ISSN: 2716-9227 Algerian Journal of Engineering and Technology 08 (2023) 333–340 e-ISSN: 2716-9278

Algerian Journal of Engineering and Technology

Journal homepage: https://jetjournal.org/index.php/ajet

Original Article

Consolidation and collapse behavior of silty soil reinforced with plastic water bottles wastes

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ARTICLE INFO

Article history:
Received 13 May 2023
Revised 01 July 2023
Accepted 13 July 2023

Keywords:
silty soil;
water bottles wastes;
compaction;
consolidation;
collapse.

ABSTRACT

This research paper has focused on the influence of plastic waste materials (water bottles) on the consolidation and collapse behavior of silty soil. The silty soil was randomly reinforced with various fiber content (0.5, 1.0 and 1.5% of the dry weight of soil) having various lengths of 10, 20 and 30 mm. The soil samples were prepared at the maximum dry unit weight and the optimum moisture content of unreinforced soil, (natural soil) using standard compaction efforts. The variation in the compaction, collapse and consolidation characteristics of unreinforced and reinforced soil samples were evaluated. The test results indicated that there was a slight reduction in both the maximum dry unit weight and the optimum moisture content of soil samples with fiber addition. The collapse index increased with increasing fiber content, while the fiber length enhance the collapsibility of silty soil. Further, the compression index of reinforced soil samples followed the same trend as the collapse index.

1. Introduction

Silty soils are largely widespread in various parts of the World. Their engineering properties (such as low plasticity, small shear strength parameters, low bearing capacity, high liquefaction susceptibility, etc.) make them unsuitable for civil engineering constructions [1-2]. Construction on silty soils has been conducted with different techniques to overcome the problem, like compaction, mechanical gradation, chemical stabilization and soil reinforcement techniques [3-7]. Soil reinforcement using natural, synthetic, and waste materials represents a significant technique to enhance the engineering properties of silty soils [8-10]. The soil reinforcement method is originally defined as soil that is reinforced by a material able to sustain tensile stresses and which bounds with the soil particles through adhesion and friction [11-13]. Scholars added different types of reinforcement elements to enhance the engineering characteristics of soils, such as fibers, geotextiles, geogrid, etc. [14-16].

In different countries in the World, plastic waste materials (PWM) have been generating environmental and disposal problems. Using these materials in geotechnical applications can solve disposal problems in an environmentally friendly and cost-effective manner [17]. PWM can be used as fibers to enhance the engineering properties of different types of soils [18]. In previous researche, the use of PWM as fibers has shown promising results. when these fibers inclusion in soils, significant enhancements are demonstrated in the overall mechanical properties of reinforced soils. Sequentially, the randomly distributing methods of fibers have involved increasing

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Peer review under responsibility of University of El Oued.

 https://doi.org/10.57056/ajet.v8i2.152

attention in geotechnical applications due to their efficiency in improving soil properties [19]. Kar and Pradhan, [20] studied the compressibility properties of low-plasticity clay soil with both random inclusion fibers (polypropylene and coir fibers). They concluded that both compression index and coefficient of volume change reduced with increased fiber content. They also noticed that the coefficient of consolidation increased with increased fiber content. Similar remarks were noticed by Malekzadeh and Bilsel, [21] during their study of the influence of fibers on the compressibility of expansive soil. Soltani, [22] studied the impact of plastic waste content on the behavior of clay soil. Triaxial tests result illustrated that the shear strength and pore water pressure of reinforced samples depend on the plastic waste percentage. Generally, the friction angle value of reinforced samples is lesser than the value of unreinforced samples. While the cohesion value showed inverse behavior as compared with the angle of friction. Boz et al., [23] have reported that the use of plastic fibers increases the strength of the clay soil and both fiber type and fiber length are important elements in fiber-reinforced clay soil. Peddaiah et al., [24] examined the behavior of waste plastic bottle-reinforced young loam soil with varying percentages of this waste. The tests result presented that the maximum strength values were achieved for 0.4% plastic waste percentages. Hassan et al., [18] reported that, according to the design codes of road pavement which are used the California Bearing Ratio (CBR) and resilient modulus (Mr), the plastic waste fiber is cheap and can be positively used for road construction as compared with chemically stabilized soils. Huang et al., [25] studied the impact of two kinds of waste materials as fibers on the engineering behavior of expansive soil. These fibers were recycled from solid waste termed glass fiber (GF) and polypropylene fiber (PF). The results display that both fibers significantly increase the shear strength of expansive soil. The major factor governing the performance of fiber-enhanced expansive soil is the adhesion between soil particles and fibers. In general, the enhancement effect of PF is better than that of GF due to their surface roughness.

This research paper aims to explain the impact of PWM on the consolidation and collapse behavior of silty soil. Various percentages of PWM fibers (ranging from 0 – 1.5%) were added to the soil to achieve this target. Besides, fiber length (varied from 10 – 30 mm) was taken into account. Finally, statistical relationships were constituted for predicting compression and collapse indices with varying PWM fiber percentages.

2. Materials

2.1 Soil

The soil used in the current study was silty soil obtained from Mosul City – Iraq. Based on the main property tests following the ASTM standards, the main index, physical and chemical properties of silty soil were mentioned in Table 1. The grain size analysis results of silty soil achieved by sieve and hydrometer analysis tests are illustrated in Table 2. It is well-known that the main composition of the soil used in this study is mainly silt particles having a diameter ranged 0.075 mm to 0.005mm, with silt percent as high as 48 %. The grain size distribution and the compaction curves of natural soil were presented in Figs. 1 and 2, respectively.

Table 1. Some physical properties of natural soil

Organic content (%)	**Specific gravity**	**Liquid limit (%)**	**Plastic limit (%)**	**OMC (%)**	**MDUW (kN/m^3)**
1.37	2.67	----	----	16	17

Table 2. Grain size analysis of natural soil

Particles size (mm)	**Gravel** > 4.74	**Sand** 4.74–0.075	**Silt** 0.075–0.005	**Clay** < 0.005
Value (%)	10	30	48	12

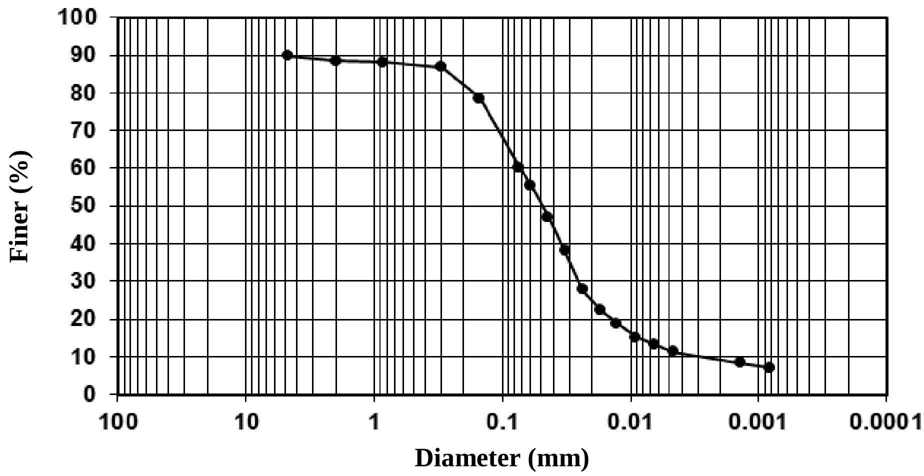

Fig 1. Grain size analysis of natural soil

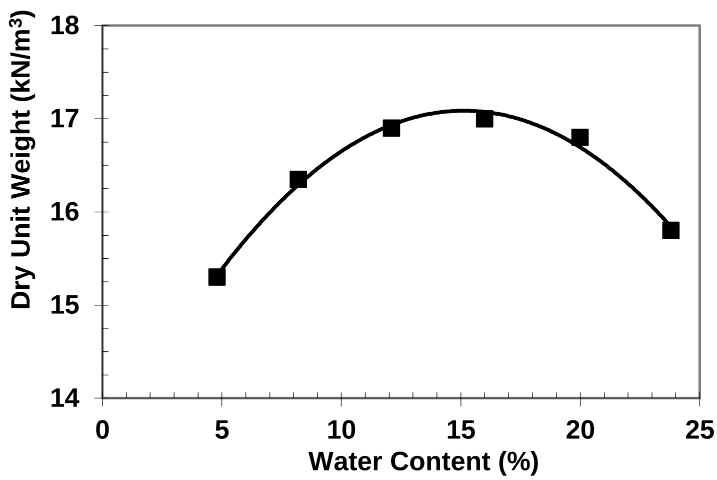

Fig 2. Compaction curve of natural soil

2.2 Plastic waste materials

In the present study, plastic waste materials from water bottles (PWM) were used as fiber reinforcement elements as illustrated in Fig. 3 PWM fibers were prepared by cutting waste water bottles into fibers having (2-3 mm) in width and three different values in lengths of 1, 2 and 3 cm. The fiber percentages were added to the soil at 0.5, 1 and 1.5% of the dry weight of the silty soil. Some mechanical and physical properties of PWM were tabulated in Table 3.

Fig 3. Preparation of the fiber from the water bottles

Table 3. Some physical properties of PWM

Property	Length (mm)	Width (mm)	Thickness (mm)	Specific gravity (ASTM D792)	Tensile strength (Mpa) (ASTM D882)	Resistance to acid and alkaline
Value	10-30	2-4	0.05	1.26	354	High

3. Testing Program

3.1 Sample preparation

In sample preparation and for all tests adopted here, the desired fiber percentages were first manually mixed into the oven-dried soil (2 days at 60 ^{o}C), and the plastic waste fiber was added to the soil by weight. Significant care was taken into account to accomplish a homogeneous mixture throughout the mixing process. Thereafter, a desired quantity of water content according to the optimum moisture content of natural soil was added to the soil samples. The blends were thoroughly remixed again to attain a uniform mixture, then the soil-fiber mixture was placed into plastic bags for 24 hours before compaction in order to moisture equilibrium. Finally, the samples were statically compacted to achieve the maximum dry unit weight of natural soil using standard compaction effort.

3.2 Collapse potential test

To characterize the collapse potential of the unreinforced and fiber-reinforced soil samples, the single collapse potential test was used. This test procedure followed the ASTM standards (D-5333). An Oedometer device and cylindrical soil samples (63.5 mm in diameter and 19 mm in height) were used in this test. The soil sample was progressively loaded up to 200 kPa at initial water content (i.e. before wetting). After 1 hour of applying 200 kPa, the deformation reading was recorded and the water was added to the soil sample (see Fig.4). Then The test was continued under wetted condition. The collapse potential index (Ic) was estimated according to the next equation:

$Ic = \Delta e/1+e_o$

Where:
Ic = collapse potential index.
Δe = variation in void ratio due to wetting.
e_o = initial void ratio.

It is worth noting that, the period between load increases before wetting is fixed to 1 hour to reduce the evaporation of moisture from the soil samples that would cause wrong results.

3.3 Consolidation test

A series of consolidation tests were conducted according to ASTM standards to determine the consolidation behavior due to the presence of PWM fibers (D2435). These tests were conducted for both natural and reinforced soil samples. For reinforced soil samples different percentages of PWM fibers (0, 0.5, 1.0 and 1.5%) were added to the soil. Cylindrical soil samples (63.5 mm in diameter and 19 mm in height) were used in this test. The soil samples were enclosed with filter paper (only for upper and lower faces) to avoid clogging of porous stone pores by soil particles. After that two porous stones were put at the upper and lowest of the soil samples to accelerate the soil compression due to the double drainage condition. The soil samples were loaded up to 800 kN/m^2 starting from 7.5 kN/m^2, at a standard load increment ratio of duplicated. At the end of the test, the compression index (C_c) was estimated from the void ratio – consolidation pressure relationship.

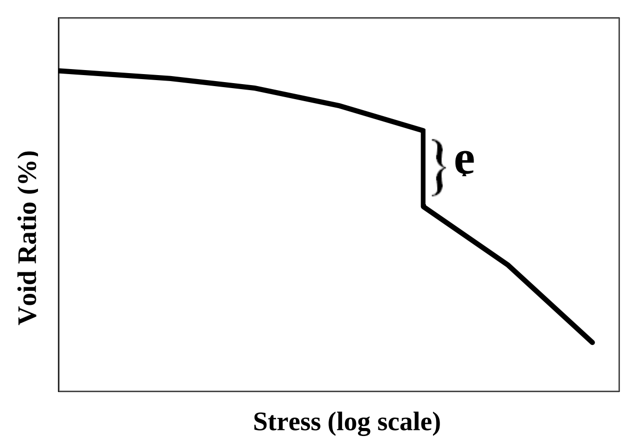

Fig 4. Typical collapse curve

4. Results and Discussions

4.1 Compaction characteristics

Fig. 5 presents the variations of maximum dry unit weight (MDUW) and optimum moisture content (OMC) of soil samples with various percentages of PWM fibers. It is observed that both MDD and OMC of soil samples decrease with increasing fiber content and fiber length.

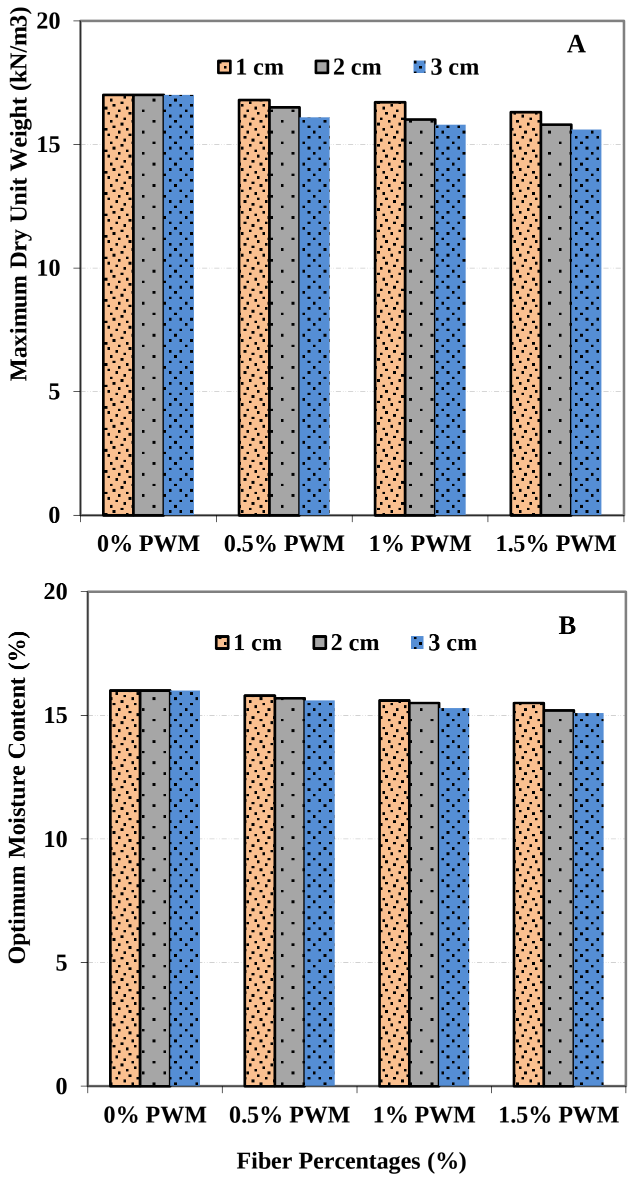

Fig 5. Variation of both maximum dry unit weight with PWM fibers (A) and optimum moisture content (B)

The reduction in MDD with fiber addition could be attributed to that, fibers are more resistant to compaction effort than soil particles which results in less dense packing in the soil-fiber mixture. Therefore, as fibers increase in soil mixture the energy absorption capacity of reinforced soil samples is increased. The reduction in OMC of reinforced soil samples as compared with those of natural soil is related to the low moisture absorption properties of plastic materials. Generally, plastic materials are more resistant to moisture absorption compared to soil particles which are represented as porous materials. Similar observations were noticed by [18 and 26].

4.2 Collapse characteristics

Fig. 6 illustrates the variation in the collapse potential (Cp) of reinforced soil samples versus both fiber content and fiber length.

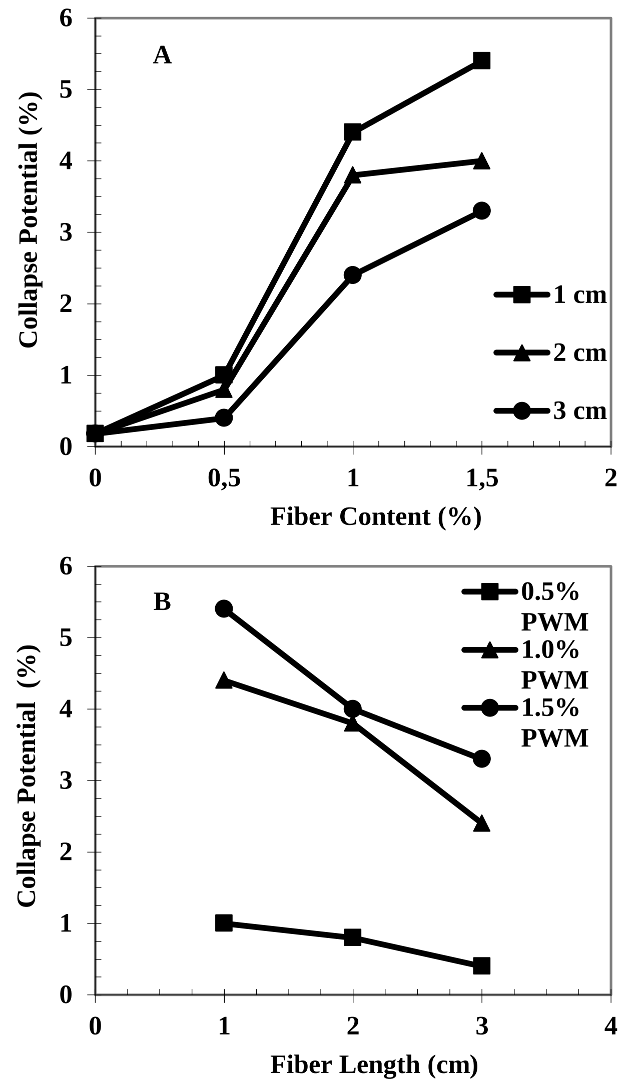

Fig 6. Variation of collapse index with PWM fibers content (A) and with PWM fibers length (B)

The obtained results showed that the PWM addition affected the variation in the collapse behavior of silty soil. The Cp value of unreinforced soil samples (0.18 %) increased linearly with increasing fiber content (see Fig. 6-A). The maximum values of Cp were recorded for soil samples reinforced with 1.5% of PWM. These values were (5.4, 4 and 3.3%) for soil samples reinforced with fibers having 10, 20 and 30 mm in length, respectively. The values of Cp of reinforced soil samples and according to ASTM D5333-03 revealed that the collapsibility behavior was increased from slight to moderate, which indicated a negative influence of PWM addition on the collapse behavior of soil samples. The increase in the Cp of reinforced soil samples with PWM may be attributed to that fiber addition causing more open soil structure due to the fiber clumping, (see Fig. 7) then resulting in more voids between soil and fiber at the contact points. Further, the flexibility of the fiber itself could create the reinforced soil to be more collapsible than the unreinforced soil. To achieve the influence of fiber length on the collapse potential of reinforced soil samples, the relationship between fiber length against Cp was presented in Fig. 6-B**.** The Cp values are affected by the fiber length, where these values decreased as the fiber length increase. However, minimum values of Cp were 0.4, 2.4 and 3.3% of soil samples reinforced with 0.5, 1.0 and 1.5% fiber content having 30 mm in length. This phenomenon could be caused by the decrease in voids among fibers and soil grains. Also, increasing fiber length results in more tangling between fibers leading to form a more stable soil structure rather than soil samples with shorter fibers.

Fig 7. The clumping phenomenon of PWM fibers

4.3 Consolidation characteristics

The variation in the soil compressibility (represented by the compression index Cc) of reinforced samples with various fiber content and fiber length was shown in Fig. 8. The variation in Cc values of reinforced soil samples followed the same trend as the variations in Cp values. This means that Cc values of soil samples increased with the inclusion of PWM fibers for all the fiber contents and fiber lengths investigated.

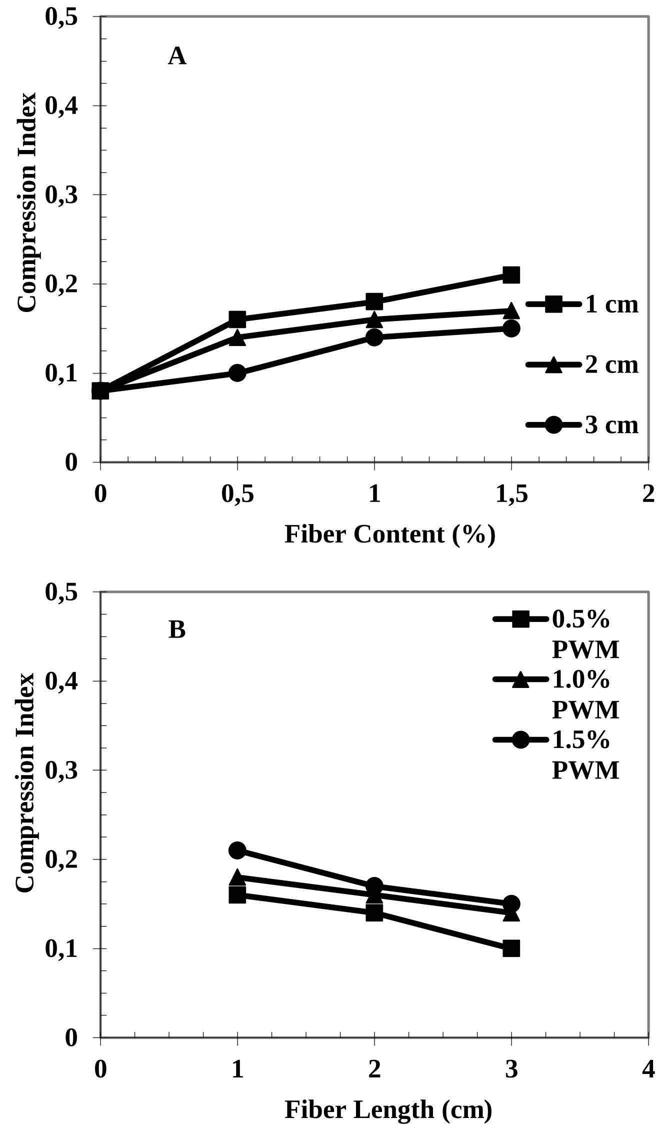

Fig 8. Variation of compression index with PWM fibers content (A) and with PWM fibers length (B)

These Cc values were increased from (0.08) for unreinforced samples to the maximum values of 0.21, 0.17 and 0.15 for soil samples reinforced with 1.5% fibers having 10, 20 and 30 mm in length, respectively. This behavior could be attributed to the fact that fiber addition caused more voids in the soil matrix and compression of these voids resulted in greater Cc values than the soil alone. Further, the inclusion of more fiber content causes issues with sample preparation and will finally have more voids resulting in higher Cc values. Estabragh et al., [27] conclude similar results during their study about the effect of nylon fibers on the compressibility of clayey soil. To study the influence of the fiber length on the soil compressibility, the relation between Cc values and different fiber length were illustrated in Fig. 7-B. Similar to the Cp values of reinforced soil samples, the increases in fiber length cause an increase in the Cc values. The minimum values of Cc were 0.1, 0.14 and 0.15 of soil samples reinforced with 0.5, 1.0 and 1.5% fiber content having 30 mm in length. The reduction in Cc values with increasing fiber length could be attributed to the volume occupied by the fiber, leading to extra fiber interaction and thus compression of the fiber will be dominant. Similar results were obtained by Moghal et al., [28], where an increase in Cc values was noticed with an increase in fiber length.

5. Conclusions

According to the obtained results, the next conclusions were drawn:

- PWM showed an insignificant effect on the compaction characteristics (especially the optimum moisture content) since these materials do not absorb water as the soil grains.
- Both the collapse and the compression indices showed the same trend with the addition of the PWM fiber. These indices were increased with increasing fiber content, while increasing fiber length causes some reduction in these indices whether a comparison was made between reinforced samples.
- The presence of PWM fibers reduces the resistance of soil to compression by increasing voids formation among fibers and soil grains.
- For future work it is strongly recommended to use a chemical agent (like cement or lime) when using the PWM as fiber in soil reinforcing, to reduce the collapse potential of reinforced soil more than the reinforcement technique itself.

Conflict of Interest

The authors declare that they have no conflict of interest.

References

1. Ma Q, Duan W, Liu X, Fang P, Chen R, Wang T, Hao Z. Engineering Performance Evaluation of Recycled Red Mud Stabilized Loessial Silt as a Sustainable Subgrade Material. *Materials*. 2022;15, 33-91.
2. Lin Q, Zhen X, Rong Y, Li Y, Zhang H, Zhang Q, Yao Z, Yao K. Investigation on mechanical and microstructure properties of silt improved by titanium gypsum-based stabilizer. *Materials*. 2023;16, 2-71.
3. Cai G, Zhang T, Liu S, Li J, Jie D. Stabilization mechanism and effect evaluation of stabilized silt with lignin based on laboratory data. *Marine Georesources Geotechnology*. 2014;34:331–340.
4. Horpibulsuk S, Rachan R, Chinkulkijniwat A, Raksachon Y, Suddeepong A. Analysis of strength development in cement-stabilized silty clay from microstructural considerations. *Construction and Building Materials*. 2010;24: 2011–2021.
5. Jauberthie R, Rendell F, Rangeard D, Molez L. Stabilisation of estuarine silt with lime and/or cement. *Applied Clay Science*. 2010; 50: 395–400.
6. Aldaood A. Impact of fine materials on the saturated and unsaturated behavior of silty sand soil. *Ain Shams Engineering Journal*. 2020;11: 717–725.
7. Xu G, Chen J, Shi S, Tian A, Tang Q. Shear behaviors of the inter-surface between rice straw rope and dredger fill silt: experimental and mechanism studies. *Advances in Civil Engineering*. 2020.
8. Hejazi SM, Sheikhzadeh M, Abtahi SM, Zadhoush AA. simple review of soil reinforcement by using natural and synthetic fibers. *Constrcution and Building Material*. 2012;30: 100–116.
9. Wu YK, Li YB, Niu B. Investigation of mechanical properties of randomly distributed sisal fibre reinforced soil. *Materials Research Innovations*. 2014;18(2):953–-959.
10. Correia ND, Rocha SA. Reinforcing effect of recycled polypropylene fibers on a 492 clayey lateritic soil in different compaction degrees. *Soils and Rocks*. 2021;44(2):1-13.
11. Bordoloi S, Garg A, Sekharan S. A Review of Physio-Biochemical Properties of Natural Fibers and Their Application in Soil Reinforcement. *Advances in Civil Engineering Materials*. 2017;6(1):323–359.
12. Shukla SK. Fundamentals of fiber-reinforced soil engineering. *Series of Developments in Geotechnical Engineering*. 2017.
13. Mohajerani A, Hui S, Mirzababaei M, Arulrajah A, Horpibulsuk S, AbdulKadir A, Rahman MT, Maghool F. Amazing types, properties, and applications of fibres in construction materials. *Materials*. 2019;12(16): 1-45.
14. Sayeed MMA, Janaki RB, Rawal A.Interface shear characteristics of jute/polypropylene hybrid nonwoven geotextiles and sand using large size direct shear test.*Geotextiles and Geomembranes*. 2014;42(1):63–68.
15. Stacho J, Sulovska M, Slavik I. Determining the shear strength properties of a soil-geogrid interface using a large-scale direct shear test apparatus. *Periodica Polytechnica Civil Engineering*. 2020;64(4): 989–998.
16. Aldaood A, Khalil A, Bouasker M, Al-Mukhtar M. Experimental Study on the Mechanical Behavior of Cemented Soil Reinforced with Straw Fiber. *Geotechnical and Geoenvironmental Engineering*. 2021;39:2985–

3001.
17. Bozyigit I, Bulbul F, Alp C, Altun S. Effect of randomly distributed pet bottle strips on mechanical properties of cement stabilized kaolin clay. *Engineering Science and Technology, an International Journal*. 2021;24(5):1090–1101.
18. Hassan HJA, Rasul J, Samin M. Effects of plastic waste materials on geotechnical properties of clayey soil. *Transportation Infrastructure Geotechnology*. 2021;8:390-413.
19. Mistry M, Shukla T, Venkateswalu P, Shukla S, Solanki C, Shukla SK. A new mixing technique for randomly distributed fibre-reinforced expansive soil. *Environmental Geotechnology, Lecture Notes in Civil Engineering*. 2019;31: 161-171.
20. Kar RK, Pradhan PK. Strength and Compressibility Characteristics of Randomly Distributed Fibre-Reinforced Soi. *International Journal of Geotechnical Engineering*. 2011;5(2): 235-243.
21. Malekzadeh M, Bilsel H. Swell And Compressibility of Fibre Reinforced Expansive Soils. *International Journal of Advanced Technology in Civil Engineering.* 2012;1(2).
22. Soltani JH .Undrained Behavior of Clay-Plastic Waste Mixtures. International Congress On Advances In Civil Engineering. Turkey. 2014 :1-7
23. Boz A, Sezer A, Özdemir T, Hızal GE, Dolmacı ÖA . Mechanical properties of lime-treated clay reinforced with different types of randomly distributed fibers. *Arabian Journal of Geosciences*. 2018;11 (6)
24. Peddaiah S, Burman A, Sreedeep S .Experimental study on effect of waste plastic bottle strips in soil improvement. *Geotechnical and Geological Engineering*. 2018;36 (5):2907–2920.
25. Huang Z, Sun HY, Dai YM, Hou PB, Zhou WZ, Bian LL. A study on the shear strength and dry-wet cracking behaviour of waste fibre-reinforced expansive soil. *Case Studies in Construction Materials*. 2022;16.
26. Kumar T, Panda S, Hameed S, Maity J. Behaviour of soil by mixing of plastic strips. *International Research Journal of Engineering Technology*. 2018; 05(05):2578-2581.
27. Estabragh AR, Bordbar AT, Javadi AA. Mechanical behavior of a clay soil reinforced with nylon fibers. *Geotechnical and Geological Engineering*. 2011; 29(5):899-908.
28. Moghal AAB, Chittoori BCS, Basha BM. Effect of polypropylene fiber reinforcement on the consolidation, swell and shrinkage behavior of lime blended expansive soil. Road Materials and Pavement Design. 2018.

Recommended Citation
Mishaal FZ, Aldaood A. Consolidation and collapse behavior of silty soil reinforced with plastic water bottles wastes. *Alger. J. Eng. Technol. 2023*, 8(2): 333-340. DOI: https://doi.org/10.57056/ajet.v8i2.152