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The Effect of Adding High-Density Polyethylene Polymer on the Engineering Characteristics for Sandy Soil

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ABSTRACT

The loose sand is subject to large settlement when it is exposed to high stresses. This settlement is due to the nature of the high drainage of sand, which displays foundations and constructions to a large danger. The densification of loose sandy soils is required to provide sufficient bearing capacity for the structures. Thus soil stabilization is used to avoid failure in the facilities. Traditional methods of stabilized sandy soil such as fly ash, bituminous, and cement often require an extended curing period. The use of polymers to stabilize sandy soils is more extensive nowadays because it does not require a long curing time in addition to being chemically stable. In this study, the effect of adding different percentages of high-density polyethylene HDPE to the sandy soils' engineering characteristics such as the angle of internal frictions $Ø^0$, shear strength τ, California Bearing Ratio CBR, and permeability k was studied. The results of laboratory tests showed that using of HDPE at percentages (0.1, 0.3, 0.6, 1, and 3%) led to a decrease in soil permeability by 18% and an increase in both the angle of internal friction, the CBR value, and shear strength about 27.2%, 180.9%, and 38.6 % respectively by adding 1%. HDPE.

Keywords: High-density polyethylene HDPE, Sandy Soil, Permeability, Angle of Internal Friction, CBR.

تأثير إضافة بوليمر بولي إيثلين عالي الكثافة على الخصائص الهندسية للتربة الرملية

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لخلاصة

تخضع الرمال الرخوة لهطول كبير عندما تتعرض لضغوط عالية ، وهذا الهطول بسبب طبيعة التصريف العالي للرمل، والتي تعرض الأساسات والمنشآت لخطر كبير ، كما أن تكثيف التربة الرملية الرخوة مطلوب لتوفير قدرة تحمل كافية للهياكل. وبالتالي

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يتم استخدام تثبيت التربة لتجنب الفشل في المنشآت. غالبًا ما تتطلب الطرق التقليدية لتثبيت التربة الرملية مثل الرماد المتطاير والبيتومين والأسمنت فترة معالجة طويلة ، لذا فإن استخدام البوليمرات لتثبيت التربة الرملية يكون أكثر شمولاً في الوقت الحالي لأنها لا تتطلب وقت معالجة طويل بالإضافة إلى كونها مستقرة كيميائيا. في هذه البحث، تمت دراسة تأثير إضافة نسب مختلفة من البولي إيثلين عالي الكثافة HDPE إلى الخصائص الهندسية للتربة الرملية مثل زاوية الاحتكاك الداخلي Ø0 ، ومقاومة القص τ ، ونسبة التحمل الكاليفورنية CBR ، والنفاذية k. أظهرت نتائج الاختبارات المختبرية أن استخدام البولي إيثلين عالي الكثافة بنسب مئوية (0.1 ، 0.3 ، 0.6 ، 1 ، 3٪) أدى إلى انخفاض في نفاذية التربة بنسبة 18٪ وزيادة في زاوية الاحتكاك الداخلي وقيمة CBR. وقوة القص حوالي 27.2٪ ، 180.9٪ ، 38.6٪ على التوالي بإضافة 1٪ HDPE.

الكلمات الرئيسية: البولي إيثلين عالي الكثافة HDPE ، التربة الرملية ، النفاذية ، زاوية الاحتكاك الداخلي ، CBR.

1. INTRODUCTION

High-density polyethylene HDPE is a new category of petrochemical products. It consists of two carbons and four atoms of hydrogen in the base polymer repeat unit. One of the characteristics of polyethylene is that it is highly durable, soft, lightweight, easy to manufacture, cost low, very little absorbency to water, inert chemically (that is, it is insoluble in any of the solvents at room temperature). Still, it is lightly swollen by liquids such as benzene. It has good resistance to acids and bases, the degree of glass transition of polyethylene is very little (-120°C), which gives it flexibility and high resistance to moisture in addition to its electrical insulation properties **(Rafiq et al., 2011)**. Sandy soil contains many geotechnical problems, including high permeability, less shear strength **(Bruand et al., 2005)**, sand dunes **(Al-Taie and Al-Shakarchi, 2016)**, and liquefaction **(Al-Taie and Albusoda, 2019)**. Therefore, it is necessary to stabilize the sandy soil to improve its engineering properties. There are three purposes for stabilizing soil. The first purpose is to improve strength, which increases the bearing capacity of weak soils. The second purpose is to control dust. This is done to remove or mitigate dust generated from the operating equipment during dry climates. Soil waterproofing is the third purpose for soil stabilization and is done to maintain soil strength by preventing surface water from entering. Various additives can be used for stabilization soils, such as calcium chloride, cement, bituminous products, lime **(Air Force Manual, 1994),** and polymers**.** Polymers used for soil stabilization must have excellent physical characteristics such as compressive strength, high tensile, good adhesion, flexural, high resistance to chemicals and waters **(Palmer, 1995).**

(Chebet et al. 2019) explained the effect of the polyethylene terephthalate (PET) plastic chips of (2, 4.75, and 5.6mm) sizes, in ratio from 2.5% - 20% by dry weight soil on the strength behavior of cape flat sand ($Ø^0$=38.5° and C= 9.4 kPa) and klipheuwel sand ($Ø^0$=41.6°and C= 4.8 kPa). The result showed a 25.4% increase in the angle of internal friction $Ø^0$, 68% increase in cohesion, 42.5% increase in shear strength at 10% PET for cape flat sand, and 26.6% increase in the angle of internal friction $Ø^0$, 187.5% increase in cohesion, and 50.8% increase in shear strength at 12.5% PET for klipheuwel sand.

(Talib, 2018) showed that the addition of high-density polyethylene HDPE (2-5mm) size with a ratio of (20, 40, 50, 75, and 100%) to dry weight of sandy soil will affect the properties of sandy soil, such as a decrease in maximum and minimum density of sand about 64% and 60% respectively at 75% HDPE, increase in the angle of internal friction $Ø^0$ and a large increase in permeability of sand with adding HDPE.

(Agbolade and Ojuri, 2015) studied the effect of adding strips of high-density polyethylene (HDPE) waste on the properties of sandy soil. Strips size is (15 × 20 mm, 20 × 25 mm, 25 × 30 mm) in a ratio of (1, 2, 3, 4, and 5%) by dry soil weight. The results showed a 68.54% increase in shear strength, 55.56% increase in the angle of internal friction $Ø^0$at 2% HDPE for small size strip

(15 × 20 mm), and 61.9% reduction in permeability at 5% HDPE for large size strip (25 × 30 mm).
This current research aims to study the effect of adding different percentages (0.1, 0.3, 0.6, 1, and 3%) of high-density polyethylene HDPE to the sandy soils' engineering characteristics, such as the angle of internal frictions, shear strength, California Bearing Ratio, and permeability.

2. EXPERIMENTAL WORK

2.1 Sandy Soil

The sandy soil used in this research was collected from Najaf Governorate, southern Iraq. The physical properties of sandy soil were tested in the civil engineering laboratories at Al-Nahrain University, as shown in Table 1.

Table 1. Engineering properties of sandy soil.

Mechanical properties	Percentage	Standard method
Gravel Sand Fine grain	0% 94.8% 5.2%	ASTM D 422
Water content, wc	5.5%	ASTM D 2216
Specific gravity, Gs	2.68	ASTM D 854
Relative Density, Dr (%)	40	
Max. Unit Weight, γ_{max} (kN/m^3)	16.2	ASTM D4253
Min. Unit Weight, γ_{min} (kN/m^3)	11.6	ASTM D4254
Dry unit weight, γ_d (kN/m^3)	13	
Angle of internal friction, $Ø^0$	33^0	ASTM D 3080
Permeability, k cm/sec	0.0045	ASTM D 2434
CBR %	33	ASTM D 1883
Classification According to Unified Classification System (UCS)	SP	ASTM D2487

2.2 High-Density Polyethylene HDPE

The tests are carried out at Physics laboratories in AL-Nahrain University; the grain size distribution for natural soil and polyethylene polymer HDPE is shown in **Fig. 1**. **Fig. 2** shows the HDPE used in the current study. The chemical and physical properties of HDPE are shown in **Tables 2** and **3**, respectively.

Table 2. Chemical properties of HDPE.

Chemical properties	**Carbon**	**Nitrogen**
Content %	98.14	1.85

Table 3. Physical properties of HDPE.

Chemical formula	**(C2H4)n**
Appearance(Form)	powder
Solubility	Dissolved in (toluene or xylene) dissolvent
Color	White
Density(g/cm^3)	0.960
Flow index (at190°C, g (10 min)$^{-1}$	1.5
Tensile strength (psi)	4300

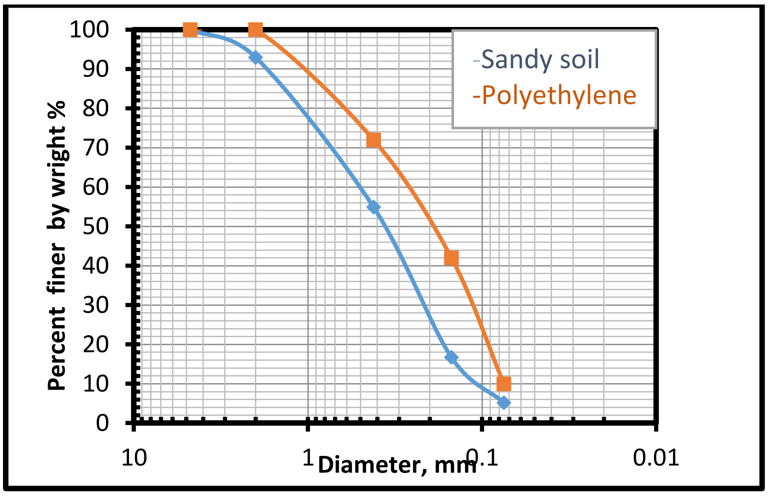

Figure 1. Grain size distribution for natural soil and polyethylene polymer HDPE**.**

Figure 2. HDPE used in the current study**.**

3. LABORATORY TESTS

3.1 Permeability Test

The permeability test was conducted on the natural soil according to **ASTM D2434**. The coefficient of proportionality k **(q=kiA)** is called "Darcy's coefficient of permeability". Permeability enters all problems involving the flow of water through soil, such as drainage of subgrades, seepage under dams, and backfill.

3.2 Direct shear test

The direct shear test for soil is determined according to **ASTM D3080**. The shear strength of a soil mass is the internal resistance per unit area that the soil mass can offer to resist failure and to slide along any plane inside it. In the direct shear test, a square prism ($6 \times 6 \times 2$ cm) of soil is laterally restrained and sheared along a mechanically induced horizontal plane while subjected to a normal pressure applied to that plane.

3.3 California Bearing Ratio (CBR) Test

The CBR test was conducted on soil according to **ASTM D1883**. The CBR test is used to evaluate the potential strength of subbase, subgrade, and recycled materials for use in road and airfield pavements. When a cylindrical plunger is made to penetrate the soil at a given rate, the concept of CBR is to establish the relationship between applied load and penetration. The California Bearing Ratio is known as the ratio of applied load to a standard load, expressed in percentage, at specific penetration values. This principle is used in most parts of the world as an essential criterion in flexible pavement design**.**

4. RESULTS AND DISCUSSION

4.1 Effect of HDPE on Shear Strength for Sandy Soil

93.6 grams of sandy soil was weighed (depending on the size of the direct shear box and the dry unit weight of the sandy soil) and placed in a direct shear box in the dry state, then 1, 2, and 4 kg loaded were supplied on a sample and tested before and after adding HDPE. **Fig. 3** and **4** show the effect of adding polyethylene HDPE on shear strength for sandy soil. An increase in the angle of internal friction was observed upon increasing the polymer ratio, which reached an increase of 27.2% when 1% of HDPE was added.

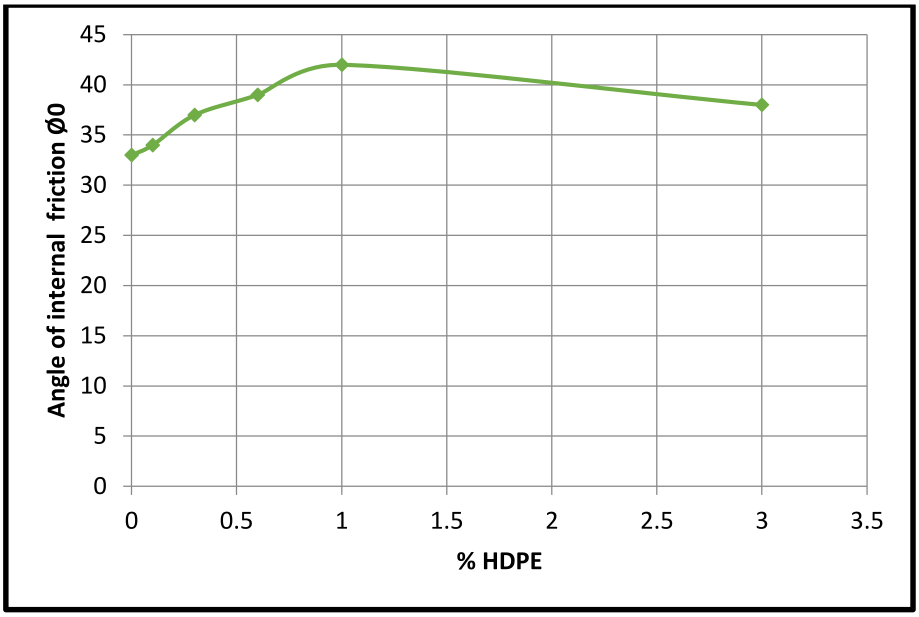

Figure 3. The effect of adding HDPE on $Ø^0$ of sandy soil.

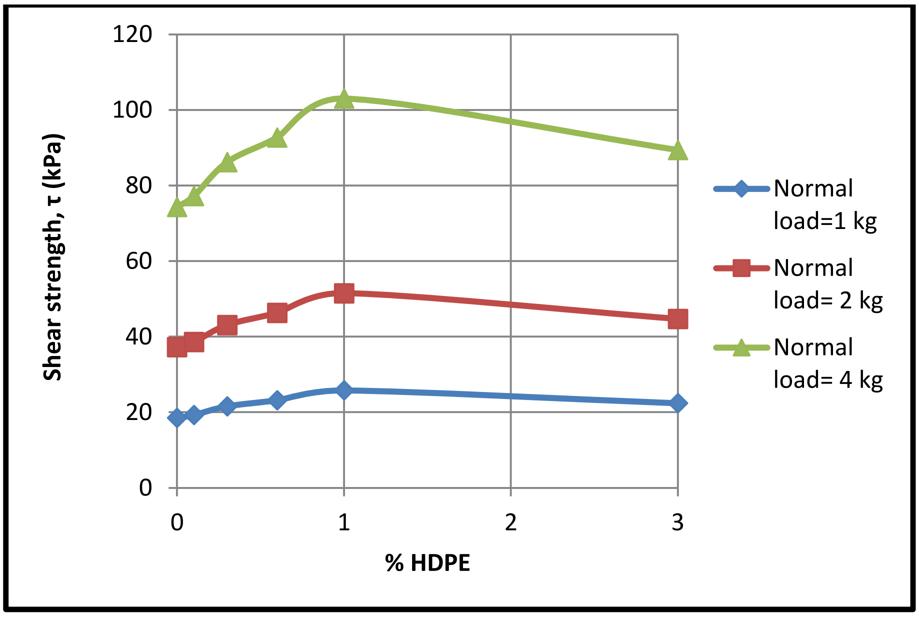

Figure 4. The effect of adding HDPE on shear strength for sandy soil.

4.2 Effect of HDPE on Permeability for Sandy Soil

The permeability values for sandy soils begin to decrease when adding a polyethylene polymer gradually. After 3% HDPE, the permeability started to rise slightly, as shown in **Fig, 5.** The small size particles give less permeability and because the grain size of HDPE is smaller than the size of sandy soil grains (it contains more fine particles), as shown in **Fig, 1.** Therefore, the void ratio is less, and this leads to a decrease in permeability.

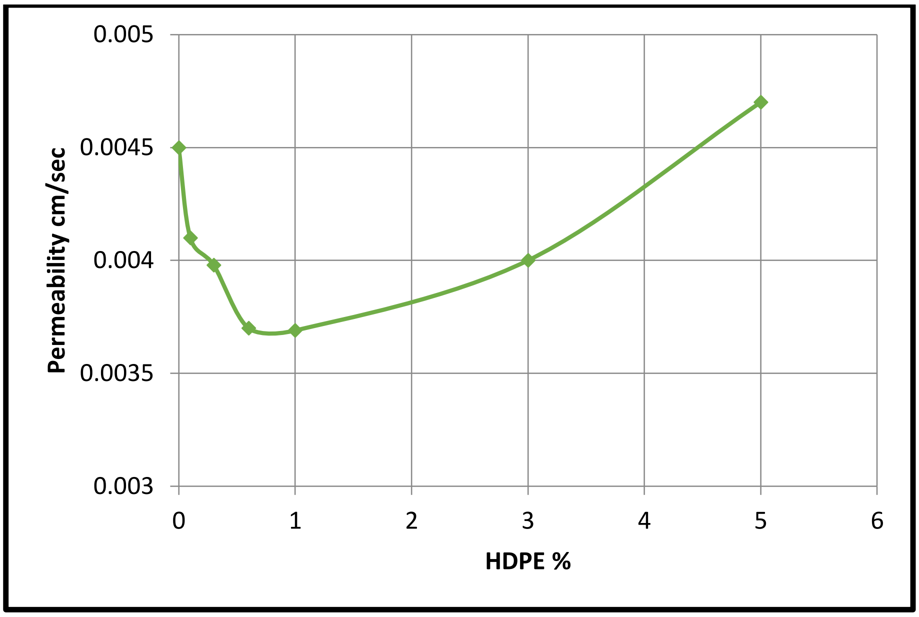

Figure 5. The effect of adding HDPE on permeability.

4.3 Effect of HDPE on CBR for Sandy Soil

The soil was prepared for the CBR test by first the required soil weight, which was 4.5 kg, and then the HDPE was mixed with the dry soil randomly at a moisture content of 5.5%. The sandy soil was compacted in three layers by applying 56 blows distributed on each layer with a hammer weighing 24.5 N at a free fall. A load of 2.5 kg was seated on the last layer. Then the mold was placed under the CBR machine. The penetration plunger was installed at the center of the sample to be in contact with the soil surface. The test was carried out by applying the load through the penetration readings of 0.0, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5, 7, and 7.5 mm.
In general, the CBR values increase when the polymer ratio was increased, and the maximum increase in the CBR value was given at 1% of HDPE, as shown in **Fig. 6**. Whereas the presence of this type of polymer, which acts as a filler between the particles of soil, increases the strength of the soil particles. **Fig. 7** shows soil molds in the CBR test with adding HDPE.

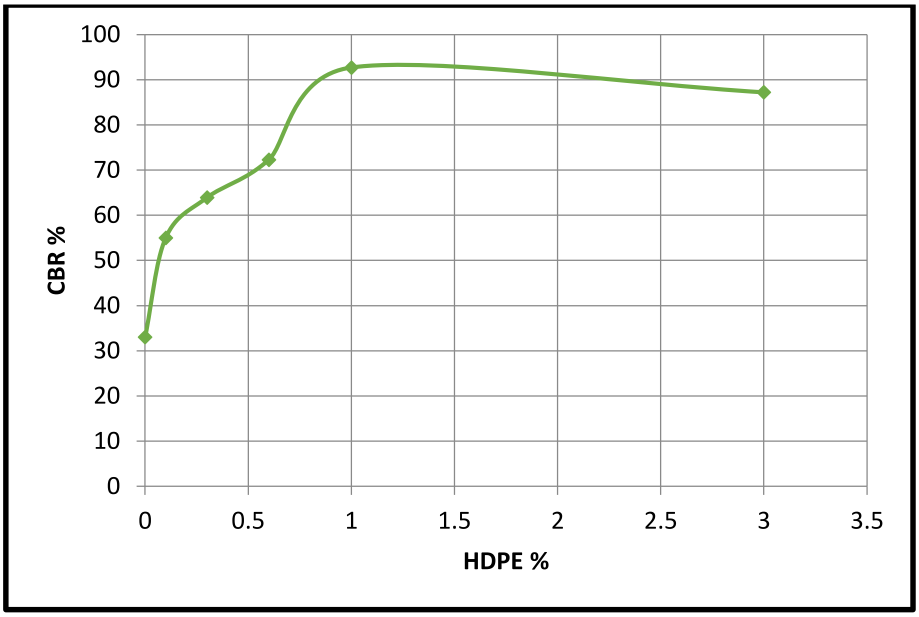

Figure 6. Effect of adding HDPE on CBR.

Plate 7. Soil molds in CBR test with adding HDPE.

5. CONCLUSIONS

This research was carried out to investigate the effect of adding high-density polyethylene HDPE at different percentages to improve some engineering characteristics of sandy soil. The following conclusions may be drawn based on the results of the laboratory tests of this research:

1- Increase in the angle of Internal Friction ($Ø^0$) and shear strength (τ) with increasing HDPE percentage. The maximum increase in the angle of internal friction and shear strength was 27.2% and 38.6%, respectively, at 1% HDPE.
2- The permeability values for sandy soils began to decrease when adding a polyethylene polymer gradually. The optimum decrease in permeability was 18% at 1% HDPE.
3- The CBR values of sandy soil increased when the polyethylene ratio was increased, and the maximum increase in the CBR value is given as 180.9% at 1% of HDPE.

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