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Soil stabilization with waste plastic and waste tyre fibres

Stabilisation des sols avec déchets de plastique et fibres de pneus usagés

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ABSTRACT: There are significant amounts of wastes that presently end in landfills or are incinerated. Plastic wastes and fibres from tyres are among these wastes and could benefit from more valorisation options. Some studies refer that soil stabilization with these wastes can be a technically viable solution. In this work a soil was stabilized with a plastic waste and fibres from scrap tyres. Laboratory tests were performed to assess their ability to improve soil properties for embankment construction and pavement layers. Three contents of plastic waste and waste tyre fibres were used for stabilization, 1%, 2% and 3%. The bearing capacity was determined using California Bearing Ratio (CBR) test. Tyre fibres were hard to mix with the soil and good dispersion was not achieved, whilst with the plastic waste a good dispersion of the flakes was observed. An increase in the bearing capacity was achieved with plastic waste stabilization. Optimum waste content ranged from 0.5 to 1.5%. Increase in the bearing capacity was more effective for high penetration values. Reduction in the bearing capacity was observed in the specimens stabilized with waste tyre fibres. This could be caused by the poor dispersion of the fibres in the soil matrix. Maximum dry unit weight decreased with increasing waste contents.

RÉSUMÉ: Il existe d'importantes quantités de déchets qui aboutissent actuellement dans des décharges ou sont incinérées. Les déchets plastiques et les fibres de pneus font partie de ces déchets et pourraient bénéficier de plus d'options de valorisation. Certaines études indiquent que la stabilisation du sol avec ces déchets peut constituer une solution techniquement viable. Dans ce travail, un sol a été stabilisé avec un déchet de plastique et des fibres de pneus usagés. Des tests de laboratoire ont été effectués pour évaluer leur capacité à améliorer les propriétés du sol pour la construction de remblais et les couches de chaussée. Trois teneurs des déchets de plastique et des fibres de pneus ont été utilisés pour la stabilisation, 1%, 2% et 3%. La capacité portante a été déterminée à l'aide du test CBR (*California Bearing Ratio*). Les fibres des pneus étaient difficiles à mélanger avec le sol et une bonne dispersion n'était pas obtenue, tandis qu'avec les déchets plastiques, une bonne dispersion était observée. Une augmentation de la capacité portante a été obtenue avec la stabilisation des déchets plastiques. La teneur optimale en déchets variait de 0,5 à 1,5%. L'augmentation de la capacité portante s'est révélée plus efficace pour des valeurs de pénétration élevées. Une réduction de la capacité portante a été observée avec des échantillons stabilisés avec des fibres de pneus usagés. Cela pourrait être dû à la faible dispersion des fibres dans la matrice du sol. Le poids volumique maximal du sol sec diminue avec l'augmentation du contenu en déchets.

Keywords: Soil stabilization; CBR test; Plastic waste; Waste tyre fibres; Road embankments

1 INTRODUCTION

There is a need for significantly reduce waste production an increase recycling rates. Many wastes and industrial by-products can benefit from more reuse and recycling solutions, reducing the life cycle impacts. Soil stabilisation using waste materials as an additive can have technical and environmental advantages. Some researchers have studied the use of waste materials, mainly produced from waste plastics, in soil stabilization. These wastes can be used for stabilization as plastic strips, plastic flakes or fibres. Plastic wastes included, as example, plastic strips in HDPE or PET from bottles (Rawat and Kumar 2016; Paramkusam et al. 2013; Babu and Chouksey 2011), shredded labels in PE and PP from packages (Gardete et al. 2017), flakes from grounded PET bottles (Gardete and Luzia 2017) and waste tyre textile fibres (Abbaspour et al. 2018).

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). Stabilization with these types of waste materials 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, Akbulut et al. 2007).The resistance increases to an optimum waste content, decreasing for higher percentages. Optimum contents are mostly in the 0.5% to 1.5% range (Paramkusam et al. 2013; Singh et al. 2017, Kumar et al. 2018). The addition of waste materials, such as plastic strips or fibres, affects the Optimum Moisture Content (OMC). Some authors refer dissimilar trends in OMC values, however variations are in general moderate (Kumar et al., 2018; Peddaiah et al.2018; Hejazi et al. 2012, Prabakar and Sridhar 2002). Maximum Dry Density (MDD) decreases with the increase of waste (Damion et al. 2016; Kumar et al. 2018). This could be explained because the wastes used are made from polymers that have densities, in general, between 0.90 to 0.95 Mg/m3, much lower than soil particles.

2 MATERIALS

2.1 Soil

A clayey sand soil was used. Visually, the soil is reddish-brown with a significant quantity of fines and evident plastic behaviour. The soil was characterized in laboratory and the soil gradation is presented in Figure 1.

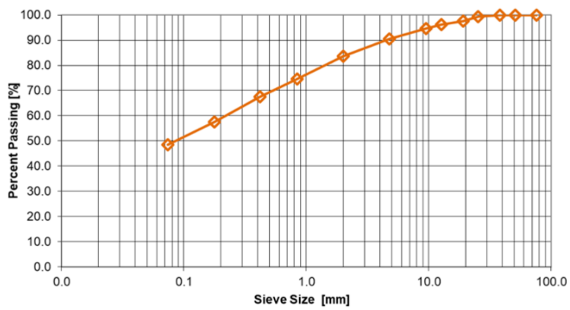

Figure 1. Gradation curve of the soil

The following properties of the soil were characterized, liquid limit, plastic limit, sand equivalent, organic matter content and methylene blue value. The results are presented in Table 1. The soil has a content of fines of almost 50% and a Plasticity Index of 10.9%. The organic matter content is 2.48%, which is a value that could limit the use of the soil in road embankment construction. The soil is classified as SC – Clayey Sand (USCS), A-4(2) (AASHTO) and A1 (AFNOR).

Modified Proctor compaction test was used to determine MDD and OMC of the soil. The test procedures followed standard LNEC E 197. OMC is 12.8% and MDD 1.92 Mg/m^3, Figure 2.

Table 1. Soil properties

Property	Plastic Limit [%]	Liquid Limit [%]	Sand Equivalent [%]	Organic Matter Content [%]	Methylene Blue Value [g/kg]	Methylene Blue Value [g/100g]
Standard	NP 143	CEN ISO/TS 17892-12	LNEC E 199	NLT-117	NP EN 933-9	NF P18-068
Value	20.6	31.5	14.4	2.48	0.78	0.325

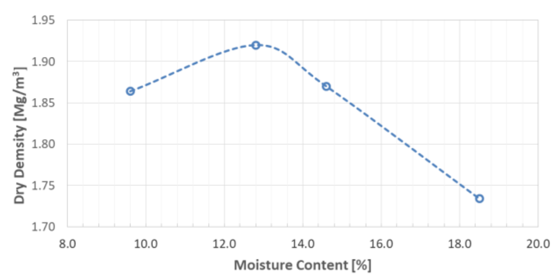

Figure 2. Modified Proctor test results

2.2 *Plastic waste and waste tyre textile fibres*

Used wastes were provided by the industry and were used as provided, without any modification. The wastes were selected for having low recycling and reuse value. The plastic waste used was provided by plastic recycling company Ecoiberia - Reciclados Ibéricos, S.A, waste tyre fibres were provided by tyre recycling company Biogoma - Sociedade de Reciclagem de Pneus, Lda.

The plastic waste used was made from shredded labels in PE and PP. The flakes are highly flexible, very thin, irregular shape and areas in average 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.

The textile fibres used are known as fluff because they resemble a fluffy agglomerate of cotton, Figure 4.

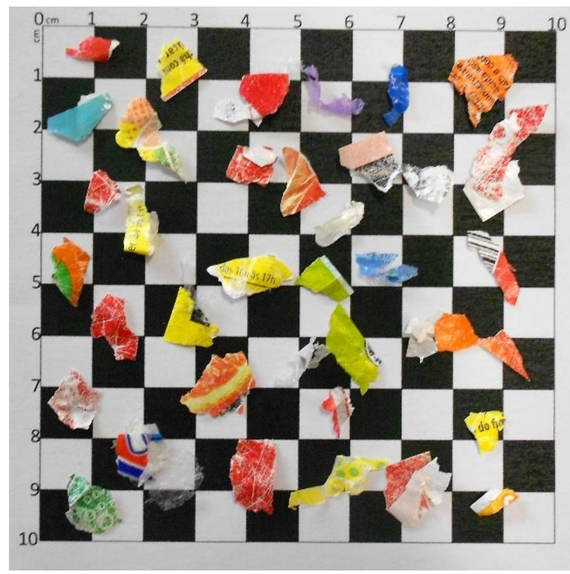

Figure 3. Waste plastic flakes

Fluff is mainly incinerated or goes for energy recovery. Textile fibres used in this work are burn in the kilns of the cement industry. The fibres are non-homogeneous and have as main component Nylon6.6, however other components include Nylon6, Dacron, Rayon and Aramid (Acevedo et al. 2015). Fluff has a high content of rubber and some steel fibres and reinforcement fibres. The micro textile fibres represent approximately 40% of the weight of fluff (Landi et al. 2018). The diameter of the fibres is in the range of 18-20 µm and the length in the 3 to 5 mm range (Onuaguluchi and Banthia 2017).

Figure 4. Waste tyre fibres, fluff, used for soil stabilization

3 SOIL STABILIZATION

3.1 Mixing

The soil was mixed with both wastes by hand. The contents of waste used were 1%, 2% and 3%, weight of waste / weight of dry soil. The values for 0% waste content are referred to the original soil without stabilization. As mentioned, the stabilization with wastes can lead to variations in OMC. However, variations in the OMC are moderate and it was mixed water to achieve the OMC of the original soil for the production of the specimens.

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. The fluff was manually separated in small clumps and mixed with soil. However, fibres are hard to separate, and clumps of fibres were still noticeable in the soil after mixing. The dispersion of fibres in the soil was hard and low homogeneity was achieved, with clumps visible in the soil after mixing.

3.2 CBR test results

CBR test procedures followed standard LNEC E 198. In Figure 5 is presented the relative compaction values for CBR specimens. As expected, higher waste contents content lead to lower relative compaction. The relative compaction for 2% waste tyre fibre content is lower than expected and it affected the CBR results.

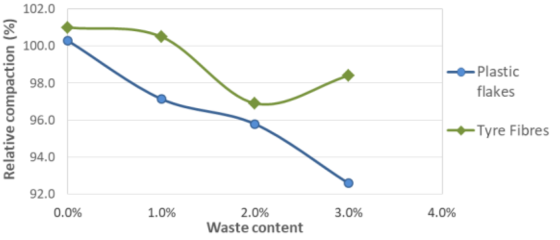

Figure 5. Relative compaction in CBR specimens

In Figure 6 and 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. Stabilization with tyre fibres did not show evident benefits, with the 2% waste tyre fibres specimens performing worse. It could be related to the lower compaction and presence of fibre clumps. For lower penetration values the effect of the stabilization in the CBR was less noticeable. There is a significant difference in the CBR values of the original soil in the two series. One part of the explanation could be linked to different relative compaction, Figure 5, however differences were expressive for higher penetrations.

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 values was observed for waste tyre fibre stabilization. The original soil achieved higher CBR2.5 and CBR5.0 values and CBR values tend to decrease with increasing waste tyre fibre content.

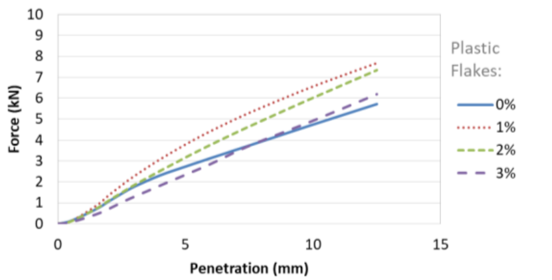

Figure 6. Force-penetration curves for soil stabilized with waste plastic flakes

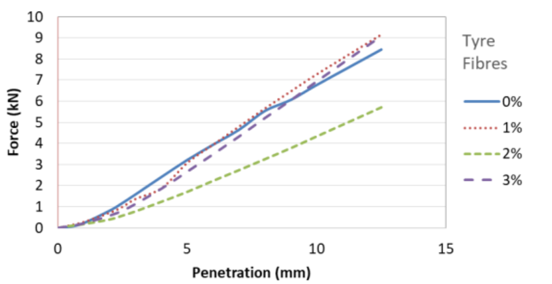

Figure 7. Force-penetration curves for soil stabilized with waste tyre fibres

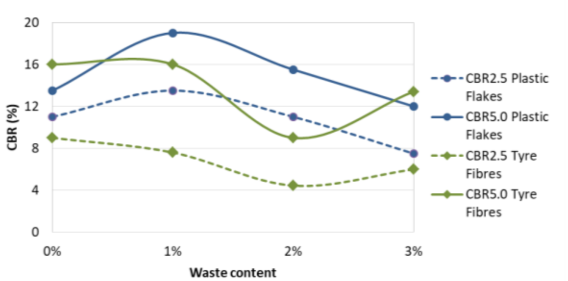

Figure 8. CBR2.5 and CBR 5.0 values

4 CONCLUSION

Waste plastic flakes and waste tyre fibres, fluff, were used for the stabilization of a clayed-sand soil. Contents of 1%, 2% and 3% were used. Results show a decrease in the relative compaction with increasing waste 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 decreased with waste tyre fibre addition. This could be explained by the weak dispersion observed and presence of fibre clumps in the soil matrix. The dry unit weigh decreased with the increase in plastic waste content for both waste materials used. This decrease was more evident with waste plastic flakes stabilization. The use of waste materials for soil stabilization can be an interesting option. Waste plastic flakes showed better results, the dispersion in the soil was easy and increased CBR values for percentages close to 1%. Waste tyre fibres were hard to mix, with low homogeneity achieved and CBR values decreased for all percentages used. The use of fluff could be interesting for soil stabilization. However, procedures to achieve a good dispersion are important to ensure good results.

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