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Behavior of a Clayey Soil Mixture with Fine Crushed Polyethylene Terephthalate.

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SUMMARY: Every year millions 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 to 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 in this research came from the Experimental Field II located in PUC-Rio campus, which is a residual tropical. It has a micro-granular texture, constituted by quartz, altered garnet, clay minerals (mainly kaolinite) and iron and aluminum oxides. The soil was mixed with 10 and 20% of fine crushed PET (resulted of a specific method of crushing, and the PET comes out with a particle size up to 50 mesh.) by dry weight. Characterization tests such as grain size, Atterberg limits and compaction test were performed on the clayey material. 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 upon the confining level which the samples were submitted. It is observed that in both mixtures, when material is submitted to a low confining stress the insertion of fine crushed PET does not improve the strength parameters of the soil. However, at higher confining stresses the improvements of the strength parameters are evident. The fine crushed PET works as a grain size improvement, and in higher confining stress, when the consolidation step is applied, the fine crushed PET fills the remaining voids in the soil, leaving less gaps between the soil particles. So at the same axial strain, the mixture withstand a higher deviator stress comparing with the pure clayey soil. 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 soil reinforced with waste PET. The use of this material in geotechnical works, may reduce the wrong disposal of the residue in nature, being a low coast and environmentally friendly option for soil reinforcement.

KEYWORDS: triaxial tests, Fine Crushed PET, waste, reinforced soil.

1 INTRODUCTION

Soil reinforcement is defined as a technique to improve the geotechnical characteristics of the soil (Ling et al, 2003). Reinforcement consists of inserting certain material in another, in order to increase its properties. Therefore, many different kinds of materials have been studied with the aim of improving the strength properties of some soils.

PET bottles production are increasing annually and they are still wrongly discharged. This research aims to evaluate the use of a fine crushed PET as a soil reinforcement, through experimental laboratory tests, giving an environmentally friendly end to this material. Finally, the use of fine crushed PET would decrease the demand of natural resources, and add value to this material, it also could reduce the impact in nature such as, air pollution, river's aggradation, and eliminating current problems of waste disposal in dumps and landfills.

2 MATERIALS

2.1 Clayey Soils

The clayey soil used in this research came from the Experimental Field II located in PUC-Rio campus, as shown in Figure1.

Figure 1. Collecting field in Puc-Rio.

Figure 2 shows the clayey soil studied, which is a residual tropical. It has a micro-granular texture, constituted by quartz, altered garnet, clay minerals (mainly kaolinite) and iron and aluminum oxides by Moreira, 1998 apud Soares, 2005.

Figure 2. Clayey soil sample.

2.2 Fine Crushed PET

The fine crushed PET used in this research, is a result of a specific method of crushing, and the PET comes out with a particle size up to 50 mesh (Figure 3).

Figure 3. Fine Crushed PET

The crushing process can be summarized in three steps (Melo, 2004):
1st step: gathering the PET bottles (label and caps are removed) and crush them into a mill.
2nd step: the agglomeration, where the flakes receive a thermic treatment, in order to decrease the volume and consequently increase the density. Later the material passes through another milling process.
3rd step: consist in the micronization, reducing the material in a powder with particle size passing 0.42 mm seive.

2.3 Mixtures

The clayey soil was mixture with two different contents of fine crushed PET, 10 and 20% on dry weight. The water was added according to the optimum moisture content, which was obtained from the Standard Proctor test, performed in each mixture. The Table 1 shows the materials used in the tests end the abbreviations adopted for the mixtures.

Table 1. Abbreviations used for the soil and mixtures.

Material/ Mixture	Soil (%)	Fine Crushed PET (%)	Abbreviation
Clayey Soil	100	0	S100
Mixture 1	90	10	S90P10
Mixture 2	80	20	S80P20

3 EXPERIMENTAL PROCEDURE

3.1 Physical Characterization Tests

With the aim to determinate the index properties of the samples of the clayey soil and mixtures, characterization tests were performed in each sample. The soil was prepared according to the Brazilian technical standard (Brazilian Association of Technical Standards – ABNT). The performed tests followed next standards:

- NBR 6457/1986 – Soil Sample – Preparation for compaction test and characterization;
- NBR 7181/1984 – Soil – Particle Size Analysis;
- NBR 6508/1984 – Soil –Determination of the specific gravity of the soil solids;
- NBR 6459/1984 – Soil – Determination of the liquid limit;
- NBR 7180/1984 – Soil – Determination of the plastic limit.

The specific gravity of soil solids, particle size analysis, liquid limit and plastic limit test were carried out using material that passed through the mesh #40 (0.425mm). The results will be present in section 4.1.

3.2 Standard Compaction Test

The standard compaction test was performed on the clayey soil and the mixtures, in order to determinate the optimum water contest (wopt) and the maximum dry density (γdmax) of all materials. The compaction test was carried on following the Brazilian standard ABNT NBR 7182/1986.

3.3 Triaxial Tests

After compact the clayey soil and the mixture with their optimum moistures and maximum dry densities were molded samples with 3,8 cm of diameter and 7,2 cm of height.

To achieve the strength parameters it was carried triaxial consolidated-drained tests on the clayey soil and mixtures. The samples were saturated using backpressure and water percolation. To guarantee that the samples were saturated it was used the Skempton's parameter B.

The value of the time of failure for this king of triaxial test is given by 8.5 times the value of t100 (time to occur the 100% of the primary consolidation). However, if the time is smaller than 120 min, Head (1986) proposes to use a minimum value for the time of failure of 120 min. The shear velocity used for all samples was 0.030 mm/min, in order to avoid any pore pressure excess during the shear phase.

4 RESULTS AND ANALYSIS

4.1 Physical Characterization

The results of the characterization tests are presented in Table 2. According to UCS the soil used can be classified as a silt with high plasticity (MH), however it has more than 50% of clay, so it is called in this research as a clayey soil. Figure 4 shows the particle size distribution of the clayey soil and the fine crushed PET.

Table 2. Clayey soil physical characterization

Gs	Sand (%)	Silt (%)	Clay (%)	LL (%)	LP (%)	IP (%)
2.72	36.4	10.8	52.7	53	39	14

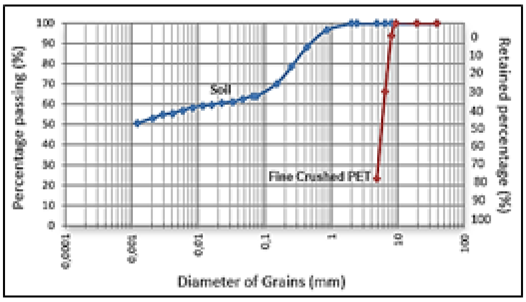

Figure 4. Particle size distribution.

The compaction test for the clayey soil and mixture are shown in Figure 5, where it is possible to notice that the maximum dry weight and the optimum moisture of the mixture decrease in relation to clayey soil. Table 3 summarizes the results found in the compaction tests.

Table 3. Compaction test results.

Material/ Mixture	W_{opm} (%)	γ_{dmax} (g/cm^3)
S100	25.8	1.55
S90P10	24.1	1.48
S80P20	23.6	1.40

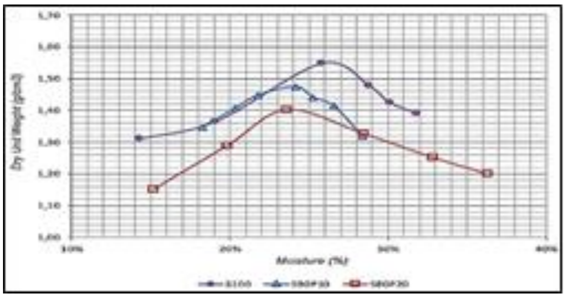
Figure 5. Compaction test curves.

4.2 Mechanical Tests

The triaxial tests were carried in three confining stress (50, 150 and 300 kPa). Next, will be presented the graphics of deviator stress vs axial strain and volumetric strain vs axial strain of the clayey soil and each mixture. Figures 6 to 8 show the behavior of the mixture S90P10, S80P20 compared with the clayey soil.

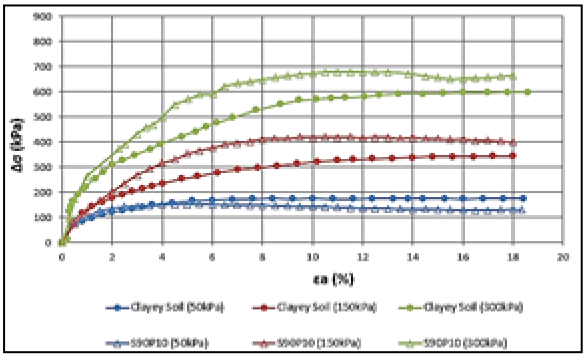

Figure 6. Relationship between Δσ and εa for the S90P10 and the clayey soil.

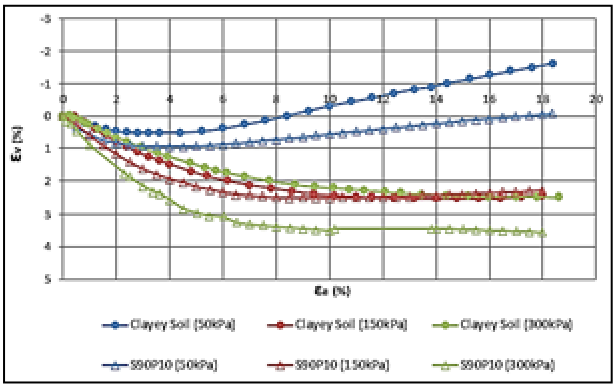

Figure 7. Relationship between εv and εa the S90P10 and clayey soil.

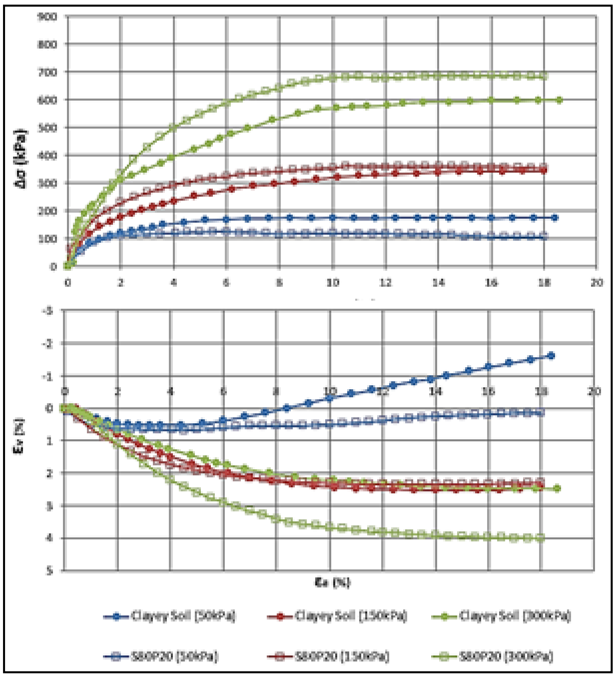

Figure 8- Relationship between Δσ and εa and εv x εa for the S80P20 and clayey soil.

Table 4 summarizes the Mohr-Coulomb strength parameters of the clayey soil and mixtures.

Table 4- Mohr-Coulomb strength parameters.

Material/ Mixture	c' (kPa)	ϕ'(°)
S100	24.5	27.0
S90P10	22.0	30.5
S80P20	17.0	31.0

It is observed that in both mixtures, when material is submitted to a low confining stress the insertion of fine crushed PET does not improve the strength parameters of the soil. However, at higher confining stresses the improvements of the strength parameters are evident. This behavior can be explained because, the fine crushed PET does not react with the soil particles, as it happened with lime or ashes of solid urban residue (Szeliga, 2014 and Quispe, 2013). The fine crushed PET works more as a grain size improvement, and in higher confining stress, when the consolidation step is applied, the fine crushed PET fills the remaining voids in the soil, leaving less gaps between the soil particles. So at the same axial strain, the mixture withstand a higher deviator stress comparing with the pure clayey soil.

Because the results of deviator stress vs axial strain, at a lower confining stress, were slightly below the ones found for the pure clayey soil, the strength envelopes provided values for cohesion smaller than the pure clayey soil, and higher for the friction angle. As said previously, the fine crushed PET works as grain size improvement, do not causing any cementation process with the soil particle. So, cohesion parameters does not suffer any improvement with the addition of this material, however the friction angle does get higher, because this parameter is affected in a grain size improvement.

It was also noticed that, even for the mixtures and the pure clayey soil, in the graphic of volumetric strain vs axial strain, the curves had approximately the same behavior, either for the mixture S90P10 or for the mixture S80P20.

5 CONCLUSION

It could be concluded through the triaxial tests that:

• The addition of fine crushed PET increase the clayey soil behavior improving its shear strength.

• The influence of the confining stress is an important point. There is a limiting confining pressure where, beneath this the presence of the fine crushed PET degrades the strength of the clayey soil. It could be explained because the fine crushed PET acts as a grain size improvement, at low confining stress it does not fill all the voids in the soil, and so, during the shear phase when the fine crushed PET is requested it is not interacting with the soil particles, minimizing the load capacity of the soil.

• This mixture is an adequate material to be used in some geotechnical application such as: layers of landfills, small embankments on soft soils, temporary landfills, subgrade reinforcement for construction roads over soft soil. In these projects the presence of high confinement stresses enable the use of this material, however it is needed more researches to evaluate other characteristics of this material in order to make it usable in the practice of geotechnical engineering.

• The use of this material in geotechnical works, may reduce the wrong disposal of the residue in nature, being a low coast and environmentally friendly option for soil reinforcement.

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