Micro-reinforcement of dune sands with pet wastes: Laboratorial studies

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ABSTRACT: The application of geosynthetics for improving the geotechnical characteristics of soils is already a subject with a considerable development in Geotechnical Engineering. However, the direct use of pure geosynthetic fibers mixed with soils has had an interesting development in the field of micro-reinforcement of soils with very poor geotechnical characteristics. It is in the context of studying micro-reinforcement of soils, that the present work is developed, making use of PET from crushed bottles used by the soft drinks industry in mixtures with dune sands. These sands when mixed with the PET material brings an improvement of the shear strength through the improvement of the friction angle of this new soil material sand-PET mixture, when compared with the pure sand. The PET waste used in the present study is a granulate resulting from shredded Coca-Cola bottles. So, the present paper presents the results of the studies with the purpose of showing the friction angle variation with different percentages of PET waste mixed in the dune sand, from samples tested in the direct shear test and in the triaxial test. Other results of typical geotechnical tests of earthworks, with soil-PET mixture, are also presented.

Keywords: micro-reinforcement; dune sand; PET waste; atritive material; ground improvement

1 INTRODUCTION

The problem of improving the geotechnical characteristics of soils is an increasingly frequent question in the quotidian of geotechnics, either because engineering is more and more daring and there is a tendency to occupy sites with deficient geotechnical characteristics or because it is often necessary to use large amounts of soils as construction materials in earthworks and the available soils not always are the most suited ones. It is in this context that the dune sands are studied in the present work, because they occur in large areas in the nature and often have weak geotechnical characteristics.

On the other hand, society is faced with excess waste, which is a problem that needs to be resolved on several fronts. The bottled drinks industry is one of the activities that in recent years has been growing, contributing to the production of huge amounts of waste caused by bottles that are not usually reused. One way to solve the problem could be the incineration or landfilling of those bottles, or else adopt a more rational and eventually more economical attitude, that is to make its reuse or other forms of recovery. One of the materials most used in bottles is the PET, which is a synthetic polymer called polyethylene terephthalate, and being one of the materials that traditionally forms part of the composition of some geosynthetics, it is understood that it can be used in the micro-reinforcement of some soils. Thus, the present work appears as a study in the sense of trying to take advantage of these materials that at the outset are a problem and that in the future may prove to be beneficial and of added economic value. It should be noted that PET is one of the materials, such as PE (polyethylene), PP (polypropylene) and PA (nylon), among other polymers used in the geotextile industry, which are traditionally used in geotechnical works (Koerner 1999). Some works already made out on this subject, micro-reinforcement of soils with PET wastes, were presented in Ferreira Gomes (2009), Graça (2010) and Graça et al. (2012).

2 MATERIALS AND METHODS

The materials used in this experimental work (Figure 1) were: i) dune sand, which is a natural non-cohesive material and consists in a soil with mineral particles essentially of quartz and feldspar; and ii) a PET granulate (polyethylene terephthalate) that resulted from the crushing of bottles of the soft drink industry. The crushing of bottles was effected in a laboratory rock crusher.

The materials were organized into four groups of samples: i) pure dune sand (AD), ii) dune sand with 3% PET waste granulate (AD3), iii) dune sand with 5% PET waste granulate (AD5), and iv) pure PET waste granulate (PET). Tests were performed on the pure materials, for their results to serve as reference and comparison with the mixed materials. Figure 2 shows the grain size curves of the various materials studied.

Figure 1. Materials in study: a) sand dune in nature; b) crushing the PET bottles; c) PET waste granulate.

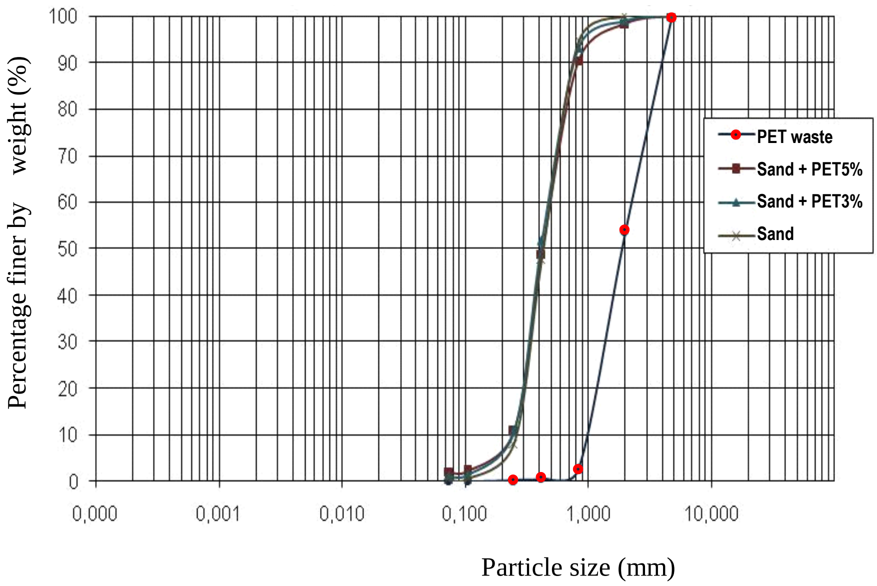

Figure 2. Particle size distributions for the samples of studied materials.

The various materials were subjected to the classic laboratory tests of the geotechnical area, generally following the Portuguese Standards and in line with the recommendations of Eurocode 7 (ENV 1997-2 2006).

As the main objective of the present work is to show the improvement of the resistance characteristics of the sand dune mixed with the PET waste granulate, some methodological aspects used in the tests of shear strength are presented in some detail: direct shear test and triaxial test.

In the direct shear test, the methodological guidelines presented in ASTM (2011b) were followed. The tests were carried out on samples imposing conditions of saturation. So, for this purpose, the samples were placed in the shear box which was completely filled with water. The shear box used had a circular section with an area of 78.53 cm^2, with specimens with average height of 2.60 cm. The tests were always carried out in two phases: the first phase where the sample was consolidated during the time of 30 minutes, which was sufficient for this soil to consolidate; the second, the shear phase with a velocity of 1.00 mm/min. In the shear phase, the normal stresses applied were the same as those used in the consolidation phase, with values varying between 47.6kPa and 353kPa, always using four specimens. The direct shear tests were performed for the four groups of samples, AD, AD3, AD5 and PET waste.

In the triaxial tests we followed the methodological orientations presented in ASTM (2011c). All samples were assayed according to the CID methodology, i.e. the samples were saturated and consolidated in a first stage and drained in the second shear phase. The specimens to be tested had a cylindrical shape, with H/D = 2 ratio and H = 0.20m (H and D, are the height and diameter of the specimen, respectively). The tests were performed with three specimens using effective confinement tensions of 50kPa, 100kPa and 200kPa, in the consolidation phase and that were equal to the confinement tensions of the shear phase. It should be noted that tests were only carried out on samples from groups AD, AD3 and AD5, because it was not possible moulding the specimens with the pure PET waste granulate.

3 RESULTS

The results of the main parameters of identification, physical and compressibility, are presented in Table 1. As for classification of these materials, according to the classification for Highway Construction Purposes (ASTM 2015), the pure sand, the mixtures at 3% and 5%, and still the granulate of pure PET, all are classified as A-1-a (0). As for the Unified Classification (ASTM 2011a), all these materials are classified as SP, poorly graded sand.

Table 1. Summary of results obtained from the geotechnical laboratory tests of the materials studied (from Graça et al. 2012).

Tests	Parameters	Samples			
		AD	AD3	AD5	PET
Granulometric analysis	D_{10} [mm]	0.26	0.25	0.25	1.00
	D_{30} [mm]	0.34	0.34	0.34	1.40
	D_{60} [mm]	0.60	0.58	0.60	2.30
	Cu [-]	2.40	2.32	2.40	2.30
Particle density	Gs [-]	2.69	2.61	2.51	1.37
Proctor Compaction	γ_{dmax} [kN/m^3]	16.8	16.3	16.00	-
	ω_{opt} [%]	0.00	0.00	0.00	-
Permeability	*k* (cm/s)	0.03	0.04	0.05	0.07
Oedometer	Cc (-)	0.033	0.050	0.064	0.611
	Cs(-)	0.003	0.001	0.001	0.035
	m_v (m^2/kN)	0.0004	0.0005	0.0010	0.0046

$D_{10, 30,60}$ – particle diameter corresponding to 10% , 30%, and 60%, respectively, finer on the cumulative particle-size distribution curve; Cu – coefficient of uniformity (D_{60}/ D_{10}); Gs – Particle density; γ_{dmax} and ω_{opt} ,- Maximum dry unit weight and Optimum water content ; *k* – Coefficient of permeability; Cc – Compression index; Cs – expansion index; m_v – coefficient of volume compressibility for the effective vertical tension at the last stage of the test.

The direct shear tests were performed on all the materials in study. The pure sand specimens as well as the specimens of the sand with the 3% and 5% PET waste, always had small peaks in the curves in terms of "shear strength versus horizontal displacement" similar to what is typical of tests in samples of medium compact granular soils. The PET waste specimens always showed a behaviour corresponding to what is typical of very loose soils, that is, as the test progressed, the "shear strength" was always increasing and simultaneously the "vertical displacement" was always in the sense of the particles approaching each other (reducing the voids ratio) until large deformations. Figure 3 generically illustrates such a situation for test specimens with vertical stresses of 85 kPa. The shear strength parameters obtained for the different materials in terms of residual stresses are shown in Table 2. The current results are consistent with those of Ferreira Gomes et al. (2009), showing clearly that the mixture of PET waste granules in the dune sand, results in a micro-reinforcement translated by the increase of the friction angle with rates of the order of 20% with mixtures of only 5% of PET waste.

It should be emphasized that soil cohesion is always zero, and it should be noted that this type of additive, PET waste granulate, allows the soil to maintain a purely friction behaviour.

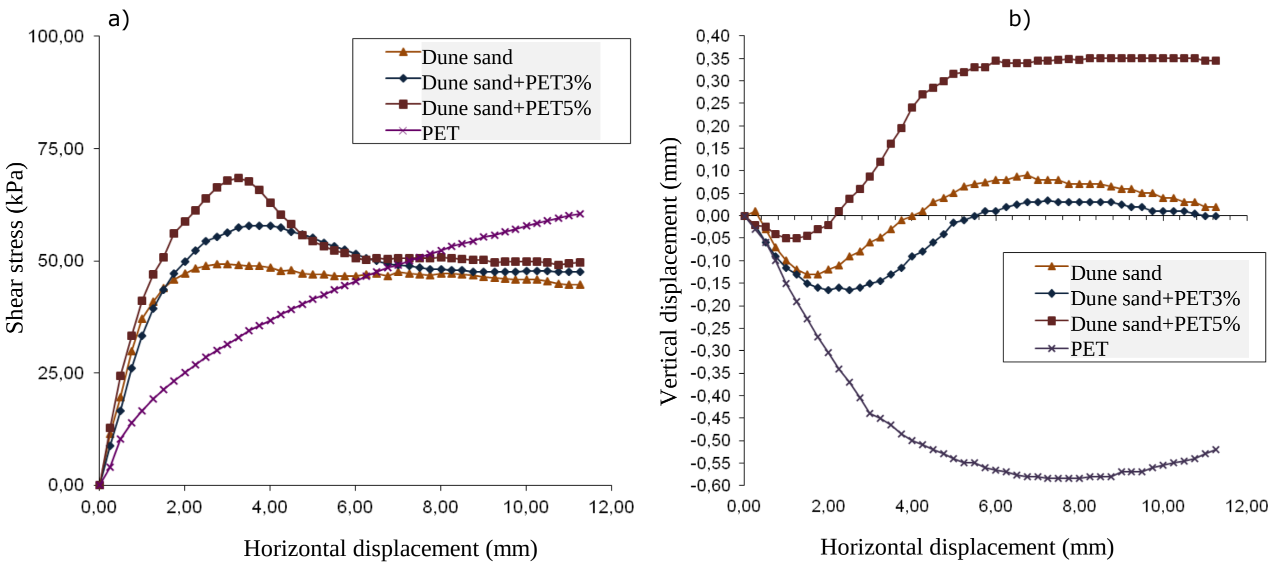

Figure 3. Direct shear test results for the materials in study, when subjected to the same normal stress of 85kPa, in terms of: a) shear stress versus horizontal displacement, and b) vertical displacement versus horizontal displacement.

Table 2. Results of the shear strength tests for the various materials in study, in terms of residual stresses.

Test	Parameter	Samples			
		AD	AD3	AD5	PET
Direct shear - CD	c (kPa)	0	0	0	0
	$\Phi_{residual}$ (°)	26,2	28,8	31,4	34,9
	$\Delta\Phi_{residual}$ (%)	-	10	20	33
Triaxial – CID	c (kPa)	0	0	0	-
	$\Phi_{residual}$ (°)	33,4	34,9	35,1	-
	$\Delta\Phi_{residual}$ (%)	-	4,5	5,1	-

CD- Consolidated / Drained, Consolidated (in isotropic stress) / Drained, c - cohesion, Φ - friction angle, Δ - increased of resistance.

On triaxial tests, as mentioned previously, they were all of the CID type, and it should be noted that they were not carried out on samples of pure PET waste granulate, due to technical difficulties, since this material, even with slight humidity, has no apparent cohesion necessary to enable the confection of the specimen, because in the attempt to prepare the specimen, when released from the mould, collapses immediately; thus only assays were performed on the AD, AD3 and AD5 samples. In the charts of Figure 4, the results are shown in terms of diagrams p'-q and the respective stress paths for samples AD, AD3 and AD5. The friction angle values obtained in terms of residual stresses, for comparison purposes with those obtained in the direct shear tests, are presented in Table 2. Figure 4d shows a typical image of the test specimen at the final stage of the test, showing a clear break in the specimen itself. In these tests the increase in the friction angle with the increase of the PET percentage mixed in the sand is also verified, however the increase of the friction angle values were not as significant as in the direct shear tests.

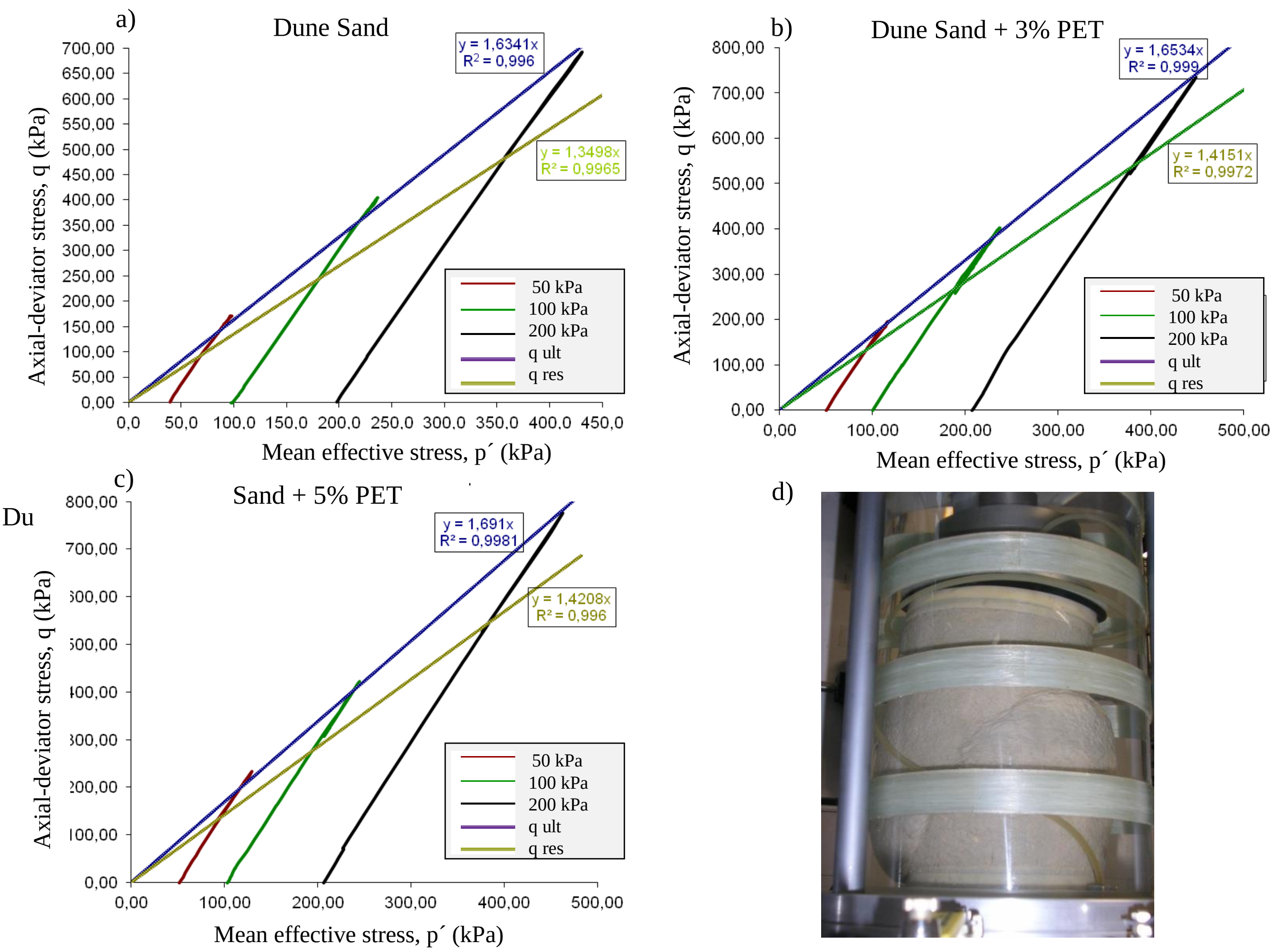

Figure 4. Results of CID triaxial tests in terms of stress path and rupture envelopes for the various materials in study (a, b, c), and typical appearance of the specimen at the end of the test (d).

The increase of shear strength for the mixed soils results from the PET residue becoming entangled in the particles (Figure 5) in order to result in greater difficulty in sliding between the particles when they are requested for shear forces.

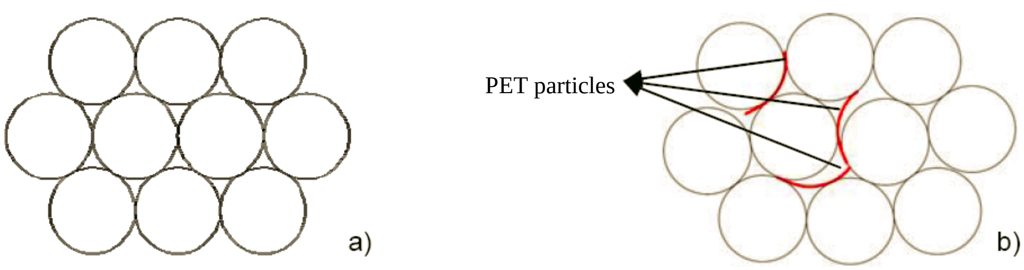

Figure 5. Schemes of the arrangement of the particles of the uniform sand: a) without PET, b) with mixed PET (Graça 2010).

4 CONCLUSIONS AND FINAL NOTES

In the present work, several studies have been done on materials that are the result of mixtures of a natural soil with a waste granulate. The natural soil used was an equigranular sand of average granulometry of dune origin. In relation to the waste, were used only 1.5 L bottles of Coca-Cola, crushed. It should be noted that in order to obtain more consistent results, it was verified the need to use only one type of bottle, because, as we know, bottles of different sizes, with different roughnesses, among others, are produced on the market, and function of such situations it would result in granulated with different roughness's, and therefore, can originate materials with different angles of friction.

The elements in the present work essentially show that the PET waste granulate from the bottles of the refrigerants industry are a component that can be used in improving the mechanical characteristics of the soils, and particularly when the soils are of lower quality than the desired one in earthworks.

Thus, several classic laboratory tests of the geotechnical field were carried out in four groups of samples or materials: pure dune sand (AD), dune sand with 3% PET waste granulate (AD3), dune sand with 5 % granulate PET waste (AD5), and pure PET waste granulate (PET). From the results of those tests the following is emphasized:

- in terms of identification and physical properties, the PET waste material can be considered as if it were a sand, based on the results of the granulometric analysis;
- in terms of grain size properties, the introduction of the PET waste granulate in the mixture with the sand does not bring about significant changes in relation to the pure sand, since the granulometric composition remains approximately equal, only varying the position of the curve in the particle size, as a function of the amount of mixed PET waste; it should be noted that this is due to the density of the PET waste in relative terms to be much lower than the density of the sand particles;
- in terms of the density of the particles of the mixture, the mixing of the PET waste entails a lower density in the mixture, which varies inversely with the amount of PET waste introduced;
- the introduction of the PET waste granulate does not cause any change in the workability of the sand, since the curves obtained in the tests remain approximately equal, slightly decreasing the maximum dry unit weight with the increase of the amount of PET waste;
- of the permeability tests it was observed that the mixture gains a greater percolation capacity, once the coefficient of permeability, k, increases with the increase of the amount of the PET waste granulate, however it is emphasized that k maintains the same order of magnitude;
- regarding compressibility, the mixture presents for the compression index, Cc, values slightly higher than that of pure sand, nevertheless always very low and typical of sandy soils, where the predominant settlements are of the instantaneous type and where the primary and secondary settlements are negligible;
- the mechanical behaviour of the mixed material is similar to the behaviour of the sand. Thus, as a result, with the increasing of the PET granulate, the shear strength increases. It should be emphasized that sand is a pure atritive material and this characteristic is kept when adding the PET waste, i.e. it remains with zero cohesion values;
- in the direct shear tests an increase of the friction angle of about 10% with 3% of mixed PET waste and of 20% with 5% of mixed PET waste was obtained, which means an increase of the friction angle values of 2,5º and 5,2º, respectively, in relation to the angle of friction obtained for the pure sand (26,2º), in the situation of residual stresses;
- in the triaxial tests the increase of the shear strength in the mixing materials in relation to the natural sand were not as significant as in the case of the direct shear tests, however, an increase of the friction angle of around 4.5% in the situation of 3% of mixed PET and of 5.1% in the situation of 5% of mixed PET, which means an increase in the values of the angle of friction of 1,5° and 1,7°, with respect to the angle of friction obtained for the pure sand (33.4°), for the residual stress values. It should be noted that the value obtained of the angle of friction for pure sand in the triaxial test was higher than that obtained in the direct shear test.

Finally, it should be pointed out that studies on the use of crushed bottles from the soft drink industry are still considered preliminary, but it is understood that they are promising and should continue with different bottles from those used in the present study, with granulates of different sizes, and it is still understood that it would be important in the future to carry out an experimental embankment, with sections of several mixtures of the sand and PET residues in different compositions.

The crushing of the bottles, in principle, can be done with rock crushers, and the mixtures at the start are also carried out with extreme ease, since they can be carried out manually and mechanically without any specific equipment, and can even be used the traditional mixer of concrete.

The application of the micro-reinforcement with these materials can bring environmental advantages, since it is the recycling of a material of great human consumption, and that in terms of application in earthworks do not foresee any kind of difficulty, because the mechanical behaviour of the sand mixtures with PET wastes is similar to that of sandy soils, so it will not create conflicts with the specifications of the traditional land works.

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