SHEAR STRENGTH OF MIXTURES OF SANDY SOIL AND PLASTIC FIBERS FROM PET BOTTLES

Key words: Reinforced soils, Waste reuse, Recyclable waste

Authors:

Gabriel Xavier Nóbrega, FECFAU – UNICAMP

Prof(ª). Dr(ª). Miriam Gonsalves Miguel, FECFAU - UNICAMP

INTRODUCTION:

Brazil had produced 81,8 million tons of solid waste in 2022, from which 13 million tons were constituted of plastic materials (ABRELPE, 2023). In Brazil, sanitary landfills are considered an environmentally appropriate disposal for these wastes. However, they have presented high operating costs and negative environmental impacts such as soil and/or groundwater contamination by leachate, due to leaks in their base layer (liner). Therefore, it becomes evident the need for different destinations of these wastes, such as reuse or recycling.

The use of plastic fibers from present-days life as soil reinforcement material is being topic of study of many researchers such as: Hassan et al. (2021), Trindade et al. (2006), Babu and Choksei (2010), Bottero et al. (2015) and Paddaiah et al. (2018). Custódio and Miguel (2022) studied the behavior of the addition of fibers from film-type plastics (bags) from landfilled municipal solid waste (MSW) with 8 and 24 years in sandy soil with 3% fines (passing through a 0.075 mm sieve). The contents of plastic fibers in relation to the dry mass of the sandy soil were 0%, 0.5%, 1.0% and 1.5%. Compaction tests at Normal energy and direct shear tests, with compacted samples of sandy soil and soil-fiber mixtures under drained conditions, were performed. The increase in the percentage of plastic fibers implied in a rise in the optimum moisture, a decrease in the maximum dry specific mass and an increase in the effective cohesion. The most significant gains in effective cohesion occurred for the mixtures with 1.0% fibers and 8 years and with 1.5% fibers and 24 years of landfilling. The increase in the effective friction angle occurred for all the mixtures with 8 years and for mixtures com 1.5% fibers and 24 years.

Thus, the present study evaluated the shear strength of a predominantly sandy soil added with plastic fibers from PET bottles, aiming at the use of these mixtures in geotechnical works. To this end, the influence of the addition of PET fibers of 30 mm length and 2 mm width in the proportions of 0%, 0.5%, 1.0%, 1.5% and 2.0% in dry mass of a sandy soil was evaluated in terms of shear strength parameters, under drained conditions.

MATERIALS AND METHODS:

Figure 1: Apparatus used to cut the plastic strips (Source: Self)

The plastic fibers used in this study were extracted from different PET bottles, without any additional selection criteria to obtain a typical sample of the material. The apparatus in Figure 1 was used to cut the PET bottles into 2 mm wide plastic strips, which were cut with scissors into 3 cm lengths, to define the 3 cm x 2 mm fibers. Afterwards, these fibers were manually mixed to obtain a homogeneous distribution of the fibers from the different types of bottles.

A commercial granular soil from a river bottom was sieved using a 10-mesh screen (D = 2.0 mm). The passing material used in this study was defined texturally as a predominantly sandy soil (S1). This soil was subjected to physical and geotechnical characterization using the following tests standardized by ABNT: a) specific grain mass (γ_s) (ABNT, 2016a), b) grain-size distribution (ABNT,2016d), c) liquid and plasticity limits (ABNT, 2016b; ABNT, 2016c).

S1 was used to create mixtures with plastic fibers, in dry mass ratio, at levels of 0.5%, 1.0%, 1.5% and 2.0%, which were named, respectively, S1F0.5%, S1F1.0%, S1F1.5% and S1F2.0%. The mixing process was manual and aimed to leave the fibers uniformly distributed in the samples but maintaining their random orientation. S1 and all other soil-fiber mixtures were subjected to compaction tests at standard proctor energy (ABNT, 2016e) with material reuse. The compaction curves of S1 and soil-fiber mixtures allowed obtaining the point of maximum compaction efficiency through the parameters maximum dry specific mass ($\gamma_{d,max}$) and optimum moisture content (w_{ot}).

The direct shear tests were performed under drained conditions and in accordance with the ASTM D 3080 (ASMT, 2011). The soil and soil-fiber mixtures were compacted at the point of maximum efficiency in metal rings of 2.5 cm in height and 5 cm in diameter with the mini-MCV compactor, thus defining the specimens. Three specimens were used for S1 and the mixtures (S1F0.5%, S1F1.0%, S1F1.5% and S1F2.0%). After the compaction, all specimens were saturated by backpressure prior to the direct shear tests. The effective normal stress applied on each specimen were of 50, 100 and 200 kN/m^2. After tests, it was possible to define the effective cohesion (c') and effective friction angle (ϕ') of the S1 and mixtures with different proportion of fibers.

RESULTS:

The results of the physical and geotechnical characterization tests of S1 are presented in Table 1. S1 showed a non-plastic behavior, which is typical of sands, given the impossibility of carrying out the plastic limit test. S1 was classified as SP – Sand poorly-graded, by Unified Soil Classification System (USCS).

The values of optimum moisture content and the maximum dry specific mass were as displayed in Table 2. As seen in such, there were practically no significant changes in the optimum moisture content values with the addition of plastic fibers, except for the S1F0.5% mixture, which presented a value 22%

lower than that obtained for S1. Likewise, the maximum dry specific mass values did not undergo significant changes with the addition of plastic fibers. Therefore, the addition of plastic fibers to the soil did not provide any improvement in S1 compaction.

The values of effective cohesion (c') and effective friction angle (ϕ'), obtained by the direct shear tests for the S1 and the mixtures are presented in the Figure 2 and Table 3. S1, without any fiber addition, showed a null effective cohesion and effective friction angle slightly higher than 30°, which is typical of non-plastic sands. The mixtures of these soil with plastic fiber presented non-null effective cohesion (c') and an increase in the effective friction angle (ϕ').

Table 1: Characteristics of the soil (Source: self)

Parameter	S1
Specific mass of grains (g/cm³)	2.646
% gravel	0
% sand	96.3
% silt	2.8
% clay	0.9
Uniformity coefficient	2.3
Coefficient of curvature	1.0

Table 2: Compaction tests results (Source: self)

Soil and Soil-fiber mixtures	W_{ot} (%)	$\gamma_{d,max}$ (g/cm³)
S1	10.8	1.708
S1F0.5%	8.4	1.727
S1F1.0%	11.3	1.727
S1F1.5%	10.4	1.705
S1F2.0%	10.0	1.724

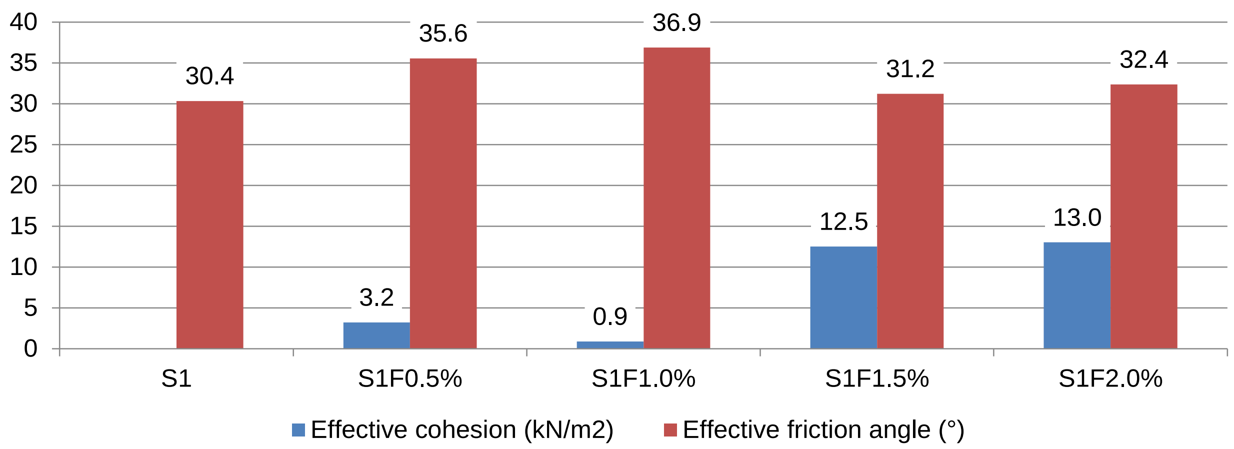

Figure 2: Effective friction angle and effective cohesion to the samples (Source: self)

Table 3: Increase of cohesion and friction angle with the increase of plastic fibers (Source: self)

Sample	Effective cohesion (c') (kN/m²)	Effective friction angle (ϕ') (°)	Increase in friction angle in respect to S1 (%)
S1	0.0	30.4	-
S1F0.5%	3.2	35.6	17.2%
S1F1.0%	0.9	36.9	21.5%
S1F1.5%	12.5	31.2	2.9%
S1F2.0%	13.0	32.4	6.6%

The gain in effective cohesion (c´) was not significant for the mixture with 0.5% and 1.0% plastic fiber content, presenting a maximum value of 3.2 kN/m² for S1F0.5%, and slightly higher values for S1F1.5% and S1F2.0%. Therefore, it was necessary to add at least 1.5% fibers to obtain c´ values slightly above 12 kN/m^2. The opposite behavior was presented by the effective friction angle (ϕ´). That is, the mixtures with 0.5% and 1.0% fiber content presented a greater increase in ϕ’ (maximum of 21.5%) than mixtures with 1.5% and 2.0% fiber content, for which such increase was limited to 6.6%.

The effective shear strength values for effective normal stresses (σ’) of 50 kN/m^2, 100 kN/m^2 and 200 kN/m^2 are presented in Figure 3. Under normal stress of 50 kPa, S1F1.5% and S1F2.0% presented higher shear strength, a consequence of their higher effective cohesion values. In the case of soil mixtures subjected to 200 kN/m^2, however, S10.5% and S1F1.0% presented higher shear strength values, which can be attributed to the higher values of specific friction angle that has a greater influence the higher the σ’. Under σ’ of 100 kN/m^2, all mixtures had similar shear strength values. In any case, the reinforced soil presented higher values of effective shear strength compared to the original soil S1, more expressively under σ’ of 200 kN/m^2.

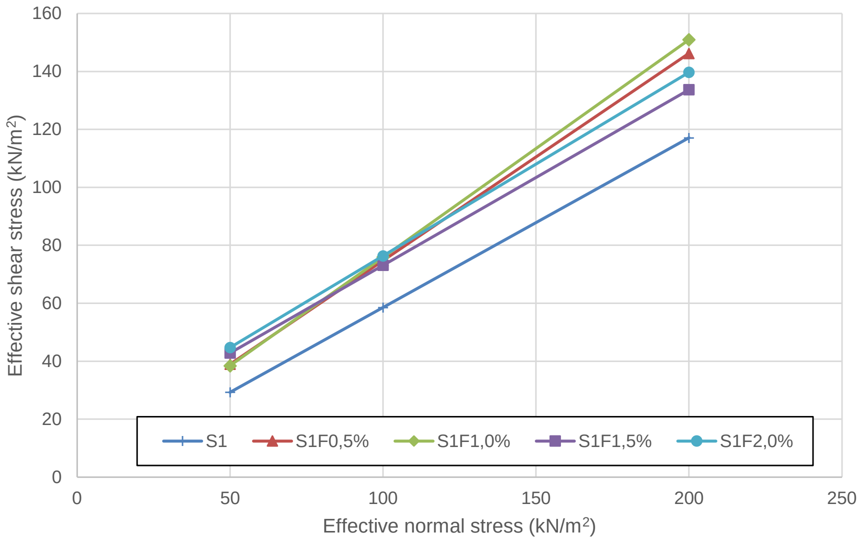

Figure 3: Failure envelope of the soil with different amounts of fibers

The sandy soil of Custódio and Miguel (2022) had sand and fines percentages like S1 used in this study, serving as a basis for comparison. The effective cohesion (c´) gain using PET fibers was not greater than c´ gain with the addition of plastic fibers from landfilled MSW, except for the mixture with 1.5% fibers with MSW of 8 years, which presented a c' value slightly lower than that of S1F1.5%. On the other hand, the gain in the ϕ' value obtained by Custódio and Miguel (2022) was between 2% and 12%, being greater for the mixtures with 8 years of landfilling. In this study, gains greater than 12% occurred for S1F0.5% and S1F1.0%.

The sandy soil of Custódio and Miguel (2022) had sand and fines percentages like S1 used in this study, serving as a basis for comparison. The effective cohesion (c´) gain using PET fibers was not greater than c´ gain with the addition of plastic fibers from landfilled MSW, except for the mixture with 1.5% fibers with MSW of 8 years, which presented a c' value slightly lower than that of S1F1.5%. On the other hand, the gain in the ϕ' value obtained by Custódio and Miguel (2022) was between 2% and 12%, being greater for the mixtures with 8 years of landfilling. In this study, gains greater than 12% occurred for S1F0.5% and S1F1.0%.

CONCLUSION:

This research analyzed the addition of plastic fibers from PET bottles to sandy soil as a reinforcement material for geotechnical purposes. A sandy soil with 3% fines and mixtures of this soil with 4 different fiber contents (0.5%, 1.0%, 1.5%, 2.0%) were studied. The addition of fibers increased the effective shear strength of the soil, in terms of effective cohesion and effective friction angle, and is therefore applicable as a reinforcement technique for sandy soil. The mixtures with more fibers (1.5 and 2.0%) presented higher effective cohesion values and lower friction angle values, compared to the mixtures with less fibers (0.5 and 1.0%).

In addition, the addition of PET fibers to the sandy soil presented, in general, a lower gain in effective cohesion than the addition of plastic fiber from urban solid waste landfilled in similar sandy soil. However, a greater potential for increasing the effective soil friction angle was observed with the addition of PET fibers. In other words, the PET fibers provided improvements in the sandy soil, mainly due to the increase in the friction angle.

REFERENCES:

ABNT – Associação Brasileira de Normas Técnicas. **NBR 6458**: Determinação da Massa Específica dos Grãos. Rio de Janeiro. 2016a

ABNT – Associação Brasileira de Normas Técnicas. **NBR 6459**: Solo - Determinação do limite de liquidez. 2016b

ABNT – Associação Brasileira de Normas Técnicas. **NBR 7180**: Solo - Determinação do limite de plasticidade. 2016c

ABNT – Associação Brasileira de Normas Técnicas. **NBR 7181**: Solo - Análise granulométrica. 2016d

ABNT – Associação Brasileira de Normas Técnicas. **NBR 7182**: Solo: Ensaio de Compactação. Rio de Janeiro. 2016e

ABRELPE - Associação Brasileira de Empresas de Limpeza Pública e Resíduos Especiais. **Panorama dos Resíduos Sólidos no Brasil.** 60 p, 2022. Available in: https://abrelpe.org.br/panorama/. Access in: 30 abr. 2023

ASTM - American Society for Testing and Materials. **D3080-11**: Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions, 2011.

BABU, G.L.; CHOUKSEY, S.K.G. **Stress–strain response of plastic waste mixed soil**. Waste Management. V. 31, n. 3, p. 481-488, 2011.

BOTERO, E; OSSA, A.; SHERWELL, G.; OVANDO-SHELLEY, E. **Stress–strain behavior of a silty soil reinforced with polyethylene terephthalate (PET)**. Geotextiles and Geomembranes, V. 43, n. 4, p. 363-369, 2015.

CUSTÓDIO, J.; MIGUEL, M.G. **Resistência ao cisalhamento de misturas de solos e tiras de plásticos tipo filme oriundos de resíduos sólidos urbanos aterrados**. XXX Congresso de Iniciação Cientifica da Unicamp, 2022.

HASSAN, H.J.A., RASUL, J.; SAMIN, M. **Effects of Plastic Waste Materials on Geotechnical Properties of Clayey Soil**. Transportation Infrastructure Geotechnology, V.8, p.390-413, 2021. http://dx.doi.org/10.1007/s40515-020-00145-4.

PADDAIAH, S.; BURMAN A.; SREEDEEP, S. **Experimental Study on Effect of Waste Plastic Bottle Strips in Soil Improvement**, V.36, p. 2907-2920. 2018. https://doi.org/10.1007/s10706-018-0512-0

TRINDADE, T.P., LASBIK, I., LIMA, D.C., MINETTE, E., SILVA, C.H.C., CARVALHO, C.A.B., BUENO, B.S., MACHADO, C.C. **Estudos laboratoriais do comportamento de um solo residual arenoso reforçado com fibras de polipropileno, visando à aplicação em estradas florestais**. Revista Árvore, Viçosa- MG, v.30, n.2, p.215-222, 2006