# Mechanical Behavior of Bentonite Reinforced with fine crushed PET

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ABSTRACT

PET (polyethylene terephthalate) is a suitable final destination material, as it takes around 100 years for its decomposition and irregular disposal in a given state of great harm to society. Despite the large amount of recycled material, only 50% of the material produced has this destination. In order to reduce the amount of polymers in nature, this work aims at the mechanical behavior of a bentonite mixed with PET micronized. The study showed the use of crushed PET around 1 mm in different contents (5% and 10%), making possible the application of strength parameters, making possible the conservation of waste in geotechnical works. The development of the study was characterized as a mechanism of physical and mechanical characterization, such as direct shear tests. The shear tests were performed with the confining stress of 50kPa, 100kPa and 150kPa, without reading the neutral pressure. With the results obtained from the direct shear tests, it can be seen that the mixture in PET is 5% with crushed PET (B95FCPET5), being more favorable the use in geotechnical works, having a relation in the strength parameters. The cohesive intercept of peak and residual increased residuals of 6kPa for 10kPa and 1kPa for 5kPa, respectively. The friction angle of peak and residual resistors reduction from 5º to 4º and 4º to 3º, respectively. Despite the possibility of substitution of the GCL for the mixture, however, it can be applied in other types of geotechnical works.

RESUMO

O PET (polietileno tereftalato) é um material que necessita de uma destinação final, pois leva em torno de 100 anos para sua decomposição e seu descarte irregular gera grandes prejuízos. Apesar da grande quantidade de material reciclado, apenas 50% do material produzido tem essa destinação. A fim de reduzir o descarte desse polímero na natureza, este trabalho tem como objetivo avaliar o comportamento mecânico de uma bentonita misturada com micronizado de PET. O estudo apresentado propõe a utilização do micronizado de PET (diâmetro médio 1 mm) em diferentes teores (5% e 10%), como reforço de uma bentonita para aumento dos parâmetros de resistência, viabilizando a utilização desses resíduos em obras geotécnicas. Para o estudo foram realizados ensaios de caracterização física e mecânica, como ensaios de cisalhamento direto. Os ensaios de cisalhamento direto foram realizados com a tensão confinante de 50kPa, 100kPa e 150kPa, sem a leitura da pressão neutra. Com os resultados obtidos a partir dos ensaios de cisalhamento direto, pode perceber que a mistura com 5% de com micronizado de PET (B95FCPET5), se mostrou favorável a utilização, tendo uma melhora nos parâmetros de resistência. O intercepto coesivo das resistências de pico e residual aumentaram de 6kPa para 10kPa e 1kPa para 5kPa, respectivamente. O ângulo de atrito das resistências de pico e residual reduziram de 5º para 4º e 4º para 3º, respectivamente. Apesar da melhora apresentada, não seria viável propor a substituição do GCL pela mistura, porém a mistura poderá ser aplicada em outros tipos de obras geotécnicas.

## 1. INTRODUCTION

The final disposal of PET bottles is a major problem for society, as its decomposition in the environment takes around 100 years. Currently only 50% of PET bottles produced are recycled. One of the reasons that hinder the increase in the percentage of recycled PET is the non-use in certain products, such as medicines, drinks, toys and hospital supplies, following a health surveillance guidance.

Concern about the disposal of these types of waste is being treated more seriously when compared to previous decades. More and more laws are being created that can reduce such environmental problems. When mishandled, non-recycled material can cause many environmental impacts from generation to final disposal.

The inclusion of alternative materials in geotechnical works helps to reduce construction costs by encouraging investment in this type of infrastructure and research.

To give another alternative to this residue, it is extremely important that the mechanical behavior of the mixture be studied, as well as its physical, environmental and chemical characteristics. Knowledge of the reinforcement mechanism will help a better understanding of the mechanical behavior of bentonite-pet mixtures. This material can act as reinforcement of bentonite to be applied in geotechnical works.

The use of pet waste as an alternative material can help to minimize problems of uneven tire disposal in rivers, dumps and landfills.

This research aims to evaluate the mechanical behavior of mixtures of bentonite with crushed pet in different granulometries and contents, seeking a possible use in substitution to GLC used in landfills.

It was used the micronized PET crushed material (average diameter 1 mm) mixed in different contents (5% and 10%) in relation to the dry weight of bentonite.

Bentonite has a high peak strength and a post peak drop. This is due to the high plasticity of the material. The inclusion of pet residue tends to increase peak strength and smooth post-peak drop, attenuating deformations and showing that there may be reinforcement in the mixture. The bottom layers used in landfills aims to prevent soil contamination.

The objective of the research can be achieved by evaluating the physical and mechanical behavior of bentonite and mixtures, establishing parameters that can measure the influence of PET addition.

According to the main objective described, the following specific objectives were established:

• Perform geotechnical physical characterization through standardized laboratory tests on bentonite and mixtures of bentonite with pet;

• Evaluate the mechanical behavior of pure bentonite and in the mixtures with different levels of pet residue through the direct shear test obtaining the shear strength parameters;

• Compare the results obtained in this research with experimental studies using other types of materials.

## 2. EXPERIMENTAL PROGRAM

The bentonite (Figure 1) presented in this research was commercially purchased in Rio de Janeiro. According to NBR 6502 (ABNT, 1995), this bentonite can be used as a clay.

Different direct shear tests were performed with normal stresses of 50kPa, 100kPa and 150kPa. Different mixtures were used to define strength envelopes of bentonite reinforced or not with PET. Several mixtures were tested.

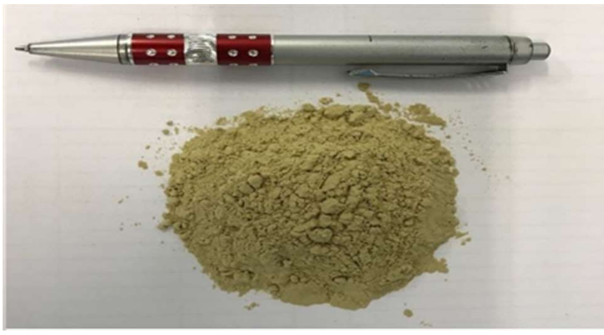

Figure 1. Bentonite Sample.

The PET powder used in this research (Figure 2) was made in Campina Grande, Paraíba – PB, Brazil. This same material was used in the study by Silva et al. (2013) is the result of a specific grinding method that manufactures fine PET particles.

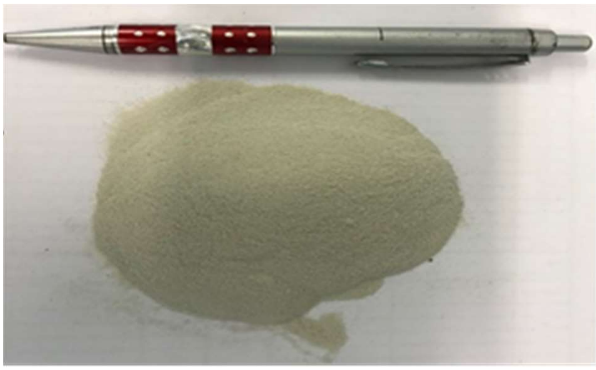

Figure 2. Fine Crushed PET.

According to Melo (2004), to produce PET powder, usually goes through the process that can be described in six steps:

1) A collection and selection of bottles with removal of labels and caps and washing in water;

2) The granulation process is done, when the bottles are milled in “knife” mills, producing “flakes” of PET, which is crushed PET;

3) The agglomeration is performed and the crushed PET, having low density, receives a thermal processing with the reduction of the volume and the reduction of its density;
4) A remodeling done to prepare the material for a grinding step;
5) A grinding consists of cutting the damaged material by rotational molding, leaving them in a round shape;
6) Micronization is made with insulating material or through powder in the 0.42 mm sieve.
As an example of the micronization process, a German pallet company crushes the material into a powder size using a PKM machine (Figure 3).

Figure 3. Machine PKM Pallmann.

In order to determine the index properties of the materials involved in the research, physical characterization tests were performed at the PUC-Rio Geotechnical and Environmental Laboratory. The materials were prepared according to the Brazilian technical standard (Brazilian Association of Technical standard - ABNT).

It was not possible to determine the true density of bentonite grains from the ABNT 6508/1984 procedures, since bentonite has very fine grain size. Calheiros (2013) method was used, where it was possible to succeed in determining the value. After the procedures it was possible to reach a Gs value of 2.90 g/cm3

Atterberg limits, liquidity limit and plasticity limit of bentonite were determined using the passing material in sieve # 40 (0.425 mm) according to ABNT standards NBR 6459/1984 and NBR 7180/1984. The particle size analysis of the material was obtained through the literature.

The direct shear tests performed had the objective to determine the shear strength parameters of bentonite. This strength is obtained by obtaining the parameters cohesion (c) and friction angle (ϕ). These tests were performed according to the methods described by ASTM D 3080/2004.

The samples were molded into the undisturbed sample mold supported on an acrylic vaseline base. After assembly, the material was passed to the direct shear box. This procedure ensured the standardization of the thickness of the samples. The specimens averaged 1.96 cm in height and 10.15 cm in side, this area of 103.02 $m^2$ and initial total volume of 201.92 $cm^3$.

The bentonite mixtures were prepared with 170% humidity, which corresponds to a void index of 4.93. The rubber percentage was 5% and 10%.

These contents were determined in order to analyze the evolution of the strength parameters of each type of mixtures, in order to establish a maximum improvement with the largest residue volume, since one of the objectives of the use of this material as reinforcement is to give a correct environmentally sound destination for as many residue as possible.

The values of 50kPa, 100 kPa 150 kPa and 200kPa were adopted for the normal applied stress, but it was observed that it was not possible to perform the test at stress above 150kPa. The material presented a fast axial strain and leaked through the shear box, which made the execution of the test unfeasible.

The table 1 shows the abbreviations used to identify each type of mixture. Thirty six direct shear tests were performed.

Table 1. Abbreviation of mixtures.

| Material/Mixture | Bentonite (%) | Vancouver | Abbreviation |
|---|---|---|---|
| Bentonite | 100 | 0 | B100 |
| Mixture 1 | 95 | 5 | B95FCPET5 |
| Mixture 2 | 90 | 10 | B90FCPET10 |

## 3. RESULTS AND ANALYSIS

The relative density (Gs) for Bentonite was obtained through the arithmetic mean of four determinations, and the maximum variation was 1.1%. The Gs value found was 2.90.

The granulometric curve of bentonite presented by Louzada (2015) was obtained through sedimentation tests (Figure 4).

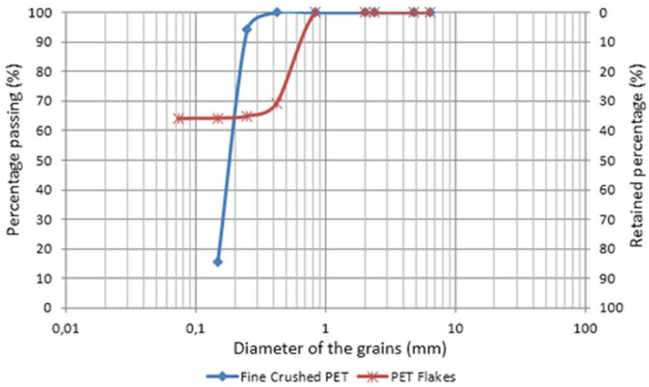


Figure 4. Particle size of fine crushed PET.

From the results obtained in the laboratory, the Bentonite Liquidity Limit 169 is 368.4% and the plasticity limit is 53.7%, resulting in a plasticity index of 314.7%.

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The fine crushed PET is a very fine material from a micronization process. The properties of fine crushed PET are shown in Table 3.

Table 3.Properties of fine crushed PET.

| Physical Index | Fine Crushed PET |
|---|---|
| Relative density (Gs) | 1,44 |
| Uniformity coefficient (Cu) | 14 |
| Curvature coefficient (Cc) | 4,6 |
| Effective diameter (D10) | 0,01 mm |
| Average diameter (D50) | 0,12 mm |
| Min void index (emin) | 0,69 |
| Max void index (emax) | 1,27 |

Figure 5 shows the graphs of shear stress and vertical displacement x horizontal displacement of bentonite x PET (5% and 10%).

From the graphs it can be concluded that for the 5% fine crushed PET, for the 50kPa and 100kPa stresses there was an increase in the peak and residual strength, and for the 100kPa stress there was a considerable increase.

For the 150kPa stress there was a slight increase in peak strength. Residual strength remained almost equal to that of pure material.

For mixtures with 10% fine crushed PET it can be noted that for the 50kPa stress the increase in the percentage of fine crushed PET to a decrease in peak and residual strength when compared to the 5% fine crushed PET material.

For the 100kPa stress it was noted that there was an increase considered in relation to the pure material, but when compared to the material with 5% fine crushed PET there was a slight decrease in the peak strength, but the residual strength remained almost the same. .

For the 150kPa stress the peak and residual strength remained very close to the material with 5% fine crushed PET, with no considerable differentiation. In relation to pure material there was a slight increase in peak strength.

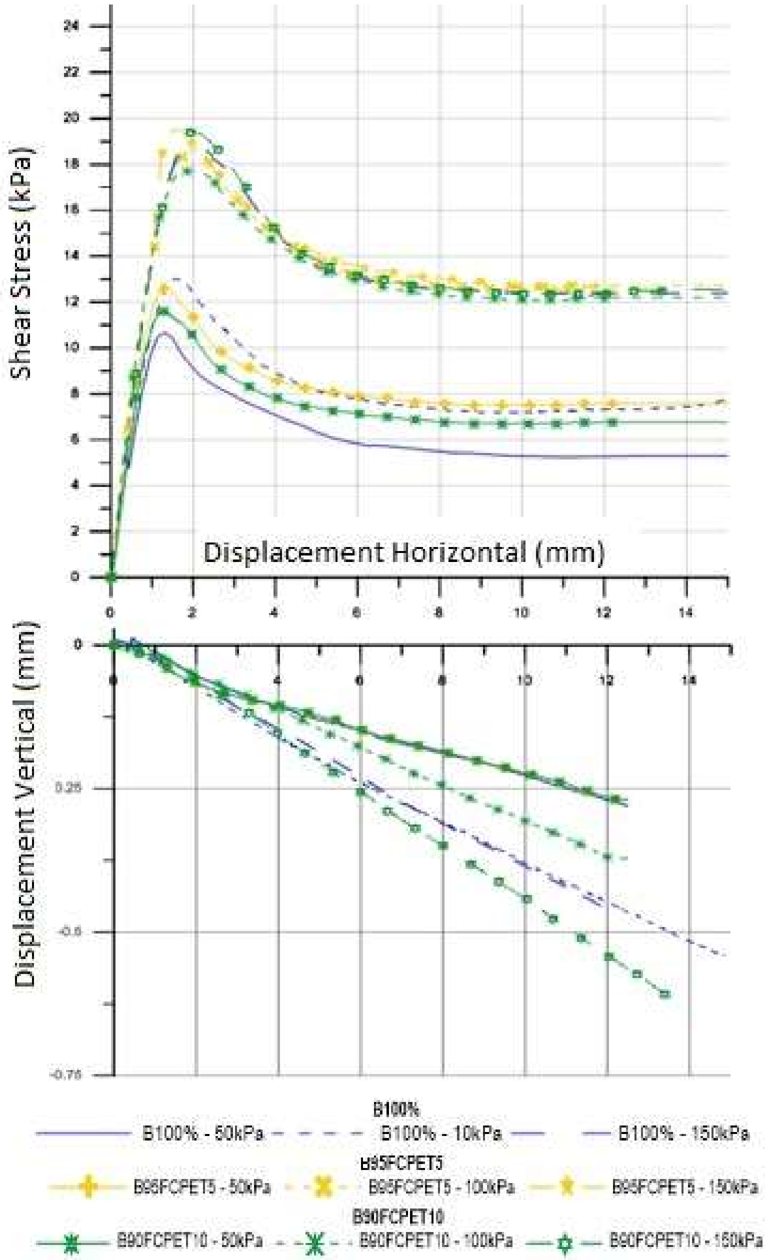


Figure 5. Graphics of shear stress x displacement horizontal and vertical displacement x displacement horizontal of mixtures with fine crushed PET.

Figures 6 and Table 4 show the peak and residual resistance parameters of bentonite and mixtures with fine crushed PET (at the point corresponding to the horizontal displacement of 15mm).

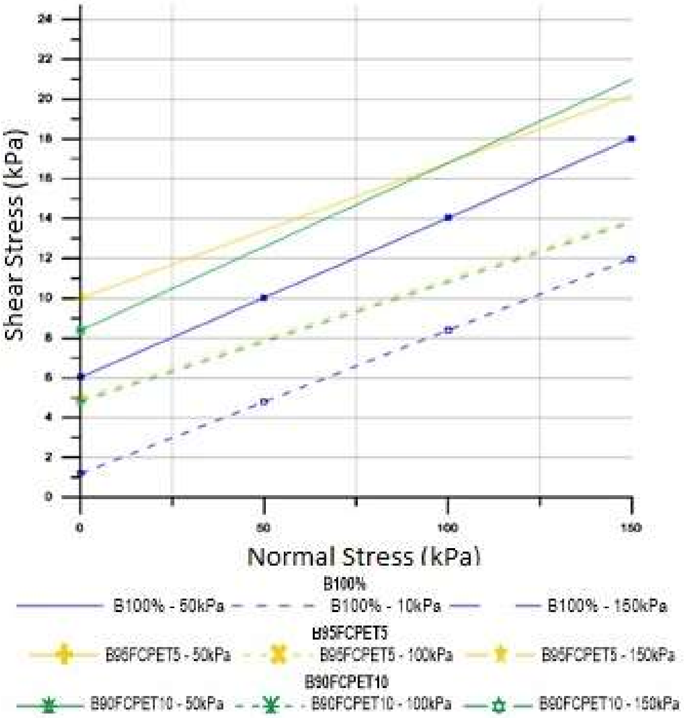


Figure 6.Shear stress x normal stress – Bentonite with Fine Crushed PET.

Table 3. Characteristics of tested soils.

| Mixtures | Peak Strength | | Residual Strength | |
|---|---|---|---|---|
| | Cohesive intercept (kPa) | Friction Angle (°) | Cohesive intercept (kPa) | Friction Angle (°) |
| Bentonite | 6 | 5 | 1 | 4 |
| Mixture 1 | 10 | 4 | 5 | 3 |
| Mixture 2 | 8 | 5 | 5 | 3 |

From the results obtained, it is observed that the addition of PET to bentonite, regardless of the amount, increased the cohesive intercept of the material, both in terms of maximum and residual resistance. For the B95FCPET5 mixture there was a reduction of the friction angle value in relation to the maximum resistance when compared to the pure material. Performing an analysis from the residual strength, it can be seen that while the cohesive intercept increased the residual friction angle decreased in all samples studied.

## 4. CONCLUSIONS

Based on the results presented and analyzed previously, it was possible to reach the conclusions discussed in this chapter.

The insertion of PET residue causes a change in behavior when inserted into bentonite, making it possible to observe the development of new geotechnical materials with PET residue. These new materials have characteristics similar to pure material, but there is an improvement in their mechanical properties.

The main conclusions for the addition of PET residue in the bentonite studied in this research were:

Analyzing the mixtures with 5% and 10% of PET powder being called B95FCPET5 and B95FCPET10, it was noted that there was no significant variation with the increase of the percentage of fine crushed PET inserted in the sample, drop in peak and residual resistances for the 50kPa stress. This fact occurred with the rubber powder and can reinforce that the particle size of the inserted material directly influences the obtained resistances.

It was possible to contact an increase in cohesive intercept and a reduction in friction angle involving all PET mixtures.

## 5. ACKNOWLEDGEMENTS

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