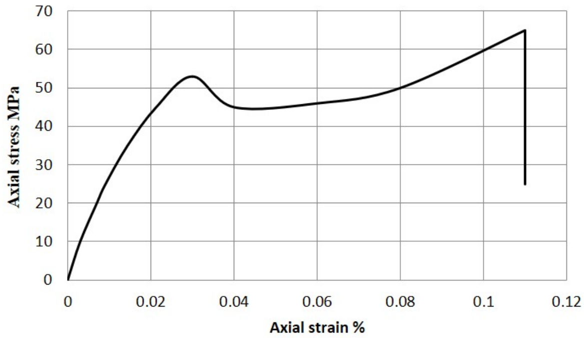


Fig. 3. The axial stress-strain relationship of the plastic strip.

of the strips lead the slip surface to follows a longer and unexpectable path.

The failure of the reinforced samples occurs after large axial strain. The initial stress–strain behavior of the reinforced samples shows the reinforced sample is less stiff than the unreinforced soil up to about 2 % axial strain. At initial and small strain levels, the sample resistance is taken mostly from the soil particles. It is well known that the plastic strips are extensible members and they require an initial strain to begin its strength mobilization. At small strain level, the plastic strips through the soil sample have not stretched enough to mobilize tensile force within it. With increase in the sample deformation, the plastic strips stretched leading to gradual mobilization of tensile strength which begins to share the sample strength. The lateral deformation of samples is restricted by the stretched fibers and this improves the stiffness of the reinforced samples at high axial strain.

Table 2 shows the percent improvement in unconfined compressive strength q_u of the soil samples when adding the plain waste plastic bottle strips as a reinforcing material. The maximum percent increase in q_u is 181.0 % for addition ratio WP% of 1 % and was when using plain plastic strip of size (1x15) mm. Moreover, when investigating the axial stress-strain relationship in Fig. 4 and the value of the axial strain% in Table 2 which corresponding to the unconfined compressive strength q_u, it is obvious that the plastic strip reinforcement increases the ductility of the reinforced soil. Moreover, the values of the lateral strain% at unconfined compressive strength q_u for each soil sample is illustrated in Table 2. It is seen from these values for a certain addition ratio WP% and for a specific strip width, the value of the lateral strain% at unconfined compressive strength q_u increases as the length of the strip increases. It is also shown that for a certain size of strip, the lateral strain% increases as the addition ratio WP% increases. This means that the reinforced samples undergo large lateral deformation at higher axial stress prior to failure stage and the inclusion of plastic strips through soil samples improves the behavior of soil under higher strains and makes it undergoes higher strains before the failure stage occur through the mobilization of the tensile strength within the strips.

The failure pattern of the samples after completion of the unconfined compression tests is shown in Fig. 5 which is for unreinforced and reinforced samples with plain plastic strip of size (1x15) mm and for addition ratio WP% of 1.0 %. It is shown from this figure that the unreinforced sample shows a brittle behavior at failure (Fig. 5a), while the samples reinforced with plastic strips tend in somehow bulge and show a ductile behavior. The inclusion of the plastic strips in soil sample increase the ductility of the sample. The ductility increases as the addition ratio WP% increases. Noting that the same behavior was observed for all samples reinforced with different plastic strips sizes and addition ratios. This behavior is also observed by Ayothiraman and Singh 2017 [13].

Fig. 6 shows the relationship between the unconfined compressive strength q_u and the addition percentage ratio WP% for all samples reinforced with different plain plastic strip sizes. It can be noticed that the unconfined compressive strength q_u increases gradually as the addition percentage ratio WP% increases. This is due to increasing the amount of the plastic strips which have the effect on increasing the shear resistance of the reinforced sample. This is compatible with Consoli et al. 2011 [3]. The maximum increase in unconfined compressive strength q_u is when using a plastic strip of minimum width and maximum length, i.e the strips of size (1x15) mm for all addition percentage ratios WP%. It can be noticed from this graph that the increase in the ultimate stress q_u for a particular addition ratio WP% occurs when using plastic strips of minimum aspect ratio and this obviously shown when using higher addition ratio WP%.

3.2. The effect of corrugated surface of the waste plastic strips

It has been shown that the best percentage of improvement in unconfined compressive strength q_u of soil was when using plain plastic bottle strips of size (1x15) mm for all plastic percentages ratios WP% of 0.25, 0.5, 0.75 and 1.0 %. Therefore, to study the effect of varying the strip surface; corrugated waste plastic bottle strips of the same size of (1x15) mm were prepared to achieve this purpose.

Fig. 7 shows the axial stress-strain relationship of soil without and with reinforcement by corrugated surface plastic strips for different addition ratios WP% of 0.25, 0.5, 0.75 and 1.0 %. A softening behavior is also noticed for all the specimens reinforced with different ratios of corrugated strips and follow the same trends. It is obvious from this figure that the unconfined compressive strength q_u of reinforced soil increased massively as compared with non-reinforced soil. The corrugated surface causes a longer interface path and a better interlocking with the soil which make the plastics strip hardly be slipped out from the soil mass and more efficient in sustaining high stresses and strains before failure stage. The largest improvement ratio of unconfined compressive strength q_u reached up to about 269.83 % at WP% of 1.0 % as shown in Table 3 which illustrates improvement ratios in q_u for soil reinforced with corrugated surface waste plastic bottle of size (1x15) mm for all percentage ratios WP%. It is worth mentioning that and from observing the stress-strain relationship of Fig. 7, the unconfined compressive stress increases notably for strain larger than about 4.25 % which means that the soil reinforced with corrugated surface plastic strip became more ductile under higher stress.

Table 3 also shows the lateral strain% that occurred in each sample at the unconfined compressive strength q_u. It is clear from these values of lateral strain%, the samples reinforced with corrugated plastic strips undergo lateral strain% at failure more than that of samples reinforced with plain plastic strips. This indicates that the corrugate plastic strips within the samples constrain the soil particles and give these samples the strength and ductility to undergo more stains before failure by mobilization of higher tensile stress through the plastic strips. Fig. 8 shows the tested reinforced sample with corrugated plastic strips of size (1x15) for different addition ratios WP%. It is clear from this figure that the tested samples undergo large deformations before failure especially when using higher addition ratio WP% of 1.0 %.

Moreover, it is obviously shown that when reinforcing with corrugated surface plastic strip, the unconfined compressive strength q_u of soil is increased considerably in comparison with that of plain strips for all addition percentage ratios WP%. The interlocking that occur between soil particles and the corrugated surface of the strip results in constraining the soil particles to each other and that led to obvious increase in shear strength. This increase was also due to increasing the surface of friction between soil particles and plastic strips. To better observe the improvement ratio in unconfined compressive strength q_u of soil reinforced by corrugated surface plastic strips in comparison with that when reinforcing with plain plastic strips, Fig. 9 shows the relationship between the unconfined compres-

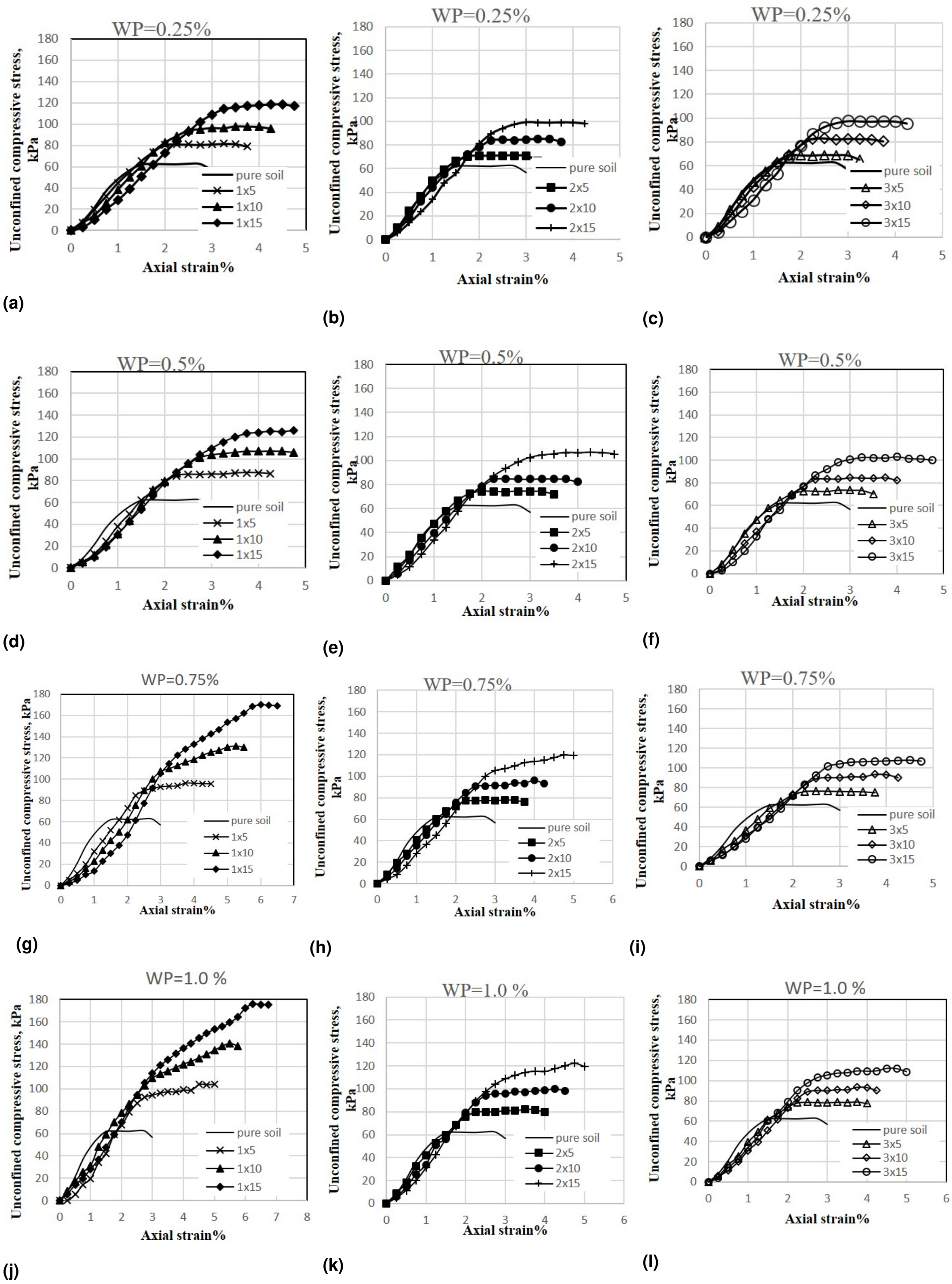


Fig. 4. The relationship between the unconfined compressive stress and the axial strain of soil samples with and without plain plastic strips tested by the unconfined compression test for different addition percentage ratios WP%.

sive strength q_u and the addition percentage ratio WP% for both plain and corrugated surface plastic waste bottle strip of size (1x15) mm. The maximum improvement ratio in unconfined compressive strength q_u by using corrugated strips with respect to that when using plain strips is 31.61 % for percentage ratio WP% of 1.0 %.

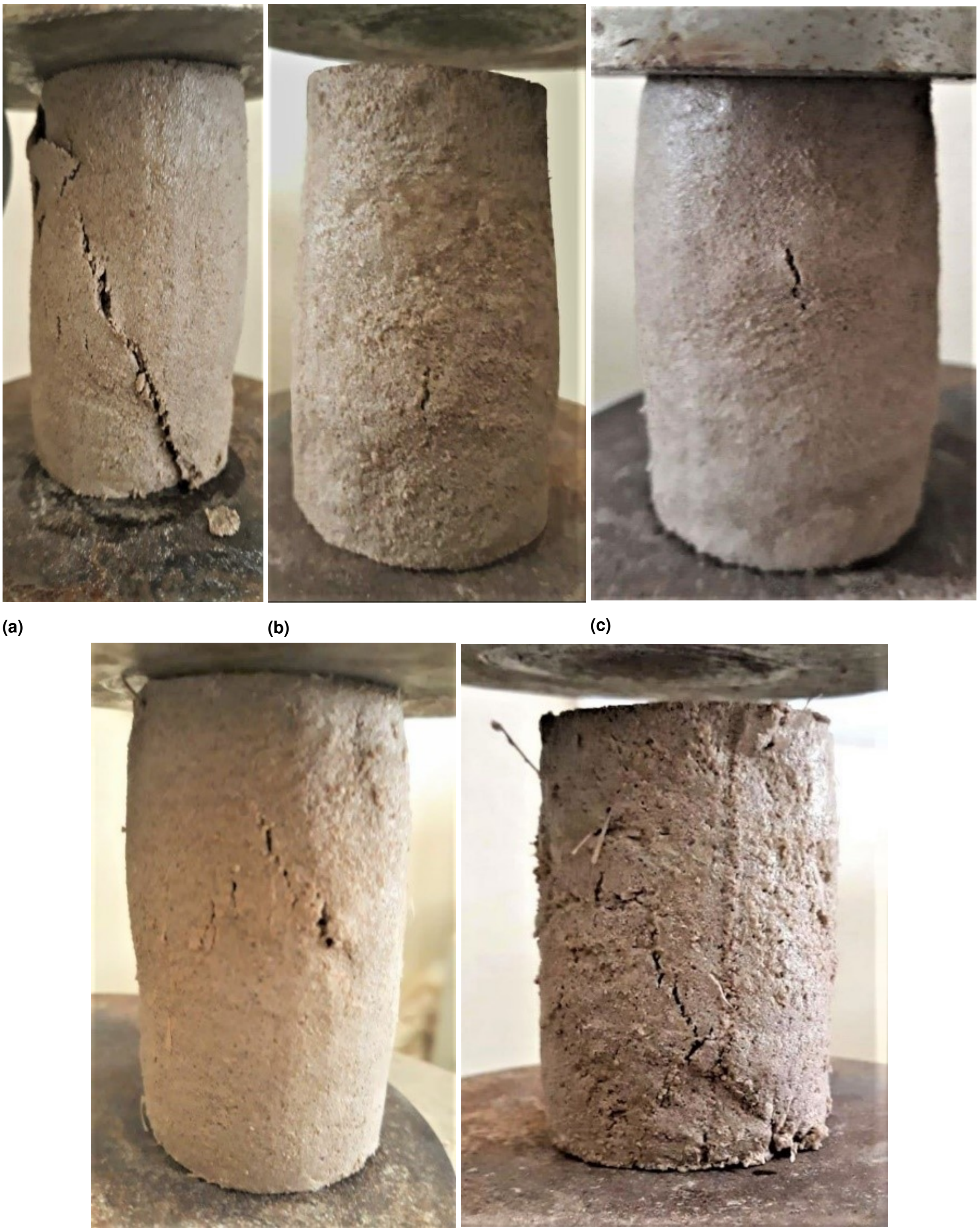
Table 2. Percent increment in unconfined compressive strength q_u for different addition ratios WP% using plain plastic strips.

WP%	Width mm	Length mm	q_u kN/m^2	Axial Strain% @ q_u	% q_u increment	Lateral Strain% @ q_u
0	-	-	62.67	2.50	-	1.27
0.25	1	5	81.6	3.25	30.21	1.67
	2		71.03	2.50	13.34	1.27
	3		68.94	2.25	10	1.14
	1	10	97.87	3.50	56.17	1.80
	2		84.99	3.25	35.62	1.67
	3		82.87	3.00	32.23	1.53
	1	15	118.68	4.50	89.37	2.33
	2		99.07	3.75	58.08	1.93
	3		97.69	3.25	55.88	1.67
0.5	1	5	87.30	3.75	39.30	1.93
	2		74.32	3.00	18.59	1.53
	3		73.63	2.75	17.49	1.40
	1	10	107.37	4.25	71.33	2.19
	2		84.99	3.25	35.62	1.67
	3		84.56	3.00	34.93	1.53
	1	15	125.85	4.75	100.81	2.46
	2		106.68	4.25	70.22	2.19
	3		102.85	4.00	64.11	2.06
0.75	1	5	96.24	3.75	53.57	1.93
	2		78.09	3.25	24.61	1.67
	3		76.60	3.00	22.23	1.53
	1	10	131.28	5.25	109.48	2.73
	2		95.99	4.00	53.17	2.06
	3		93.49	3.75	49.18	1.93
	1	15	169.19	6.00	169.97	3.14
	2		119.73	4.75	91.05	2.46
	3		107.77	4.50	71.96	2.33
1	1	5	104.09	4.75	66.09	2.46
	2		98.73	4.00	57.54	1.80
	3		79.06	3.75	26.15	1.93
	1	10	140.39	5.50	124.0	2.87
	2		99.84	4.25	59.31	2.19
	3		95.99	4.00	53.17	2.06
	1	15	176.10	6.25	181.0	3.28
	2		122.45	4.75	95.39	2.46
	3		111.86	4.50	78.489	2.33

3.3. The secant modulus of elasticity

The secant modulus is determined from one half of the strain at peak strength. Fig. 4 and Fig. 7 reveal the effect of WP% on the secant modulus. One can notice that this modulus is decreased with the addition of plastic strips.

The interaction of the soil along the smooth surface of the plastic waste strips takes a time until reaching fully mobilization at which the plastic sheets start to elongate and restrict the soil deformations. This is why the reinforced soil loss its stiffness at the earlier stage of loading and upgrade to the ultimate values at an axial strain more than around 2 % as shown in these two figures. Same behavior of the secant modulus could be found in Cai et al. (2006) [14] and Wang et al. (2019) [15] where their speci-



(a) (b) (c) (d) (e)

Fig. 5. The failure pattern of soil samples unreinforced and reinforced with plain plastic strips of size (1x15) mm with different addition ratios WP% : (a) unreinorced soil sample , (b) WP=0.25 %, (c) WP=0.5 %, (d) WP=0.75 %, and (e) WP= 1.0 %.

mens were reinforced with polypropylene fibers and wheat straw fibers respectively.

4. Conclusion

The effect of waste plastic bottle strip reinforcement on the strength of the clayey sand soil was investigated in

Table 3. Percent increment in unconfined compressive strength q_u for different addition ratios WP% using corrugated plastic strip of size (1x15) mm.

WP%	q_u kN/m^2	Axial Strain%	% q_u increment	Lateral Strain%
0	62.67	2.5	-	1.27
0.25	144.22	4.75	130.1	2.46
0.5	155.65	5.25	148.36	2.73
0.75	219.12	6.75	249.64	3.56
1.0	231.77	7	269.83	3.69

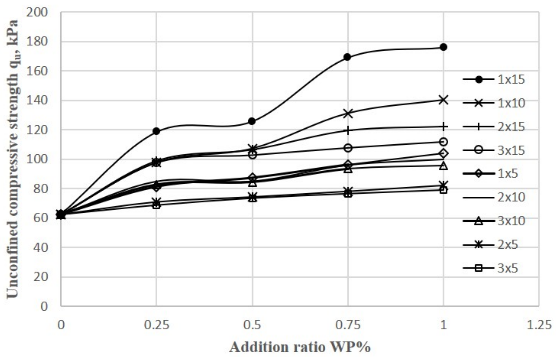


Fig. 6. Relationship between the unconfined compressive strength q_u and the addition ratio WP%.

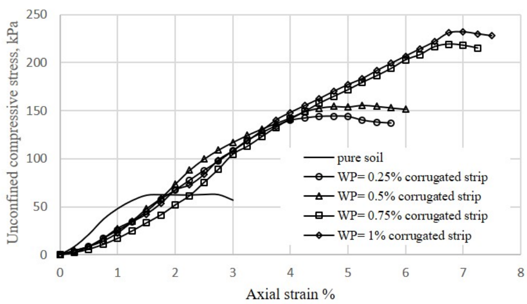


Fig. 7. Stress-axial strain relationship of soil reinforced by corrugated waste plastic bottle strips of size (1x15) mm for different percentage ratios WP%.

terms of an unconfined compression strength. Two types of strips were used; plain and corrugated surface strip. The plain strip sizes (BxL) are: (1x5), (1x10), (1x15), (2x5), (2x10), (2x15), (3x5), (3x10) and (3x15) mm, while one size of corrugated strips was used namely; (1x15) mm. Both plain and corrugated waste plastic bottle strips were used with different percentage ratios WP% namely; 0.25, 0.5, 0.75 and 1.0 %. It is concluded that for a particular width of plain strip, the unconfined compressive strength q_u increases significantly as the length of the plain plastic strip increases for all percentage ratios WP%. It is worthy mention that increasing the amount of the reinforcing plain plastic strips would increase the unconfined compressive strength q_u. The maximum improvement of the unconfined compressive strength q_u was 181.0 % for percentage ratio WP% of 1 % and was when using plain plastic strip of size (1x15) mm. Moreover, the sample lateral strain% at unconfined compressive strength q_u for a particular strip width was found to be increased as the length of the strip increased. It is also shown that for a certain size of strip, the lateral strain% also increases as the addition ratio WP% increases. This means that the soil becomes more ductile and undergoes large strains before failure stage. However, this behavior is so clear from investigating the stress-strain relationship of soil.

The surface of the plastic strip has a great influence on the unconfined compressive strength of soil, since it is increased remarkably as compared with non-reinforced soil. The largest improvement ratio of unconfined compressive strength q_u reached up to about 269.83 % at WP% of 1.0 %. however, reinforcing with corrugated plastic strip improves the unconfined compressive strength by 31.61 % for percentage ratio WP% of 1.0 % when compared with plain plastic strip.

plastic strip reinforcement shows more ductile behavior of soil when investigating the stress-strain relationship of soil. The shear stress increases considerably for larger strain more about 2.0 % when reinforcing with plain plastic strips while the unconfined compressive stress increases notably for strain larger than about 4.25 % when reinforcing with corrugated plastic strips which means that the soil reinforced with corrugated surface plastic strip became more ductile under higher stress.

It is worth mention that when investigating the stress-axial strain relationship of soil reinforced with plain and plastic strips the secant modulus of elasticity is decreased with the addition of plastic strips.

It is important to mention that these results and conclusions are valid only for the materials used in this study. The plastic strip orientation was not taken into account in this investigation. More studies are needed with different

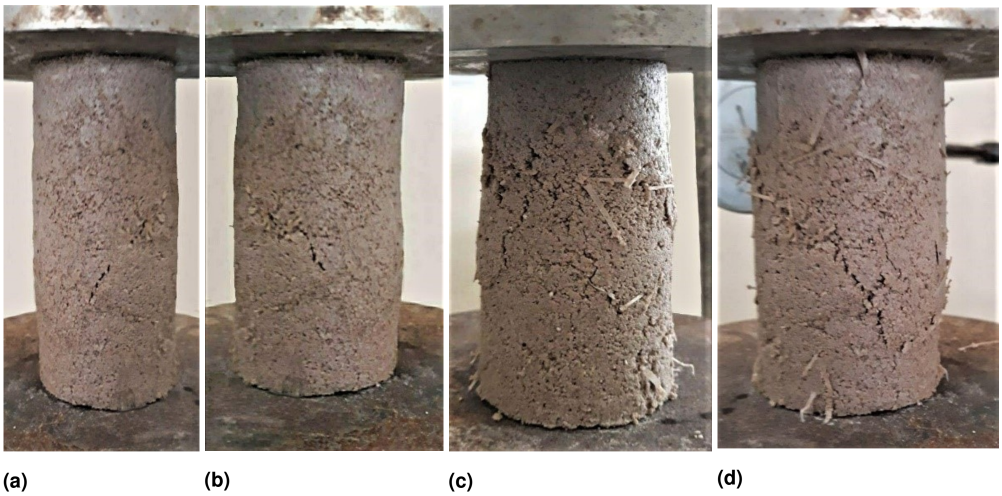


Fig. 8. The tested reinforced sample with corrugated surface plastic strips of size (1x15) mm for different addition ratios WP%: (a) WP=0.25 %, (b) WP=0.5 %, (c) WP=0.75 %, and (d) WP= 1.0 %.

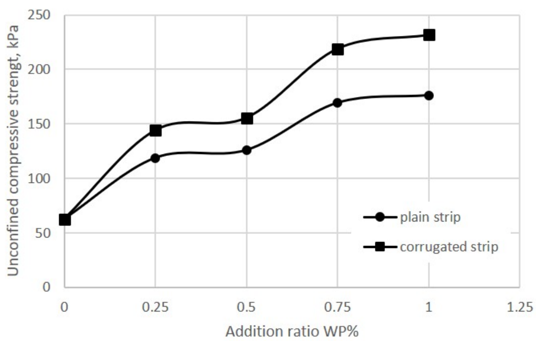


Fig. 9. The relationship between the Unconfined compressive strength q_u and the percentage ratio WP% for both plain and corrugated surface plastic waste bottle strip of size (1x15) mm.

soil types, different distribution and orientation of strips and different percentages ratios of strips WP%. In addition, more soil properties can be studied to evaluate the effect of plastic strip reinforcement; such as CBR, hydraulic conductivity, bearing capacity and settlement.

5. Acknowledgment

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