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An Evaluation of the Efficacy of Two Different Types of Plastic Waste Materials to Enhance the Geotechnical Characteristics of Soft Clay Soils

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ABSTRACT

Plastic waste materials are constantly increasing around the world as a result of the growing human consumption of these materials day by day, with no actual solutions to get rid of them without causing harm to the environment or the health of living organisms. Therefore, in this research, two types of plastic waste materials are utilized to enhance soft clay soil: polyethylene terephthalate (PET) and nylon (N), in percentages of (1, 1.5, 2, 2.5)% from dry soil weight, to enhance the clay soft soils properties, which are characterized by their excessive compressibility, low bearing capacity, and low shear strength. This study is carried out by conducting laboratory tests before and after the addition. These tests included the unconfined compressive strength (UCS) test, and the other test was the consolidation test. The results revealed a notable rise in the cohesion value (C) when using polyethylene terephthalate (PET), when the enhancement reached 246.42% with 2.5%, while the maximum improvement percent with nylon was 25% with 1.5%. On the other hand, when applied at a rate of 2%, nylon trash was more effective than plastic water bottles (PET) in reducing the compression index (Cc), dropping from 0.26 to 0.15.

Keywords: Soft clay soil, Plastic waste materials, Soil improvement, Compressibility, Shear strength of soil.

1. INTRODUCTION

Recent alluvial deposits that probably formed during the last 10,000 years are known as soft clays[Rference]. Soft clay soil is characterized as a problematic soil with a compression index (Cc) of 0.19–0.44, low undrained shear strength that is between 20–40 kPa, and elevated compressibility **(Broms, 1987)**. Since soil is used for the majority of civil engineering processes, certain construction sites will undoubtedly have poor soil conditions. If such soil cannot be removed, ground treatment techniques can frequently improve the soil's engineering behavior **(Glossop, 1968)**.

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The diverse, non-homogeneous nature of soil gives rise to several kinds of soil failures. Soil stabilization is a process that alters several aspects of soil to change the overall engineering features of the structure constructed above it **(Pachideh et al., 2021)**. The stable characteristics of poor soils can be enhanced through either compaction or the utilization of stabilization additives, such as asphalt, lime, or additional substances, however the cost of these chemicals has increased lately. Employing garbage plastic to stabilize soil is thought to be a solution to this issue because it gives an alternative for getting rid of plastic waste and provides a cost-effective technique to stabilize soil **(Mutter, 2019; Tangri, 2021)**. There is a huge issue with getting rid of all the plastic garbage created by different businesses. The presence of non-biodegradable waste in close proximity to the landfill causes contamination in the surrounding area **(Muntohar et al., 2013; Qasim et al., 2021)**. The rapid growth and harmful impact of waste on the environment and life have been extensively researched. According to **(Geyer, 2017)**, an estimated 15.4 billion pieces of disposable plastic are generated every day. The regular consumption of materials made of plastic including plastic bottles, bags made of polythene, food boxes and containers, pallets, cookware, electronics, and toys generates a range related ecological hazards. Amount of plastic will grow to reach throughout 308,000 tons by 2025 [Reference]. due to the harmful and toxic emissions they produce, these operations have been identified to be significant worldwide sources of pollutants **(Alasadi and Ali, 2022)**. Production of waste from 1964 to 2018 was growing from 15 to 360 million tones which totally indicate there is growing rate just double in upcoming two decades **(Sereda and Sahagun, 2023)**. Plastic waste has demonstrated its efficacy and advantages in enhancing the engineering properties of different soil types like increase the ability to support weight, raise in soil shear strength, improvement in robustness, CBR enhancement and reduction in settlement **(Iravanian and Ali, 2020)**.

Strips of plastic trash are used as materials to stabilize numerous types of soil, and several studies have been carried out by different researchers to find out the extent of their impact on the characteristics of the soil **(Babu and Chouksey, 2011; Ahmadinia et al., 2012; Peddaiah et al., 2018; Singh and Mittal, 2019; Salimi and Ghazavi, 2021)**. In addition, Various researchers have found that even small percentages that do not exceed 1% or less of plastic waste can make an effective contribution to improving soil properties **(Al-Neami et al., 2020; Kadhum and Aljumaili, 2020)**. research indicates that plastic waste material has demonstrated efficacy in enhancing the properties of sandy soil **(Consoli et al., 2002; Farah and Nalbantoglu, 2019; Al-Taie et al., 2020)**. Plastic waste was employed as a stabilizing agent for the weak base and subbase, yielding favorable outcomes **(Fauzi et al., 2016; Salih et al., 2022; Tiwari and Satyam., 2022)**.

Two different types of plastic waste were used to stabilize clay soil: polyethylene bottles (PET) and propylene bags (PP). The proportions used were (1, 2, 3, and 4) percent from dry soil weight. Plastic waste material was utilized in two different lengths for each type used 1 and 2 cm, and with a width ranging between (2.5 and 3) mm for both types as well. It was observed from the outcome results of the compaction test for clay soil before and after improvement, a decline of maximum dry density and optimum moisture content, while there was a significant increase in the unconfined reading, the improvement rate was 96.6% at 2 cm length and 4% of (PE) **(Hasan et al., 2021)**. The study examined the impact of plastic waste on the fundamental engineering characteristics of clay soil. In proportions equal to (0.5, 1, 1.5, and 2) % of the soil's weight, water bottles made from Polyethylene Terephthalate (PET) plastic were utilized. Tests for consolidation and unconfined compressive strength were carried out both before and after the addition of the shredded plastic (less than 1 mm).

The cohesiveness measured by the unconfined compressive strength test increased from 53 to 56 kPa, demonstrating an ideal percentage of 2% **(Sabih and Al-Ameri, 2024)**. By using (0, 0.5, 1, and 1.5)% of the plastic waste material measured by soil weight , it was mixed with the soil and tested by compaction, unconfined compression strength, and California bearing ratio test to know the enhancement between before and after addition plastic content in the properties of the soil. The plastic content of (0.5) % was the optimum percentageas the maximum dry density was obtained. Also, at this percentage, the unconfined compressive strength reading increased from (0.022 to 0.040) N/mm^2. However, it was found that the optimum ratio increased the CBR value from (1.85 to 2.35) was 1% **(Wani et al., 2021)**. The researchers examined the relationship between moisture and density, unconfined compressive strength (UCS) and elastic modulus (E50), in addition to the relationship between the behavior of one dimension of consolidation and the CBR of expansive soil when adding plastic waste in proportions starting from 0% and ending with 0.8% by weight of soil, with a difference of 0.2%. at 0.4% of plastic fiber obtained an increased in unconfined compressive strength and elastic modulus by 279% and 113.6% respectively **(Ali et al., 2020)**.
The study aims to enhance the geotechnical properties of soft clay soil and, at the same time, dispose of plastic waste materials in a safe way that does not cause an environmental harm at the lowest cost.

2. MATERIALS USED

2.1 Clay Soil

From the village of Al-Zuhairat, 30 kilometers northeast of the city of Baqubah, in the Diyala Governorate, brown clay soil was brought. The main characteristics of the natural clay soil are shown in **Table 1**.

Table 1. The main properties of natural clayey soil.

Property	Value	Specification
Liquid Limit (LL)	37	**(ASTM D 4318, 2017)**
Plastic Limit (PL)	17	
Plasticity Index (PI)	20	
Specific gravity (Gs)	2.72	**(ASTM D 854, 2014)**
Gravel %	0	**(ASTM D 422, 2001)**
Sand%	2	
Fine grains %	98	
M.D.D* (g/cm^3)	1.77	**(ASTM D 698, 2014)**
O.M.C # %	13.3	
Classification of soil (USCS)	CL	**(ASTM D 2487, 2017)**

Note: * M.D.D refer to maximum dry density, # O.M.C refer to optimum moisture content.

2.2 Soft Clay Soil

The soft clay soil is prepared with an undrained shear strength (Cu) of 34 kPa, as determined by applying the vane shear test. Soil preparation involves adding a water content of 22% to the natural clay soil, mixing and kneading it very well to be homogeneous, and then compacting it inside a CBR mold in three layers, with each layer tamped by a special hummer. The geotechnical properties of soft clay soil are listed in **Table 2**.

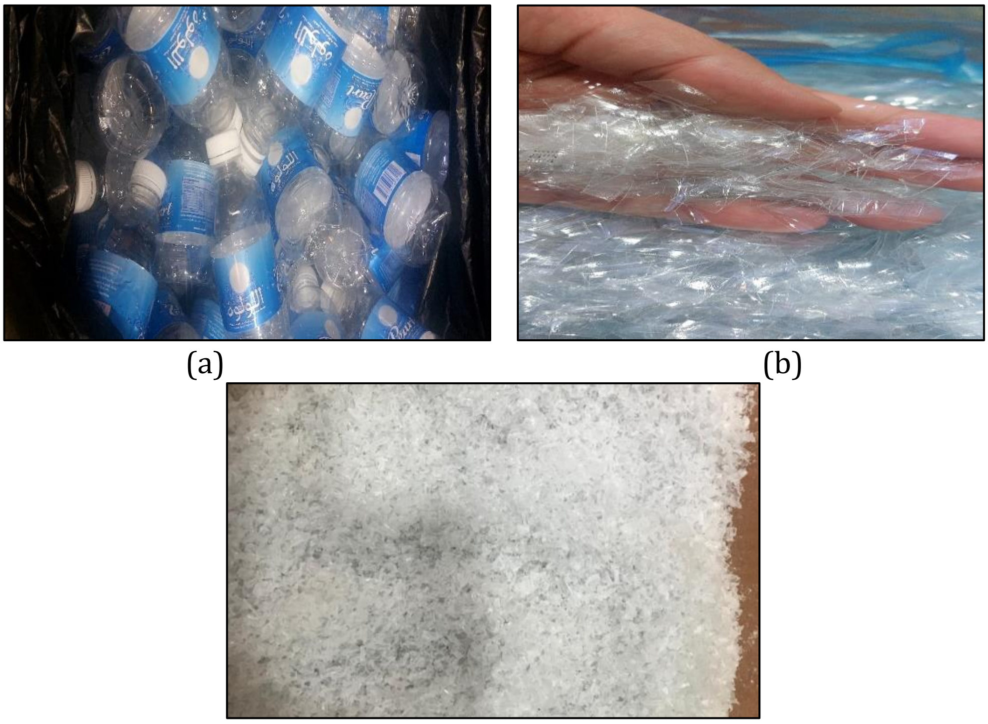
Table 2. Geotechnical properties of prepared soft soil.

Property	Value	Specification
Unconfined compressive strength (UCS) kPa	28	**(ASTM D 2166, 2016)**
Compression index (C_c)	0.26	**(ASTM D 2435, 2004)**
Recompression index (C_r)	0.026	
Initial void ratio (e_o)	0.853	

2.3 Plastic Waste Materials

2.3.1 Polyethylene terephthalate (PET)

The solid waste that results from everyday use of empty, disposable drinking water bottles (PET) in **Fig.1a.**, is utilized in this research, chopped into little bits as appears in **Fig.1b.**, and then processed in a special grinder until the pieces are extremely small, like in **Fig.1c.**, ranging between 2 and 4 mm in length and no more than 3 mm in width.



(a) (b)

(c)

Figure 1. Plastic bottles, (a) As founded, (b) As chopped, (c) As shredded.

2.3.2 Nylon

Another type of plastic trash is nylon (N), which is also known as low-density polyethylene (LDPE) in **Fig. 2a.** It is chopped and shredded to a length of 2 to 4 mm, and a width of less than 3 mm as shown in **Fig. 2b.**, with a form similar to that of water bottle plastic (PET).

(a) (b)

Figure 2. Nylon (LDPE), (a) As founded, (b) As shredded.

3. METHOD OF TESTS

3.1 Unconfined Compressive Strength Test

In the CBR mold, the soil is prepared with a moisture content of 22%, having been mixed with 1, 1.5, 2, and 2.5% nylon (LDPE) and empty water bottles (PET) from the soil's total dry weight. It should be noted that the soil sample is taken out of the CBR mold by a tube that is 6.7 cm in length and 3.8 cm in diameter, as shown in **Fig. 3.** 1.56 (mm/min) of strain is the rate at which the examination is conducted, by **(ASTM D 2166, 2016)** standard specification.

Figure 3. Mechanism of unconfined sample extraction

3.2 Consolidation Test

This test is conducted to determine the extent of the effect of adding plastic waste materials in both types (PET) polyethylene terephthalate and (N) nylon 1,1.5,2 and 2.5% on the compressibility of soft soil, which is supposed to reduce both the compression index (Cc) and the recompression index (Cr). The samples required to conduct the examination are taken from the soil prepared inside the CBR mold at 22 % moisture content by using a ring with a diameter of 5 cm and a height of 2 cm demonstrated in **Fig. 4**. Note the examination is subjected to **(ASTM D 2435, 2004)** standard.

Figure 4. Mechanism of consolidation ring extraction

4. RESULTS AND DISCUSSION

4.1 Unconfined Compressive Strength (UCS)

The outcomes demonstrated that polyethylene terephthalate (PET) wastes are significantly effective in increasing soil cohesiveness (C). The unconfined reading grows when the proportion increases and reaches 97 kPa at 2.5%, indicating an enhancement of 246.42%. This result corresponds with the finding of **(Fadhil et al., 2021)**, while utilizing the nylon wastes, cohesion of soil initially rose slightly, but as the rate approached above 1.5%, generally regarded as the optimum percent for this type of plastic waste (nylon wastes), the unconfined reading declined until it reached 27 kPa at 2.5%. All results listed in **Table 3** are shown in **Fig. 5**, as is the improvement percent shown in **Fig. 6**.

Table 3. Results of unconfined compressive strength test (kPa)

Plastic waste materials % (PET) and (N)	Cohesiveness of (PET) kPa	Cohesiveness of (N) kPa
0	28	28
1	42	33
1.5	52	35
2	77	32
2.5	97	27

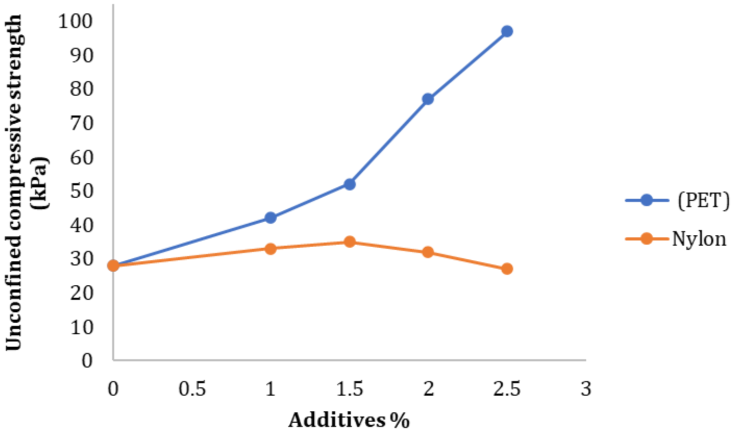


Figure 5. Unconfined compressive strength (kPa) variation with plastic additives %

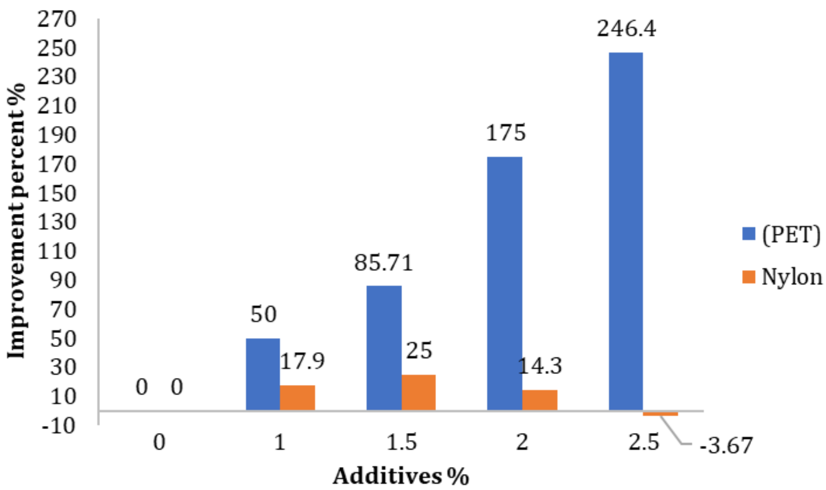


Figure 6. Improvement percent % of unconfined compressive strength after adding different percentages of waste materials

4.2 Compressibility

From the consolidation test, when 2% of the shredded plastic wastes from each type, polyethylene terephthalate (PET) as shown in **Fig. 7** and nylon (N) appeared in **Fig. 8**, are used to treat the soft clay soil.

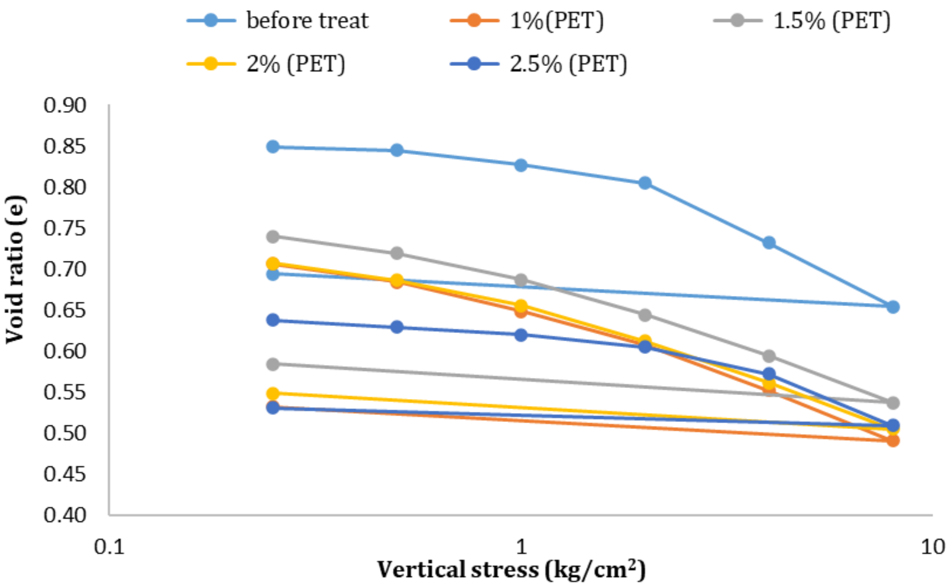


Figure 7. Variation between void ratio and vertical stress with different percents of Polyethylene terephthalate (PET) content

The compression index dropped from 0.26 to 0.19 and 0.15, respectively, demonstrated at **Fig. 9,** and the enhancement percent shown in **Fig. 10**, and the recompression index noticeably fluctuated, **Fig. 11** shows that and a significant drop to 0.014 at 2.5% of nylon (N), all findings given in **Table 4.**, and these results corroborate the assertions made by **(Salim et al., 2018)**.

Table 4. Results of consolidation test parameters Cc and Cr

Plastic waste materials % (PET) and (N)	Polyethylene Terephthalate (PET)		Nylon (N)	
	Cc	Cr	Cc	Cr
0	0.26	0.026	0.26	0.026
1	0.20	0.031	0.21	0.027
1.5	0.19	0.029	0.16	0.031
2	0.19	0.024	0.15	0.029
2.5	0.21	0.019	0.18	0.014

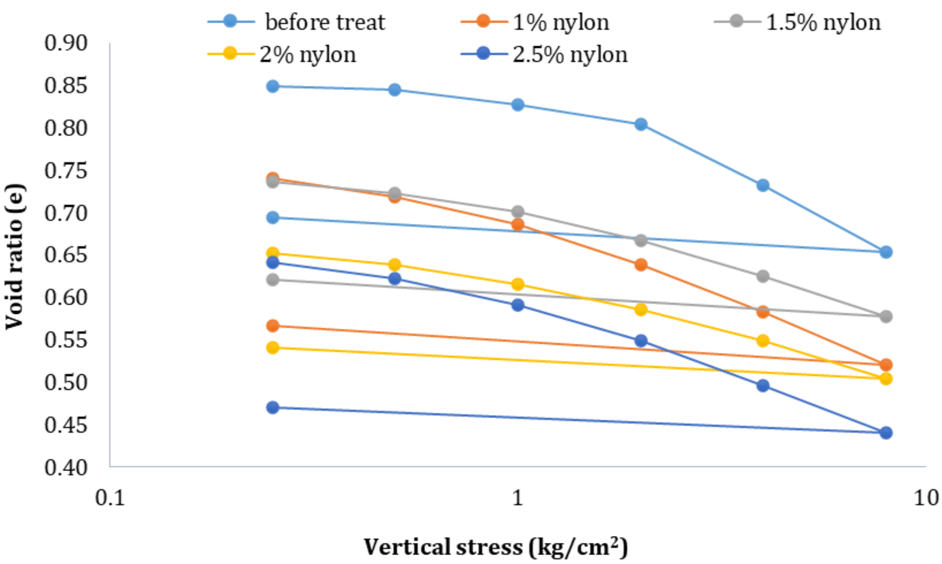


Figure 8. Variation between void ratio and vertical stress with different percents of Nylon (N) content

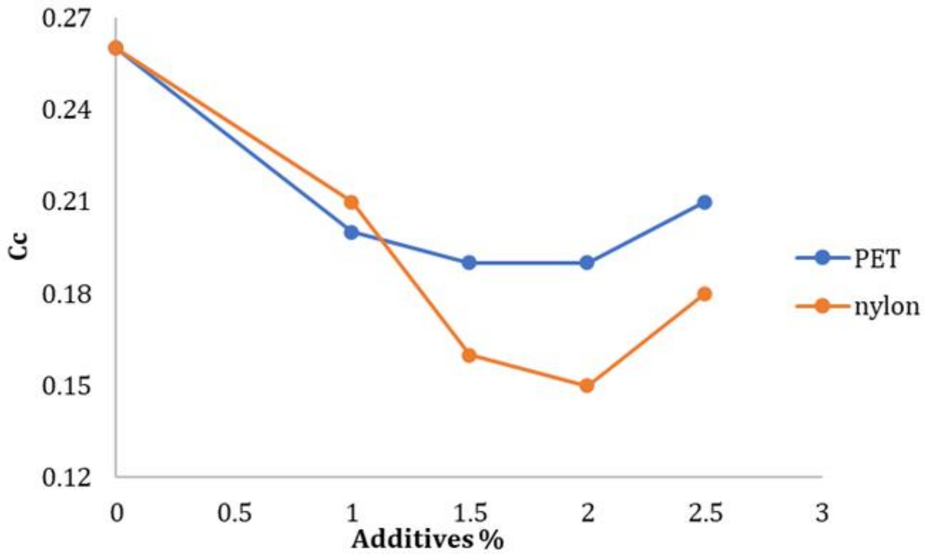


Figure 9. Variation of Cc with different additives percents

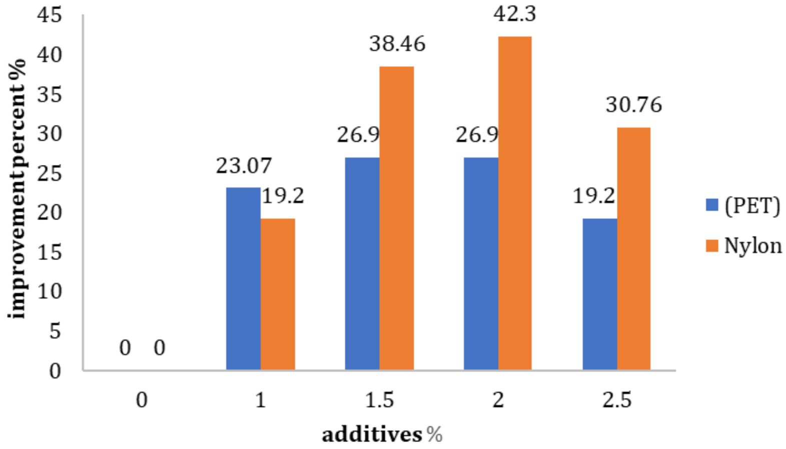


Figure 10. Improvement percent % of (Cc) after adding different percentages of waste materials

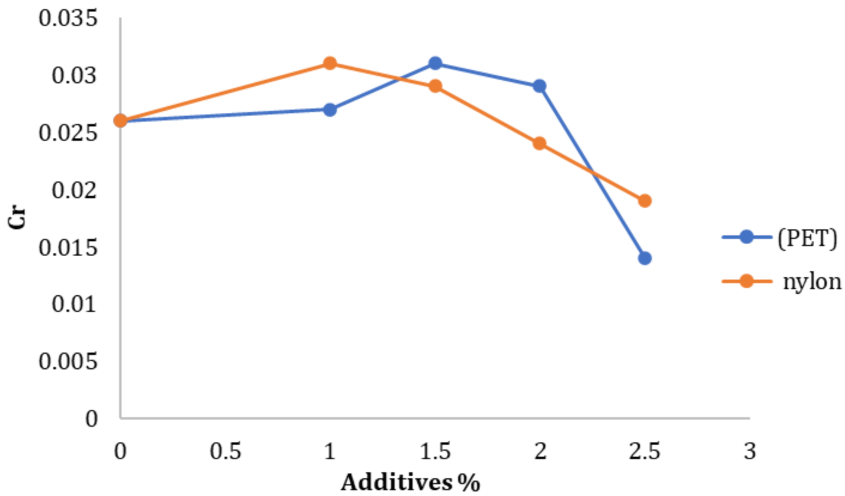


Figure 11. Variation of Cr with different additives percents

5. CONCLUSIONS

The following points explain the main findings of the research.

1. The utilization of crushed empty water bottles (PET) lead to a significant enhancement in soil cohesiveness, with an increase reaching 97 kPa at a concentration of 2.5%.
2. The addition of nylon shredded to the total dry weight of the soil led to a slight increase in soil cohesiveness, but it rapidly dropped back to 27 kPa at 2.5%.
3. The addition of nylon (N) and plastic bottles (PET) had an important effect on the compressibility characteristics of the soil, resulting in a significant reduction in both Cc at 2% (from 0.26 to 0.15 and 0.19) respectively and Cr at 2.5% (from 0.026 to 0.014 and 0.019) also respectively.
4. During the comparison between plastic bottles and nylon for enhancing the strength of soft clay soil, it is observed that polyethylene bottles demonstrated effectiveness, while nylon does not produce any discernible impact, thereby preserving the weak properties of the soil.

5. The results show that exploiting some types of plastic waste to improve undesirable properties of problematic soils is a very suitable process and has proven its efficiency in terms of reducing costs and environmental damage.

Credit Authorship Contribution Statement

Rania Hayder Fadhil: Writing – review & editing, Writing – original draft, validation, software
Balqees Abdulwahid Ahmed : Writing –review & editing, Methodology

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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تقييم فعالية نوعين مختلفين من مواد النفايات البلاستيكية لتعزيز الخصائص الجيوتقنية للتربة الطينية الناعمة.

رانيه حيدر فاضل*، بلقيس عبد الواحد احمد

قسم الهندسة المدنية، كلية الهندسة، جامعة بغداد، بغداد، العراق

الخلاصة

تتزايد مواد النفايات البلاستيكية بشكل مستمر حول العالم نتيجة لتزايد الاستهلاك البشري لهذه المواد يوما بعد يوم، مع عدم وجود حلول فعلية للتخلص منها دون الإضرار بالبيئة أو صحة الكائنات الحية. لذلك تم في هذا البحث استخدام نوعين من المخلفات البلاستيكية لتعزيز التربة الطينية الناعمة: البولي إيثيلين تيرفثاليت (PET) والنايلون (N) بنسب (1، 1.5، 2، 2.5)% من وزن التربة الجافة، لتعزيز خصائص التربة الطينية الناعمة والتي تتميز بقابليتها المفرطة للانضغاط، وانخفاض قدرتها على التحمل، وانخفاض قوة القص. وقد أجريت هذه الدراسة من خلال إجراء الاختبارات المعملية قبل وبعد الإضافة. وتضمنت هذه الاختبارات اختبار مقاومة الضغط غير المحصور (UCS)، والاختبار الآخر هو اختبار الانضمام. أظهرت النتائج ارتفاعاً ملحوظاً في قيمة التماسك (C) عند استخدام البولي إيثيلين تيرفثاليت (PET)، إذ بلغت نسبة التعزيز 246.42% عند نسبة 2.5%، في حين بلغت أعلى نسبة تحسن مع النايلون 25% عند 1.5%. من ناحية أخرى، عند تطبيقها بنسبة 2%، كانت نفايات النايلون أكثر فعالية من زجاجات المياه البلاستيكية (PET) في تقليل مؤشر الضغط (Cc)، حيث انخفض 0.26 إلى من 0.15.

الكلمات المفتاحية: التربة الطينية الناعمة، النفايات البلاستيكية، تحسين التربة، الانضغاط، قوة القص للتربة.