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Soil stabilization with plastic waste and sisal fibres

Stabilisation des sols avec des déchets plastiques et des fibres de sisal

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ABSTRACT: In Portugal, road pavements as well as their foundation are mostly built with natural aggregates, usually crushed, with high economic and environmental impacts. However, the attempt to use excavation materials has become more frequent, whenever they meet the requirements for that use, either in the foundation or in the granular layers of road pavements. Nevertheless, it often happens that the materials found on the construction site do not meet the requirements to be reused, in many situations because they are fine clayey materials. One way to make it possible to reuse those materials is to improve their properties to fulfil the requirements of use. In this work, two clayey sand soils were characterized, in its natural state and after mixing it with plastic waste and sisal fibres, respectively. Mixtures with 1%, 2% and 3% of plastic waste and with 0.5%, 1.0% and 1.5% of sisal fibres with 15 mm length were characterized. Laboratory tests were performed to assess their ability to improve soil properties for embankment construction and pavement layers. The bearing capacity ratio was determined using California Bearing Ratio (CBR) test. An increase in the bearing capacity ratio was achieved with plastic waste stabilization. Reduction in the bearing capacity ratio was observed in the specimens stabilized with sisal fibres. Increase in the bearing capacity ratio was more effective for high penetration values. The dry unit weigh decreased with the increase in plastic waste / sisal fibre content.

RÉSUMÉ: Au Portugal, les revêtements routiers ainsi que leurs fondations sont pour la plupart construits avec des granulats naturels, généralement concassés, avec des impacts économiques et environnementaux élevés. En revanche, la tentative d'utiliser des matériaux d'excavation est devenue plus fréquente, chaque fois qu'ils répondent aux exigences de cet usage, soit dans les fondations, soit dans les couches granulaires des revêtements routiers. Cependant, il arrive souvent que les matériaux trouvés sur la ligne ne répondent pas aux exigences pour être réutilisés dans les travaux. Une façon de rendre possible la réutilisation de ces matériaux est d'améliorer leurs propriétés pour répondre aux exigences d'utilisation. Dans ce travail, deux sols argilo-sableux ont été caractérisés, respectivement à l'état naturel et après mélange avec des déchets plastiques et des fibres de sisal. Des mélanges contenant 1%, 2% et 3% de déchets plastiques et 0,5%, 1,0% et 1,5% de fibres de sisal d'une longueur de 15 mm ont été caractérisés. Des tests en laboratoire ont été effectués pour évaluer leur capacité à améliorer les propriétés du sol pour la construction de remblais et les couches de chaussée. La capacité portante a été déterminée à l'aide du test CBR. Une augmentation de la capacité portante a été obtenue grâce à la stabilisation des déchets plastiques. Une réduction de la capacité portante a été observée sur les échantillons stabilisés avec des fibres de sisal. Le poids unitaire sec a diminué avec l'augmentation de la teneur en déchets plastiques/fibres de sisal.

Keywords: Soil stabilization; CBR test; plastic waste; sisal fibres; road embankments.

1 INTRODUCTION

There is a need to significantly reduce waste production and increase recycling rates. Many wastes and industrial by-products can benefit from more reuse and recycling solutions reducing the life cycle impacts. However, since natural fibres are readily available and less expensive, soil can also be stabilized with them.

Soil stabilization using waste materials or natural fibres as an additive can have technical and environmental advantages. Some researchers have studied the use of waste materials, mainly produced from plastic wastes (Paramkusam et al. 2013) and natural fibres (Fonseca da Silva, et al., 2019) in soil stabilization.

The plastic wastes can be used for stabilization as plastic strips, plastic flakes, or fibres. Plastic wastes included, as example, plastic strips of HDPE or PET from bottles (Rawat and Kumar 2016; Babu and Chouksey 2011), shredded labels of PE and PP from packages (Gardete et al. 2017), flakes from grounded PET bottles (Gardete and Luzia 2017).

Natural fibres can have different origins, such as sisal, coconut, jute, rice straw, bamboo, linen, and cut into different lengths, from 5 mm (Wu, et al., 2014) to 75 mm (Fonseca da Silva, et al., 2019) and used in different percentages, from 0.25% (Manjunath et al., 2013) to 2.0% (Mohammed, et al., 2022).

From the stabilization with several types of waste materials, it was observed that the percentages of

waste addition achieving best results are generally lower than 2% (Choudhary et al. 2010; Rawat and Kumar 2016; Paramkusam et al. 2013). From stabilization with natural fibers it was observed that the percentages of fiber addition that achieve better results are, generally, less than 1% (Nguyen and Indraratna, 2023). Nevertheless, some authors refer percentages up to 1.5% (Mohammed et al., 2022). With regard to fiber length, the optimal value varies between 10 mm (Maity et al., 2018) and 15 mm (Mohammed et al., 2022).

Stabilization with plastic waste materials and with natural fibres increased the resistance and the shear strength parameters of the soil measured in CBR tests, unconfined compression tests and simple shear tests (Hejazi et al. 2012, Nguyen and Indraratna, 2023).

2 MATERIALS

2.1 Soils

Two clayey sand soils (A and B) were used. Visually, the soils are reddish-brown with a significant quantity of fines and evident plastic behaviour. Plastic waste was mixed with the clayey sand soil A, with nearly 50% passing the No. 200 sieve. Sisal fibres were mixed with the clayey sand soil B, with nearly 37% passing the No.200 sieve.

At this point it should be said that for each of the tests referred to in the following sections, two specimens were tested. The results presented correspond to the average of the results for each of the specimens.

The gradation for both soils is presented in Figure 1 (LNEC, 1966a).

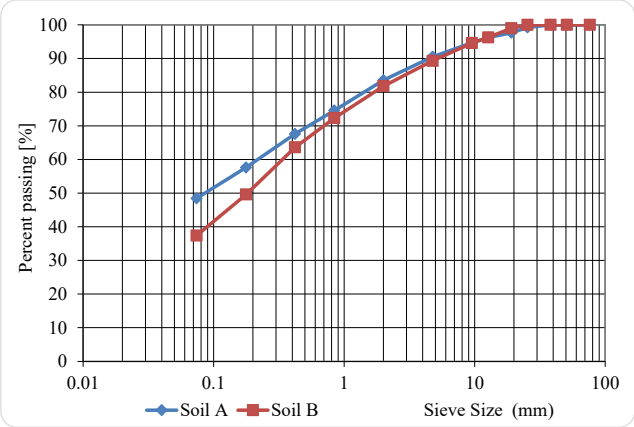

Figure 1. Gradation curves.

The following properties of the soils were characterized, liquid limit, plastic limit, sand equivalent, organic matter content and methylene blue value. The results are presented in Table 1.

Table 1. Soil properties.

Property	Standard	Soil A	Soil B
Liquid Limit [%]	NP 143 (IGPAI, 1969)	31.6	27.2
Plastic Limit [%]		20.6	20.7
Sand Equiva-lent [%]	LNEC E 199 (LNEC, 1967a)	14.4	44.6
Organic Matter Content [%]	NLT-117 (IRANOR, 1977)	2.48	3.00
Methylene Blue Value [g/100g]	NF P18-592 (AFNOR,1990)	0.8	0.5

Table 2 presents the classification of the two soils according to USCS (ASTM, 2006). and AASHTO (LNEC, 1970) classifications.

Table 2. Soil classification.

Classification	Soil A	Soil B
USCS (ASTM, 2006).	SC- Clayey sand	SC-SM – Silty clay sand
AASHTO (LNEC, 1970)	A-6-(3)	A-4(1)

Modified Proctor compaction test was used to determine MDD (Maximum Dry Density) and OMC (Optimum Moisture Content) of the soils. The test procedures followed standard LNEC E 197 (LNEC, 1966b). Soil A presented an OMC of 12.7% and MDD of 19.2 kN/m^3 and Soil B presented an OMC of 11.6% and MDD of 19.6 kN/m^3, Figure 2.

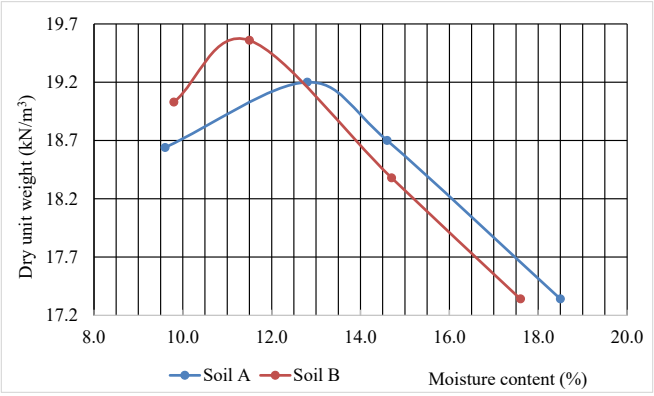

Figure 2. Modified Proctor test results.

2.2 Plastic waste and sisal fibres

2.2.1 Plastic waste

Plastic waste came from the industry and is used as it was provided without any modification. It was selected for having low recycling and reuse value. The plastic waste used was provided by plastic recycling

company Ecoiberia - Reciclados Ibéricos, S.A.. The plastic waste used was made from shredded labels in PE and PP. The flakes are highly flexible, very thin (estimated thickness from 30 to 60 µm), irregular shape and size mostly between 1.0 and 2.0 cm^2, some flakes are creased, Figure 3. The flakes are made from assorted materials and colors, therefore this type of waste has low interest for recycling.

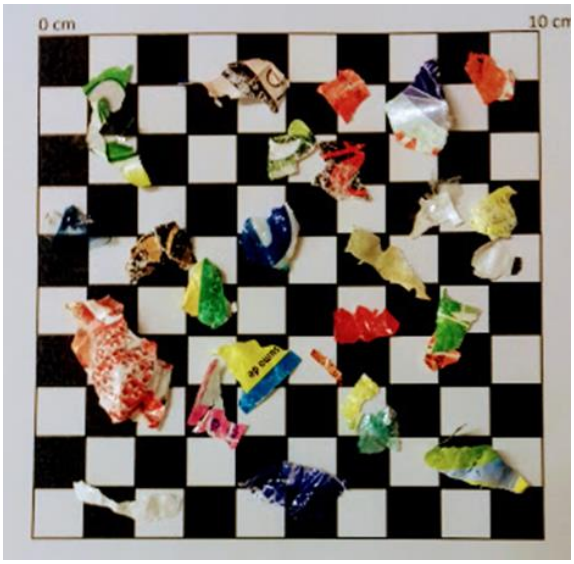

Figure 3. Waste plastic flakes.

2.2.2 Sisal fibres

The sisal fibers used were purchased in a commercial store and are generally used for civil construction work associated with plaster. Sisal fibers generally have an average diameter of 150 µm and a density of 1.35 g/cm^3 (Mohammed et al., 2022) and were cut to 15 mm in length, Figure 4.

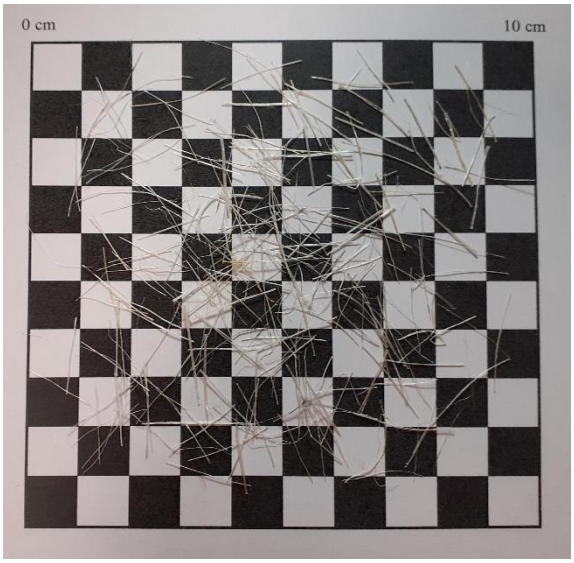

Figure 4. Sisal fibres.

3 SOIL STABILIZATION

3.1 Mixing

The soils were mixed with both plastic waste and sisal fibres by hand. The contents of plastic waste used were 1%, 2% and 3%, weight of waste / dry weight of soil and for sisal fibre were 0.5%, 1.0% and 1.5%, weight of sisal fibre / dry weight of soil. The values for 0% waste / sisal fibre content are referred to the original soils without stabilization. For the stabilization plastic waste / sisal fibres were added to the dry soils. These were mixed until a visually homogeneous mixture was observed. The water content for all specimens compacted corresponded to the OMC of the original soils (soil A for plastic waste and soil B for the sisal fibers). Water was added and mixture proceeded until a good dispersion of the water in the mixture was observed.

A homogeneous mixture was easy to achieve when using the waste plastic flakes. Flakes are easily dispersed in the soil and a visually homogeneous dispersion was observed.

With sisal fibers it was a little more complicated to mix, particularly for the higher percentage of fibre. Even so, a mixture with good homogeneity was achieved.

All specimens were compacted with 55 blows/layer (like the Modified Proctor Test specimens).

Two specimens were tested for each waste plastic / sisal fibre percentage.

3.2 CBR test results

CBR test procedures followed standard LNEC E 198 (LNEC, 1967b). In Figure 5 are presented the relative compaction (dry density of the specimen / MDD) values for CBR specimens. As expected, higher plastic waste/sisal fibre content lead to lower relative compaction.

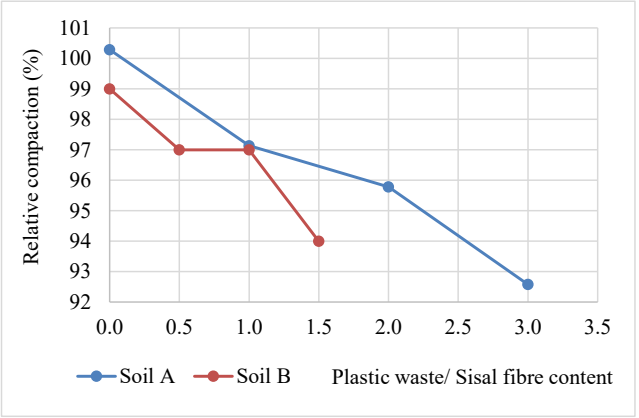

Figure 5. Relative compaction in CBR specimens.

In Figure 6 and Figure 7 the Force-Penetration curves from the CBR test are presented. The effect of the stabilization is more evident for high penetrations. For penetration values higher than 10 mm stabilization with 1% and 2% of plastic flakes provided better result than the original soil. Stabilization with sisal fibres shows that the original soil presented better performance until 6.0 mm of penetration. After 6.0 mm it was observed a change in the trend with a reduction of performance. Whereas mixtures with 1.0% and 1.5% of fibres maintained a practically linear trend up to 12 mm of penetration.

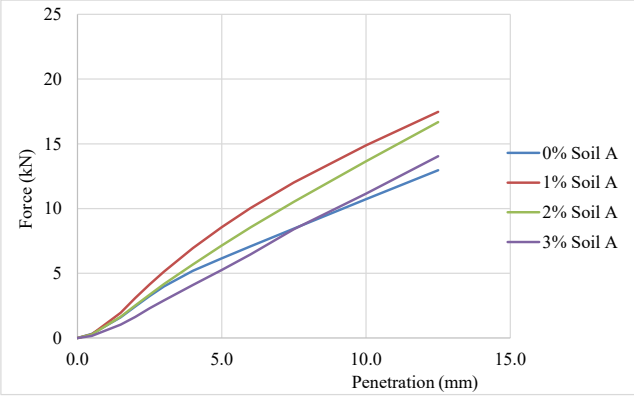

Figure 6. Force-penetration curves for soil A stabilized with waste plastic flakes.

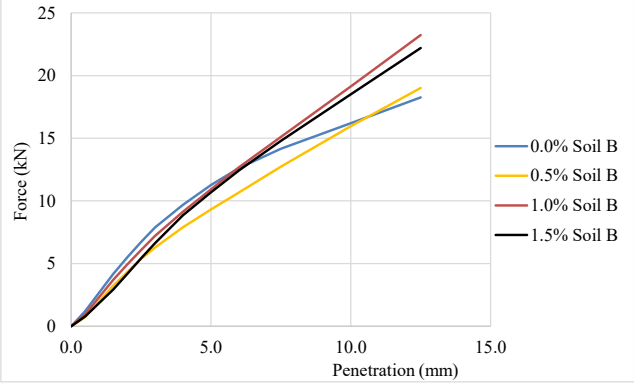

Figure 7. Force-penetration curves for soil B stabilized with sisal fibres.

The CBR values obtained for 2.5 mm and 5.0 mm penetration are presented in Figure 8. For both soils CBR values for 5.0 mm penetration were higher. Stabilization with plastic waste increased CBR values until 1% content but after this value CBR values decreased with increasing plastic waste content. For 1% plastic waste content CBR at 5.0 mm penetration increased from 14% to 19% (36% increase), and CBR at 2.5 mm penetration increased from 11% to 14% (27% increase). No increase in CBR was observed for sisal fibre stabilization. The original soil achieved higher CBR2.5 and CBR5.0 values. The CBR values decrease for 0.5% of sisal fibers, increasing to 1%, to 55%, very close to the natural soil, and decreasing again to 1.5%.

The results obtained in Figure 6 and Figure 7 show that the improvement in soil behavior obtained by stabilization with plastic waste / sisal fiber is more evident for high penetration values (greater than 5 to 6 mm). Therefore, this improvement in behavior is not captured in the CBR values (determined for 2.5 and 5 mm of penetration), Figure 8. As a consequence, it is also observed that the CBR values for 5 mm present a more favorable trend than those for 2.5mm. Despite observing an improvement in soil behavior through the analysis of force-penetration curves, in the CBR values only for stabilization with plastic waste, an increase in CBR values was obtained compared to the original soil, in this case to a percentage of 1%.

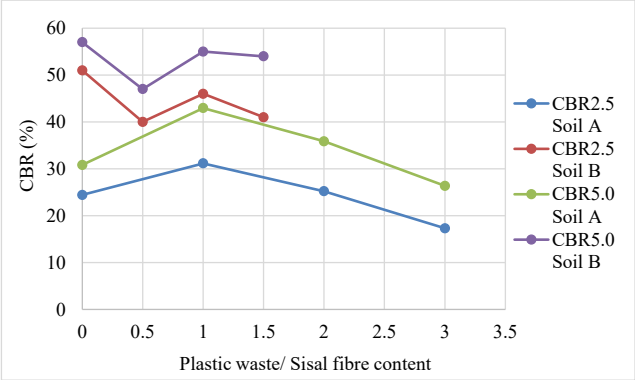

Figure 8. CBR2.5 and CBR 5.0 values.

4 CONCLUSIONS

Waste plastic flakes and sisal fibres were used for the stabilization of two clayey sand soils, Soil A and Soil B. Contents of 1%, 2% and 3% of plastic waste and 0.5%, 1.0% and 1.5% of sisal fibres were used. Results show a decrease in the relative compaction with increasing plastic waste or fibre content. Stabilization with waste plastic flakes increased CBR by more than 20% when compared to the original soil. Optimum waste plastic flakes content was 1%. CBR values decreased for higher contents. CBR values generally decreased with the addition of sisal fibres. However, for 1% of fibers the CBR value, 55%, is close to the CBR of natural soil, 57%. For 1.5% the CBR decreases again. This maybe could be explained by the fact that the mixture with sisal fibers is less homogeneous.

The use of waste materials and natural fibres for soil stabilization can be interesting options. Waste plastic flakes showed better results, the dispersion in the soil was easy and increased CBR values for percentages close to 1%. Sisal fibres were more complicated to mix, with low homogeneity achieved and CBR values generally decreased.

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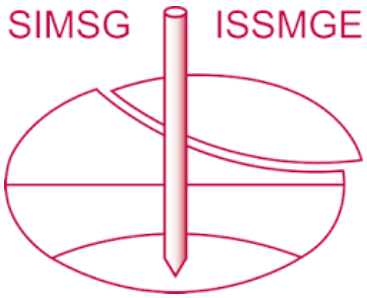

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