Study of Clayey Soil Reinforced with Fine Crushed Polyethylene Terephthalate (PET)

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Abstract

Currently a lot of bottles of polyethylene terephthalate (PET) are discarded into the environment. In order to reduce the disposal of this polymer in nature, this study aims to evaluate the mechanical behavior of a clayey soil mixed with fine crushed PET. The potential use of this waste material in geotechnical applications may ultimately reduce the problem of improper disposal and improve the strength and deformation characteristics of the soil. This paper presents an experimental study to evaluate the mechanical behavior of pure soil and mixtures with different contents of PET waste by triaxial tests, in order to obtain the strength parameters of the Soil-PET mixtures. The clayey soil used was mixed with 10 and 20 percent of fine crushed PET by dry weight. Characterization tests such as grain size, Atterberg limits and compaction test were performed on the soil-PET mixtures. Triaxial tests at confining stresses of 50, 150 and 300 kPa were done on the soil and mixtures. The results show that the soil strength parameters are influenced by the addition of the fine crushed PET, thus improving characteristics such as friction angle and cohesion of the Soil-PET mixtures. This improvement also depends on the confining level which the samples were submitted. These mixtures may be used in pavement and other geotechnical works, so this paper proposes to contribute to a better understanding and interpretation of the behavior of reinforced soil with waste PET.
Keywords: Triaxial tests, PET waste, Reinforced soil.

1 Introduction

Currently environmental and economic issues have motivated interest in the development of alternative materials that can satisfy geotechnical design specifications. The soil improvement is an alternative considered when the natural soil does not meet the engineering requirements for a project. A soil improvement technique is sought that would make a shallow foundation feasible (Briaud, 2013) (1).

According Consoli et al (2002) (2), stabilized and reinforced soils are, in general, composite materials that result from combination and optimization of the properties of individual constituent materials. Materials such as polyethylene terephtalate (PET) plastic bottles are abundantly produced, and after their use, there are placed in disposal sites. This type of materials needs long time to decompose and they use up a lot of space in the landfill. Several studies have been conducted on the use of alternative materials in order to reinforce the soil and improve its geotechnical properties, at the same time giving an appropriate allocation to different environmental contaminants materials. Among such studies we can cite the research carried out by: Ramirez (2012) (3), Bolaños (2013) (4), Calheiros (2013) (5) e Szeliga (2014) (6).

With the proposal to reduce recycled polymers disposal, such as PET, they should be used in long-life applications such as pavement and geotechnical solutions. In this paper we describe an experimental study of the use of fine crushed PET in the reinforcement of a clayey soil. The stress-strain response was evaluated by drained triaxial compression tests. Influence of the fine crushed PET content on mechanical behavior of soil was evaluated.

2 Experimental Program

2.1 Materials.

The soil used in the present study is a clayey residual tropical soil (Fig. 1 (a)). This clayey soil is classified as MH (silt of high plasticity) according to USCS (Unified Soil Classification System). This soil has a micro-granular texture, constituted by quartz, altered granite, clay minerals (mainly kaolinite), iron and aluminum oxides. Physical characterization tests were carried out in the soil for determining the index properties of clayey soil. The specific gravity of solids is 2.72. The Atterberg limits for the portion passing No. 40 sieve are liquid limit 53% and plastic limit 39%.

The fine crushed PET (Fig. 1 (b)) used in this research proceeds recycled PET plastic bottles. The process to obtain this material is called micronization. According to Melo (2004) (7), the process of micronization is divided into six steps:

1) Collection and selection of bottles: labels and caps are removed and the bottles are washed with water;
2) Granulation: the bottles are ground in a mill, resulting in flakes;
3) Agglomeration: the flakes are treated with heat to decrease in volume and, consequently, to increase density, thus making it more suitable for rotomoulding equipment;
5) "Pellets" production: after rotomoulding, the material is ground in a mill producing the form of "Pellets";
6) Micronization: occurs the reduction of "pellets" to particles with size passing 0.42 mm mesh.

(a) (b)

Figure 1 – Materials: (a) Clayey soil; (b) Fine crushed PET.

The grain size distribution of clayey soil and the fine crushed PET is depicted in Fig. 2.

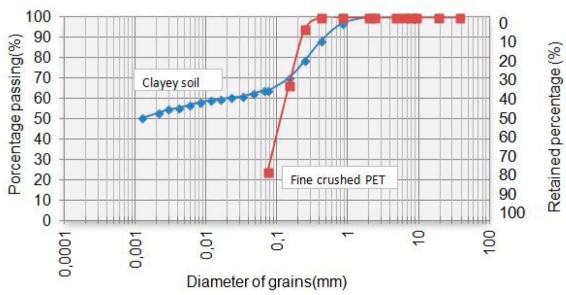

Figure 2 – Particle size distribution curves of clayey soil and crushed PET.

2.2 Specimen preparation.

The clayey soil was mixed with 10% and 20% of fine crushed PET by dry weight of soil. Soil-PET mixtures were prepared at maximum dry density and optimum moisture content, obtained by conducting standard Proctor's tests on each mixture using the standard compaction effort. Fine crushed PET and soil were mixed thoroughly by hand using rubber gloves to achieve a fairly uniform mix.

The main characteristics of soil-PET mixtures used in this study are shown in Tab. 1. We use the following nomenclature to designate the soil-PET mixtures: mixtures with 90% of soil and 10% of fine crushed PET will be called S90P10, and the mixture with 80% of soil and 20% of fine crushed PET will be named S80P20. Specimens made of pure soil, without fine crushed PET, will be designated by the name of clayey soil.

Table 1 – Soil-PET mixtures characteristics.

Material / Mixture	Clayey soil (%)	Fine Crushed PET (%)	Specific gravity of solids (Gs)	Dry unit weight (gr/cm3)	Water content (%)
Clayey Soil	100	0	2.72	1.56	26.3
S90P10	90	10	2.49	1.48	24.1
S80P20	80	20	2.13	1.40	23.6

2.3 Triaxial test.

The consolidated drained triaxial tests were carried out under total saturation at effective confining pressure of 50, 150 and 300 kPa, which are consistent with realistic assumptions made in some engineering applications like shallow foundations placed on improved soil layer.

Cylindrical specimens of soil with nominal height of H = 78 mm and a nominal diameter of D = 38 mm, were used for the triaxial test in order to apply an axisymmetric stress condition. Soil response was obtained by three steps: saturation, consolidation and shearing of the specimens.

In consolidated drained test, the saturation of the specimen is important to ensure that all voids within the specimen are filled with water. The saturation of specimen was achieved by percolation of water into the specimen and by increased of back pressure. Percolation of water was obtained by application of different pressures in the top and in the base of the specimen. It was applied in the top of the specimen, a pressure of 5 kPa lower than in the base of the specimen, to allowing the ascendant flow of water by the specimen. During saturation by increase of back pressure, a constant effective stress of 10 kPa was maintained.

To check if the degree of specimen saturation is sufficiently high before beginning the consolidation step, a short test was execute to determine Skempton's B-value. As confining pressure (σ3) is applied, the pore water pressure of the specimen increases by (if drainage is prevented). This increase in the pore water pressure can be expressed as a nondimentional parameter as follow:

$$B = \frac{Uc}{\sigma_3} \qquad (2.1)$$

where, B is the Skempton's pore pressure parameter (Skemptom, 1954) (8). For saturated soils, B is approximately equal to 1. After a minimum acceptable B-value of 0.90 was obtained, the second step of consolidation procedure was started.

The consolidation procedure begins when the connection to drainage is opened and the dissipation of the excess of pore water pressure occurs. Over time, the will become equal to 0. According to Das (2010) (9), in saturated soil, the change in the volume of the specimen () that takes place during the consolidation can be obtained from the volume of pore water drained.

The third phase is the shearing specimen by applying an axial strain to the specimen at a constant rate. The strain rate was kept constant in a velocity of 0.032 mm/min. This value was calculated using the consolidation response, and it is slow enough to result in a negligible pore pressure variation. Because the pore water pressure developed during the test is negligible, the total stress is equal to the effective stress.

3 Test results and Analysis

The mechanical behavior of the studied materials was examined focusing on the influence of fine crushed PET inclusion (0%, 10% and 20%) and of effective confining pressure (50, 150 and 300 kPa). The deviatoric stress – axial strain – volumetric strain curves obtained in the triaxial tests are depicted in Figs. 3, 4 and 5, respectively, for 50, 150 and 300 kPa confining pressures. A summary of the strength and strain characteristics obtained from the triaxial tests is shown in tab. 2. Cohesion intercept at failure and friction angle was obtained by application of Mohr Coulomb criterion.

Table 2 – Summary of triaxial tests results.

Material / Mixture	Effective confining pressure (kPa)	Deviatoric stress at failure (kPa)	Cohesion intercept at failure (kPa)	Friction angle at failure (deg)
Clayey Soil	50	149.0	25.4	27.3
	150	304.9		
	300	549.3		
S90P10	50	143.1	22	30.6
	150	400.5		
	300	621.1		
S80P20	50	113.3	17	30.8
	150	335.7		
	300	602.1		

The ultimate strengths of specimens increase with the inclusion of fine crushed PET, with the exception of low confining pressure of 50 kPa (Fig. 3). Likely, it is because at low confining pressure, the fine crushed PET does not work as grain size improvement. The axial stress – deviatoric stress curves (Figs. 3 to 5) show an almost perfectly plastic behavior, in other words, the soil--PET mixtures underwent irreversible deformation without any increase in stresses, especially when the mixtures reached large strains.

The volumetric response was strongly influenced by fine crushed PET inclusion, increasing the compressive behavior of the soil, especially for large confining pressures (300 kPa) (Fig.5). The stiffness of Soil-PET mixtures appears to be increased by addiction of fine crushed PET. As shown in Figs. 4 and 5, the linear part of the graphs have a greater inclination for the soil-PET mixtures than the clayey soil.

A substantial increase in the shear strength, compared to that in unreinforced clayey soil, can be gained with a concentration (by weight) of 10% of fine crushed PET. Despite, concentrations above to 10% of fine crushed PET do not provide the best results concern to improvement strength, as it was observed on the results of mixture S80P20 for all confining pressures. It is likely because the high concentration of fine crushed PET inside of clayey soil can generate a lot of contacts only between PET grains rather than contacts between soil and PET grains, and then no reinforcement effects can be activated.

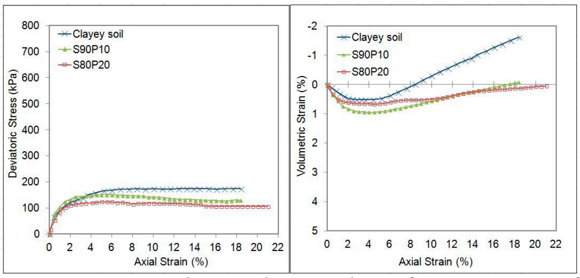

Figure 3 – Drained triaxial test with confining pressure of 50 kPa.

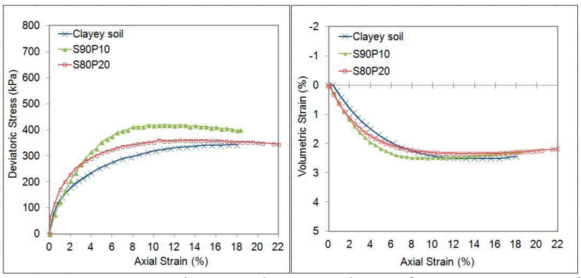

Figure 4 - Drained triaxial test with confining pressure of 150 kPa.

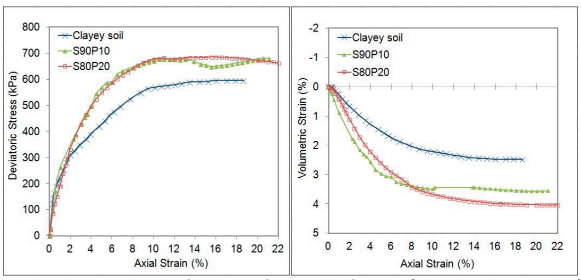

Figure 5 – Drained triaxial test with confining pressure of 300 kPa.

Due to deviatoric stress at failure decreased with the inclusions of fine crushed PET in low confining pressure (50 kPa) (Fig. 3) and increased in high confining pressure (150 and 300 kPa) (Figs. 4 and 5), therefore, the cohesion intercept at failure value reduces as the same time as friction angle at failure increases (tab. 2). It was expected because inclusion of fine crushed PET causes enhance of strength parameters by improvement of grain size distribution.

4 Conclusion

The results of this study suggest that mechanical behavior of clayey soil improved with inclusion of fine crushed PET. The comparison between clayey soil and S90P10 mixture showed that the increase of deviatoric stress at failure was 31.3% and 13.7% under confining pressure of 150 kPa and 300 kPa, respectively. The S80P20 mixture showed less improvement of strength: when confined pressure was 150 kPa, the deviatoric stress at failure increased 10.1% and when confined pressure was 300 kPa, the increase was 9.6%.

Therefore, mixtures of clayey soil with fine crushed PET can have potential application in reinforcement of shallow foundations or any other earthwork that may be exposed to high stresses. The results obtained in this study allow having an alternative to reduction of the improperly final disposal of recycled polymers like PET. They could be used in long-life applications such as pavement and geotechnical solutions in order to contribute to better quality of life and sustainable development.

As future work, cementation processes (chemical reactions) could be used in order to have better results of the cohesion intercept value, since grain size distribution approach with fine crushed PET inclusions did not show cohesion intercept improvement in low confining pressures.

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