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Evaluation of Resilient Behavior of a Clayey Soil with Polyethylene Terephthalate (PET) Insertion for Application in Pavements Base

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Abstract. The growing production and consumption of PET bottles represent a major environmental problem because they end up being improperly discarded in nature or simply stocked. With the aim to attenuate the environmental problem, this research proposes the use of powder of PET and PET flakes as an alternative material for pavements base. In order to analyze the geotechnical performance of the material, physical tests, compaction and Cyclic Triaxial tests (Resilient modulus) were carried out on pure soil as well as on the mixture of soil-PET. Powder of PET was added to soil in weight percentages of 10, 20 and 30 % and Pet flakes was added to soil in weight percentages of 3, 5 and 7 %. The computer program SisPav (Franco, 2007) was used to perform a mechanistic-empirical design for a typical pavement structure with parameters obtained for the mixtures. The results indicated that the insertion of PET influences the mechanical behavior of the soil. It was found that resilient modulus increases, with respect to that of pure soil, for mixtures with the lowest content of PET (10, 20 and 3%). For tests with higher contents of PET flakes, the Resilient Modulus decreases. This research concluded that the clayey soil mixed with PET flakes can be used as an alternative material for pavements base, as long as a low content of PET is used.

Keywords. Polyethylene Terephthalate (PET), resilient modulus, pavements base.

1. Introduction

The use of waste from various industrial activities in engineering works is an environmental solution that has become widely spread in recent years, especially because of the diffusion of the sustainable development concept. Following this trend, recent geotechnical research of pavements is testing the use of certain waste materials as an alternative for the construction of this type of structures.

The need to provide an appropriate destination for waste composed of PET bottles, which has been increasing due to the large production and consumption in the last years, has motivated this research. The author proposes the addition of PET flakes in a clayey soil from Distrito Federal/Brazil, to be used as an alternative material in pavements base.

There are many studies that evaluate the use of PET residue as an alternative material for pavements, all of them add PET in the asphalt mixture, as an aggregate or asphalt

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modifier. In Brazil, for example, Arao [1] and Queiroz [2] evaluated the behavior of asphalt mixtures with addition of PET flakes. The results of the measured parameters of the asphalt mixtures indicated a mechanical improvement of the material. Others researchers around the world, like Alzate [3] and Moghaddam & Karin [4] have also proved the feasibility of using recycled PET in different types of asphalt mixtures.

Powder of PET and PET flakes were used by Louzada [5] in an experimental study of reinforced soil. She evaluated the mechanical behavior with static loading tests of mixtures of soil and PET (powder and flakes) with different contents. The results indicated an improved behavior for the desired purpose.

1.1. Polyethylene terephthalate (PET)

The polyethylene terephthalate is a thermoplastic polymer, which means that this plastic material softens when warmed becoming a fluid that can be re-molded. The PET was developed in 1941, by John Rex Whinfield and James Tennant Dickson. According to Romão *et al*. [6] PET became one of the more produced thermoplastic material in the world because of the mechanical properties, thermic properties, and the production cost.

Its large production and the long degradation time have made of PET a major problem for the environment. For this reason, it is extremely necessary the recycling of PET, in order to reduce the improper disposal in nature and the volume placed in the landfills. In Brazil, for example, 4 % of the solid urban waste is composed of PET.

According to ABIPET [7], the PET recycling rate is 51% in Brazil. The most part of the recycled PET is used in textile industry, another part is destined to the production of alkyd resins and the rest is used in the manufacture of non-food packaging, plates, tapes, and tubes. Also, products made of recycled PET have a limited application due to contamination risk.

1.2. Resilient modulus

Medina and Motta [8] said that resilience means “energy stored in an elastically deformed body, which returns when the stresses causing the deformations cease”. Thus, the resilience modulus represents the ratio of the applied stress and the corresponding resilient strain (Equation 1).

$$M_R = \frac{\sigma_d}{\varepsilon_r} \tag{1}$$

where M_R=Resilient modulus (MPa) σ_d=Cyclic deviator stress (σ_1-σ_3) (MPa) and ε_r=resilient strain (vertical).

The resilient modulus can be determined through cyclic triaxial tests, in which different deviator stresses are applied to the specimen, at a constant frequency, combined with different confining stresses. The stresses applied repeatedly are to represent the effect of traffic on the pavement structure approaching the in-situ solicitations. For each material tested the resilient modulus can be expressed by a mathematical model that is function of the state of stresses to which the specimen was subjected. For sandy soils the resilient modulus depends on the confining stress, while for clayey soils it depends on the deviator stress [8].

Others types of models relate the resilient modulus to deviator and confining stresses simultaneously. These models have been widely used in recent years because its better fit for materials. An example of these models is the composite model (Equation 2) developed by Macêdo (1996) [9].

$$M_R = k_1 \sigma_3^{k_2} \sigma_d^{k_3} \tag{2}$$

where k_1, k_2 and k_3 are the regression coefficients.

2. Materials

2.1. Soil

This study used a clayey soil classified as laterite, typically found over large regions of Brazil (Figure 1). In this case it was collected from the Experimental Field of the Postgraduate Geotechnical program of the University of Brasília, situated in Darcy Ribeiro Campus, Brasília.

Figure 1. Clayey soil from Experimental field of UnB.

2.2. Powder of PET and PET flakes

Powder of PET used in this research (Figure 2.a) is a result of PET bottle crushing and was produced in Campina Grande/PB –Brasil. The material has particles smaller than 0,42 mm.

PET flakes (Figure 2.b) used in this research is also a result of PET bottle crushing, performed with the Radial LaFrance equipment model SG-500F. This equipment belongs to the Laboratory of Structures and Materials of PUC-RIO.

2.3. Mixtures

The clayey soil was mixed with three different contents of powder of PET, 10, 20 and 30 %, and three different contents PET flakes, 3, 5 and 7 %, on dry weight. The water was added according to the optimum moisture content, which was obtained from the compaction test. Table 1 summarizes the materials used and the identification adopted for them.

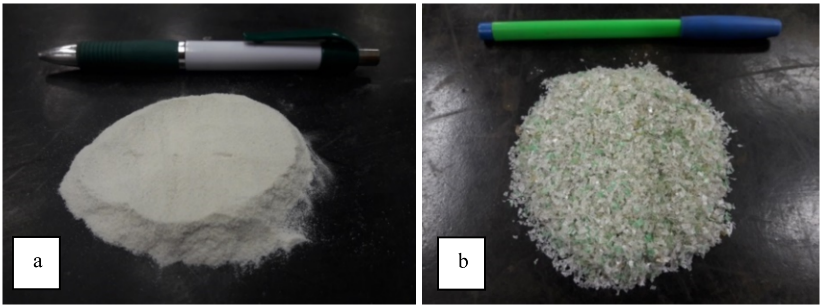

Figure 2. a. Powder of PET b. PET flakes.

Table 1. Identification used for the soil and the mixtures.

Material/Mixture	Soil (%)	PET (%)	Identification
Pure Soil	100	0	SP
	90	10	S90P10
Soil + Powder of PET	80	20	S80P20
	70	30	S70P30
	97	3	S97T03
Soil + PET flakes	95	5	S95T05
	93	7	S93T07

3. Experimental procedures

With the aim to determine physical properties characterization tests were performed in the clayey soil. The tests were executed according to the Brazilian technical standard (Brazilian Association of Technical Standards – ABNT). Particle size analyses were executed according to Standard ABNT-NBR 7181/84. The liquid limit and plastic limit were obtained according to Standard ABNT-NBR 6459/84 and ABNT-NBR 7180/85, respectively. The determination of the specific gravity of the soil was performed in the Penta pycnometer equipment. Particle size analyses and specific gravity tests were also performed for powder of PET and PET flakes.

The classification of the soil was made according to the Brazilian standard DNER-CLA 259/96 of the National Department of Highways and Roads (DNER), which is based on the methodology MCT (Miniature, Compacted, Tropical) developed by Nogami and Villibor (1981) [10]. This was necessary because there is an incoherence related to the behavior of tropical soils when these are classified by the traditional methodologies. The MCT classification depends on the parameters c', d' e e' obtained from two tests, the compaction test in the miniature equipment DNER-ME 258/94, and the test of loss of mass by immersion DNER-ME 256/94.

Compaction tests were carried out in the soil and the mixtures according to the Standard DNER-ME 228/84, using the intermediate energy (847.8 kN-m/m^3).

The resilient modulus was measured according to the American standard AASHTO T 307-99, applying principal stress pairs for base materials and sub-base of pavements. These tests were performed in the cyclic triaxial equipment, which belongs to INFRALAB laboratory at the Federal University of Brasíla.

The results of physical and mechanical characterization tests of the materials were used as input on the computer program SisPav to perform a mechanistic-empirical design for a typical pavement structure.

4. Results and analyses

The characterization tests show that the soil is composed of 47.4 % of clay, 30.5 % of sand and 22.1 % of silt. The soil particle size distribution is presented in Figure 4.a. The specific gravity of the soil, obtained in the Penta Pycnometer, was 2.7 g/cm³. The liquid limit found was 42 % and the plastic limit was 27 %, which results in a Plastic Index of 15. These results would classify the soil, according to the AASHTO classification, as a clayey material of the A-7-6 group. Based on this classification, the soil would have a poor performance for application in pavements, which turns to not be the case.

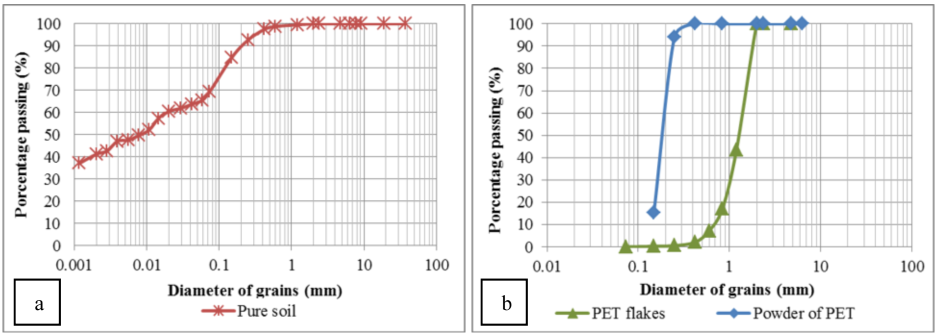

Figure 3. a. Soil particle size distribution. b. Powder of PET and PET flakes particle size distribution.

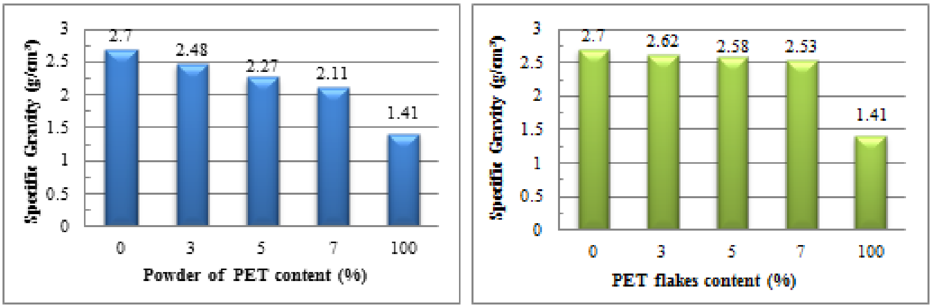

Figure 4. . Specific gravity variation with PET content.

In the other hand, according to the MCT methodology the soil is classified as lateritic-clayey soil (LG’). These soils have high support capacity, low expansion, medium to high contraction and low permeability, making possible to use this soil as subgrade, reinforcement of subgrade or base of pavements.

The compaction test on the clayey soil indicated a maximum dry unit weight of 16.8 kN/m³ and optimum moisture of 19.8%.

The maximum particle size of powder of PET used in this research is 0.42 mm and the maximum particle size of the PET flakes is 2 mm. The particle size distribution of powder of PET and PET flakes is presented in Figure 3. The specific gravity, obtained in the Penta Pycnometer, for PET materials is 1.41 g/cm³.

The variation of specific gravity of the mixtures as a function of powder of PET and PET flakes content is showed in Figure 4. The specific gravity of the mixture decreases as the amount of PET added increases.

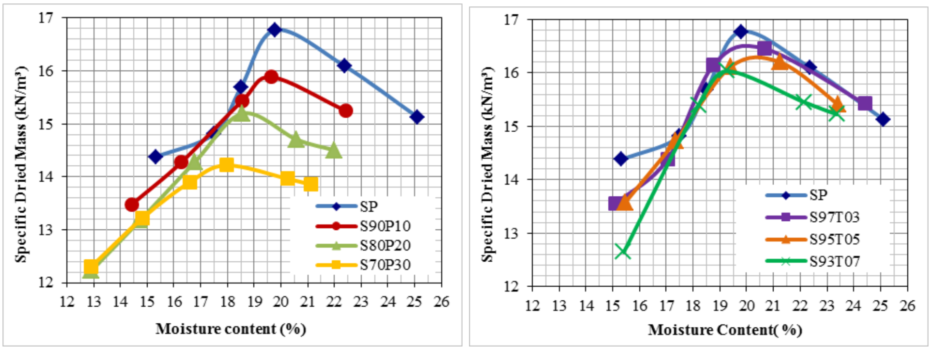

Figure 5. Compaction test curves.

The results of the compaction tests of the soil mixtures (Figure 5) show that the maximum dry unit weight of the mixture is lower than the maximum dry unit weight of the pure clayey soil, and it decreases as the amount of PET increases. The optimum moisture content also decreases as the amount of powder of PET increases while it remains practically the same as the amount of PET flakes increases.

The resilient modulus test was performed on samples molded with the optimum moisture content. The range of resilient modulus found for the pure soil is between 67 and 168 MPa. The ranges of M_R found for the mixtures are presented in Table 2.

Table 2. Range of M_R values for the mixtures with powder of PET and mixtures with PET flakes.

Mixture	M_R (MPa)	Mixture	M_R (MPa)
S90P10	115 – 247	S97F03	80 – 183
S80P20	79 – 226	S95F05	51 – 99
S70P30	60 – 148	S93F07	13 – 59

The tendency observed is that as PET content increases, the resilient modulus decreases. However, the mixture S90P10, S80P20 and S97T03 shows higher values of MR than pure soil, which means that the contents of 10% and 20% of powder of PET and the content of 3% of PET flakes provides a mechanical stabilization and a strong adherence between the soil grains and the PET particles. The others mixtures have a range of M_R lower than pure soil. The results indicate that lower contents of PET provide a greater improve on the stiffness of the mixture.

Table 3. Regression coefficients to the Composite Model.

Material	K_1	K_2	K_3	R^2
SP	235.308	0.089	0.262	0.91
S90P10	385,44	0,228	0,031	0,85
S80P20	160,88	0,690	-0.705	0,87
S70P30	45,52	0,160	-0.409	0,81
S97T03	235.887	-0.105	0.411	0,90
S95T05	123.738	0.013	0.209	0,91
S93T07	75.604	-0.206	0.626	0,89

The resilient modulus analyses show that the pure soil and the mixtures can adjust to the composite model (Eq. (2)). The regression coefficients are shown in Table 3.

4.1. Pavement design

The pavement design was calculated using the computer program SisPav, developed by Franco [11]. Figure 6 shows a pavement structure which was considered in this design, where the mechanical properties of the asphalt and subgrade layers remain constant, varying only the thickness of the base according to the resilient parameters of each material tested. It was assumed a road located in Brasília, with traffic load consisting of 25000 repetitions of a 8,200 kg double-axis vehicle.

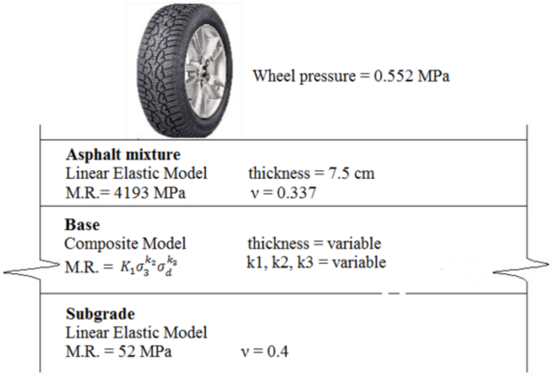

Figure 6. Pavement structure adopted.

Figure 7 shows the thickness of the base for the designs computed by the program with each material.

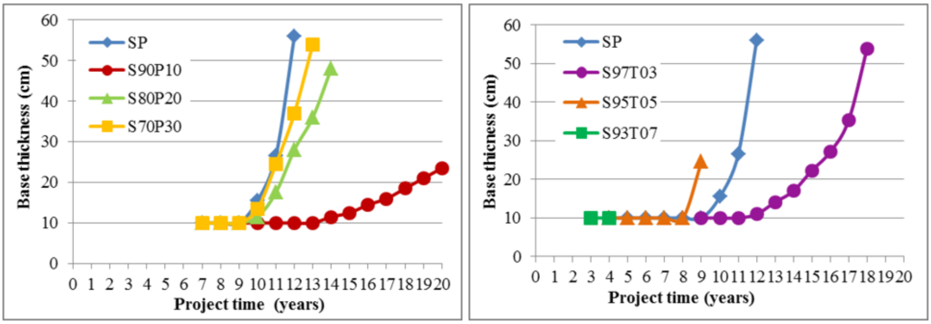

Figure 7. Layer Thickness according to project time.

The graphic shows that the size of the pavement with the mixtures with powder of PET (especially S90P10) and with the mixture S97T03 results in a thinner base layer compared to that of pure soil, which is a consequence of the higher M_R values. These mixtures can also achieve a longer project time. The layer thickness reduction can reach 80 % for a pavement with soil-PET.

As expected, the size of the pavement for the designs made considering the properties of mixtures S95T05 and S93T07 results in a thicker base layer and/or a shorter project time due to the lower M_R, that results in a lower estimated performance. However, the S95T05 mixture can still be used in a pavement designed for a project time less than 10 years, while S93T07 mixture is not recommended because of the very low mechanical properties that this material exhibits.

5. Conclusions

The results of this research allow to conclude that the addition of PET to a clayey soil modifies its properties. The addition of low contents of PET (10, 20 and 3%) to the soil can be used as an alternative material for pavement bases.

The S90P10 mixture exhibited a considerable improvement on the mechanical behavior of the soil, increasing the resilient modulus. The S80P20 and S97T03 also presented larger resilient modulus than the pure soil. As a consequence, there is a reduction in the base layer thickness in the pavement design. For this study, the content of 10 % of powder of PET showed the best results, followed by the mixture with 20% of powder of PET and the mixture with 3% of PET flakes.

It can be also concluded, from an environmental point of view, that the use of PET residue as an alternative material in pavements base, represents a good solution for its disposal and, consequently, for the mitigation of the great negative impact currently caused to the environment.

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