Conference Paper

Experimental Study on Soils Stabilized with Two Types of Plastic Waste

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Abstract

The reuse and recycling rates for plastics are still below desirable values. The valorisation of plastic wastes that presently end in landfills or is incinerated can help to mitigate this environmental problem. There have been studies in soil improvement using plastic waste. Two types of plastic waste were used to assess their ability to improve soil properties for embankment construction and pavement layers. The selected plastic wastes are made from shredded package labels and ground bottles. The main properties of the soils were characterized. Three percentages of plastic waste were used, and the bearing capacity of the soil determined using CBR test (California Bearing Ratio). The results from the tests show that plastic waste stabilization leads to an increase in bearing capacity, expressed in CBR values, for low contents of plastic waste. This increase was more effective for high penetration values. Reduction in the bearing capacity was observed for higher plastic waste contents. Maximum dry unit weight decreased with increasing plastic waste content, whereas expansion increased with increasing plastic waste content.

Keywords: Soil stabilization, Plastic waste, CBR test, Compaction, Earthworks

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Received: 26 November 2019
Accepted: 13 May 2020
Published: 2 June 2020

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the ICEUBI2019 Conference Committee.

1. Introduction

Packaging waste reuse and recycling rates have not achieved desirable values, with 79.2% recovery rate and 65.3% recycling rate in European Union (EU) [1]. Though, plastic recycling is lower, with 41% recycling rate of the collected plastic waste in EU, with highly uneven values between the countries [2]. The rates of waste plastic that ends in landfills or goes to incineration are still very high. Efforts to improve the reuse and recycling rates are being developed [3]. However, some plastic wastes have low interests in recycling and reuse and could benefit from more valorisation options.

Soil stabilization with plastic waste can be used in embankments and road pavement layers to improve the soil strength values. Stabilization with plastic waste showed interesting result with an increase in soil strength characteristics measured in different tests [4, 5]. However some researchers refer that the results differ with the type of soil and some strength values maybe decreased with waste plastic stabilization [6].

Plastic waste used comes from garbage, mainly bottles or packages, and is made from High Density Polyethylene (HDPE) or Polyethylene Terephthalate (PET) [7, 8]. Some researchers used waste plastic cut into strips, generally with dimensions of 4 mm to 40 mm [4, 9]. However, plastic wastes can also be available as flakes or fibers, which are more prone to be offered from the recycling industries [8, 10]. However, the effect in the soil strength properties is different with the type of waste. Waste plastic fibers, strips or flakes interaction with the soil matrix is different and is also influenced by the properties of the soil [6, 11].

Plastic waste stabilized soils generally show increases in CBR values. The percentages of plastic waste that offer the best results are below 2%, often in the 0.5% to 1.5% range [4, 7, 8, 12]. The CBR values increase until the optimum percentage of plastic waste, decreasing for higher contents. [9] observed that optimum moisture content (OMC) for compaction does not exhibit significant variation with plastic waste content. However, some researchers refer there is a moderate decrease of the optimum moisture content with the increase in the waste plastic content [1, 10]. Maximum dry unit weight decreases with the increase in the plastic waste content [7]. However, some researchers refer that dry unit weight can increase with plastic waste content until a maximum is achieved, decreasing subsequently for higher contents [13, 14]. The size and shape of plastic waste particles have influence on the results achieved [9, 13].

However, it should be mentioned that waste stabilized soil can have limitation for reuse and disposal at the end of the life of the infrastructure when compared to virgin soil.

2. Plastic Wastes Characterization

In this work two plastic wastes, with different properties, were used in soil stabilization, analyzing their effects in the soil CBR values. The plastic wastes used were collected from a recycling plant and are available in the market in large quantities.

Two different plastic wastes were used, one made of shredded package labels – hereon labelled as WA, and the other was made by ground bottles - hereon labelled as WB. The two plastic wastes selected for soil stabilization, whereas being made from plastic, have significantly different behavior, specifically regarding the flexibility of the particles. The behaviour of the particles from shredded package labels, WA, is highly flexible, whereas particles from ground bottles, WB, exhibit a relatively stiffer behaviour.

2.1. Shredded package labels waste (WA) characterization

WA was made from assorted labels and packages, but mainly coming from shredded labels, such as, from beverage bottles or food containers and candy packages, but other types of labels could be used. The manufacturer stated that the main components of this waste flakes were Polyethylene (PE) and Polypropylene (PP). An analysis of the flakes indicated that labels provided mainly from beverage bottles and food packages and were assorted in colour, size and composition. WA flakes showed highly flexible behaviour, with uneven shape, size in average between 1 cm^2 and 2 cm^2 and were very thin, with low thickness. Flakes were generally creased, and some were crumpled. This waste has low value for reuse and recycling because it has highly assorted materials.

2.2. Ground bottles waste (WB) characterization

WB was made from ground PET bottles. Flakes display uneven shape. These flakes had an average thickness of 0.1 mm. WB flakes showed a rigid behaviour when compared to WA flakes. This difference of stiffness between WA and WB flakes can induce distinct strengthen mechanisms when in the soil matrix. Because of WB flake's higher rigidity, it was feasible to sieve them to determine their size. WB flakes showed uniform gradation with more than 90% having sizes between 2 mm and 9.5 mm.

Plastic waste WB was entirely composed by transparent PET flakes and consequently has a high recycling value. The use of this specific waste in soil stabilization is questionable. Nevertheless, the results may be used as a reference for plastic wastes with similar characteristics and that may have less value for recycling or reuse.

3. Soil Characterization

Waste WA was used to stabilize a reddish clay soil, with nearly 50% passed in sieve n. 200, hereon labelled SA. Waste WB was used to stabilize a grey shale-soil with 25% passed in sieve n. 200, hereon labelled SB.

All characterization tests were performed on two specimens, except for the Proctor test. Thus, the results presented below correspond to the average values obtained for each specimen.

3.1. Index properties

The particle-size analysis of soils was made according to LNEC E 196 [14] standard. The corresponding granulometric curves for both soils, SA and SB, are presented in Figure 1.

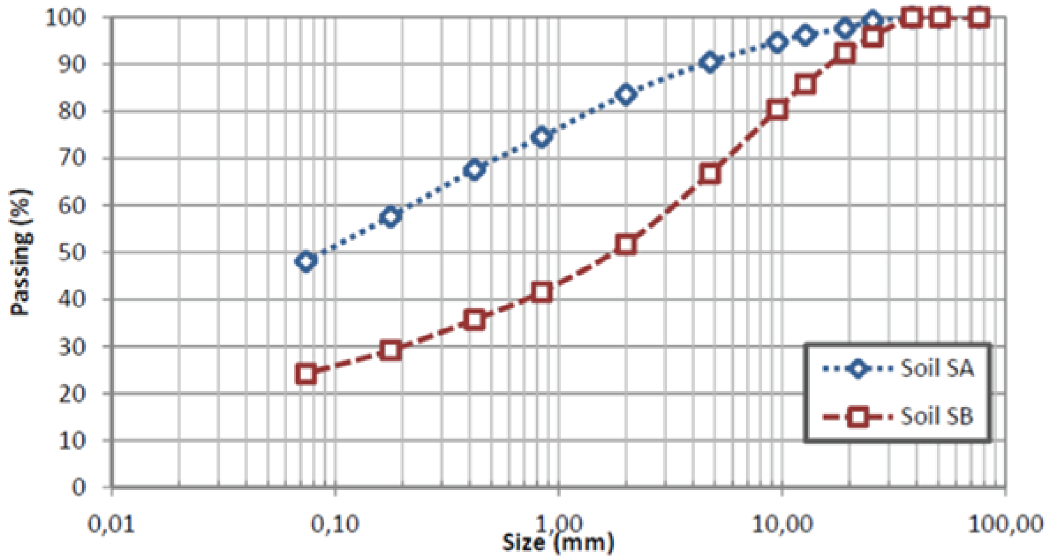

Figure 1: Gradation of soils SA and SB

Soils were characterized in the laboratory to determine the fine fraction behaviour and plasticity. For this characterization it was determined the values for the liquid limit [15], plastic limit [16], plasticity index, sand equivalent [17] and methylene blue absorption [18].

For SA soil were obtained a liquid limit of 31.5% and a plastic limit of 20.6%, with a plasticity index of 10.9%. The sand equivalent was 14.4% and the methylene blue adsorption value was 0.92 g/100g.

For SB soil were obtained a liquid limit of 34.6% and a plastic limit of 25.7%, with a plasticity index of 8.9%. The sand equivalent was 19.8% and the methylene blue adsorption value was 1.30 g/100g.

Soil SA has a classification of SC (Clayey Sand) in the USC system [19] and A-4(4) in the AASHTO soil classification system [20]. Soil SB has a classification of SM (Silty Sand) in the USC system [19] and A-2-4 (0) in the AASHTO soil classification system [20].

Modified Proctor test was performed to determine optimum moisture content and maximum dry unit weight. Compaction was made in the large mould, with 150 mm of diameter, in 5 layers and with 55 blows per layer, using the modified proctor ram, according to standard LNEC E 197 [21]. Optimum moisture content for soil SA was 12.8%

and maximum dry unit weight was 1.92 Mg/m^3. Optimum moisture content for soil SB was 7.8% and maximum dry unit weight was 2.06 Mg/m^3.

4. Stabilized Soil Bearing Capacity

California Bearing Ratio specimens were compacted with optimum moisture content (OMC) corresponding to the original soil. Addiction of plastic flakes to the soil can lead to variations in optimum moisture content and maximum dry unit weight [7, 13]. However, the variation of optimum moisture content is moderate and the optimum moisture content of the natural soil was considered as the reference for compaction for all specimens.

Soils were mixed with plastic waste using three contents, 1%, 2% and 3% (weight of plastic waste/dry weight of soil), for both soils and plastic wastes. The values obtained for the original non-stabilized soils are referred as 0% plastic waste content. Soil was mixed with water, to achieve optimum water content, and then plastic waste was added and mixed until a homogeneous mixture was reached. The soil was mixed by hand. Satisfactory homogeneity was achieved for both plastic wastes used without considerable effort.

California Bearing Ratio specimens were compacted using the same conditions as in the Proctor test, according to standard LNEC E 198 [22]. The CBR values for the plastic waste contents used, obtained for 2.5 mm and 5.0 mm penetration, are presented in Figure 2.

For both soils, CBR values for 5.0 mm penetration were higher. Stabilization with plastic waste increased CBR values until an optimum content, afterwards CBR values decreased with increasing plastic waste content. Best results were obtained in the range from 1% to 1.5% plastic waste content. For soil SA stabilized with 1% WA, CBR values at 5.0 mm penetration increased from 14% to 19% (36% increase), and CBR values at 2.5 mm penetration increased from 11% to 14% (27% increase). For soil SB stabilized with 2% WB, CBR values at 5.0 mm penetration increased from 18% to 22% (22% increase), and CBR values at 2.5 mm penetration increased from 9% to 11% (22% increase). Hence, stabilization with the plastic wastes had a significant effect on the bearing capacity.

Dry unit weight decreased for both soils with increasing waste plastic content, Figure 3. The evolution for both samples was alike, although for WB this effect was more noticeable. It should be stressed that the decrease in the maximum dry unit weight can derive from different factors. The plastic particles have lower densities than the soil particles, therefore more plastic particles can lead to lower unit weights. The plastic

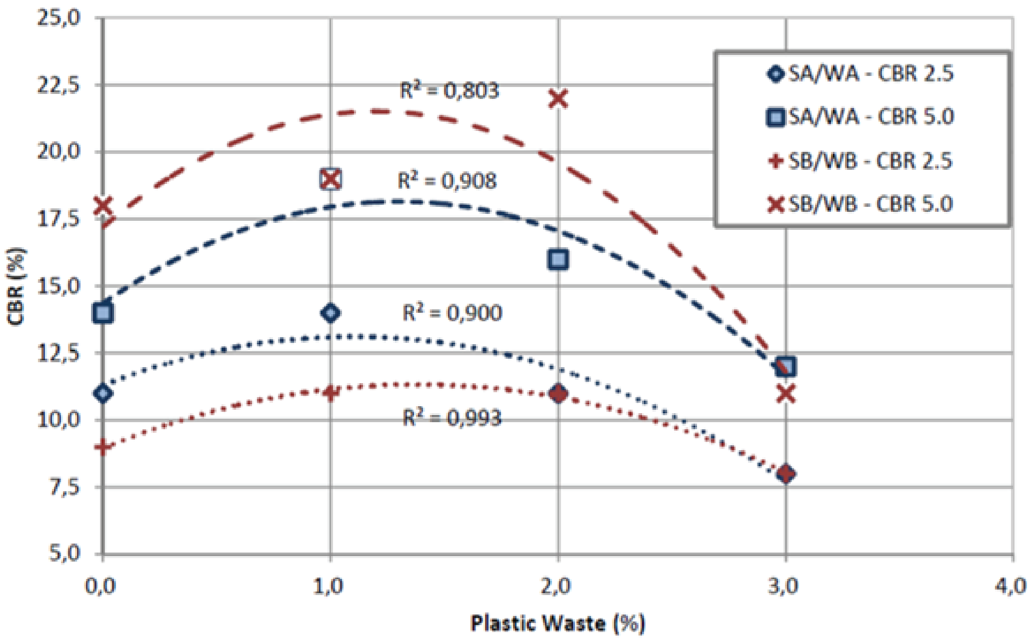

Figure 2: CBR values for stabilized soils with plastic waste, SA/WA and SB/WB

particles have high flakiness, and the WB particles are more rigid, and can difficult soil compaction, reducing the unit weight. Other factor that could contribute to the reduction of the dry unit weight is the fact that optimum moisture content for increasing waste plastic can differ increasingly from the optimum moisture content of the original soil. If optimum moisture content was determined for each plastic waste content, and used for compacting CBR specimens, this could have an influence in the dry unit weight and, therefore, in the CBR values [12, 13]. However, changes in the optimum moisture content tend to be very moderate for the percentages of plastic waste used.

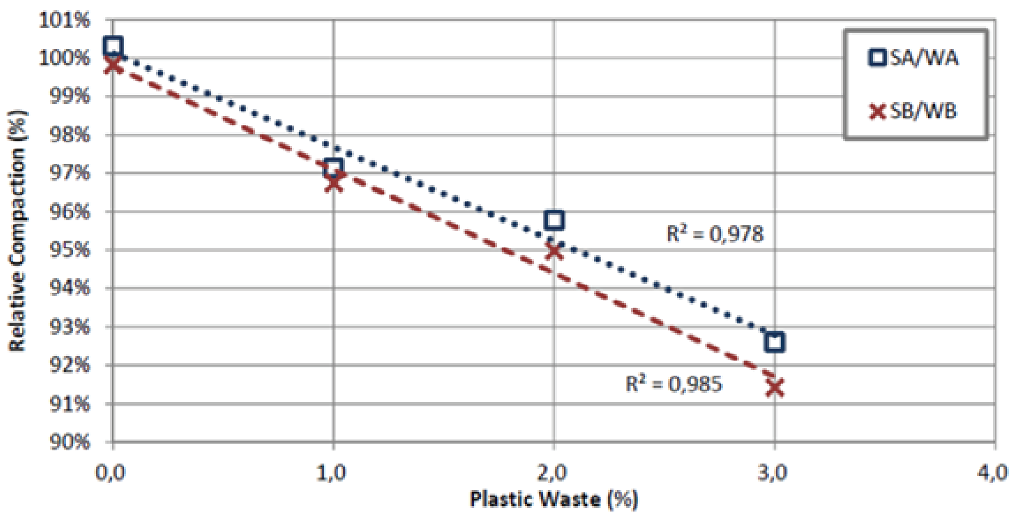

Figure 3: Relative compaction variation with plastic waste content for SA/WA and SB/WB (original soil OMC).

California Bearing Ratio specimens were immersed 96 hours in water and during that time their expansion was recorded, Figure 4. Expansion increased with plastic waste content. For soil SA stabilized with WA the increase in expansion was higher, from 2.1% for the original soil to 4.3% for 3% WA plastic waste content. This could be deterring for the use of the stabilized soil in road construction. For soil SB stabilized with WB the increase is milder, from 0.9% to 2.1%, with maximum expansion for 2% WA.

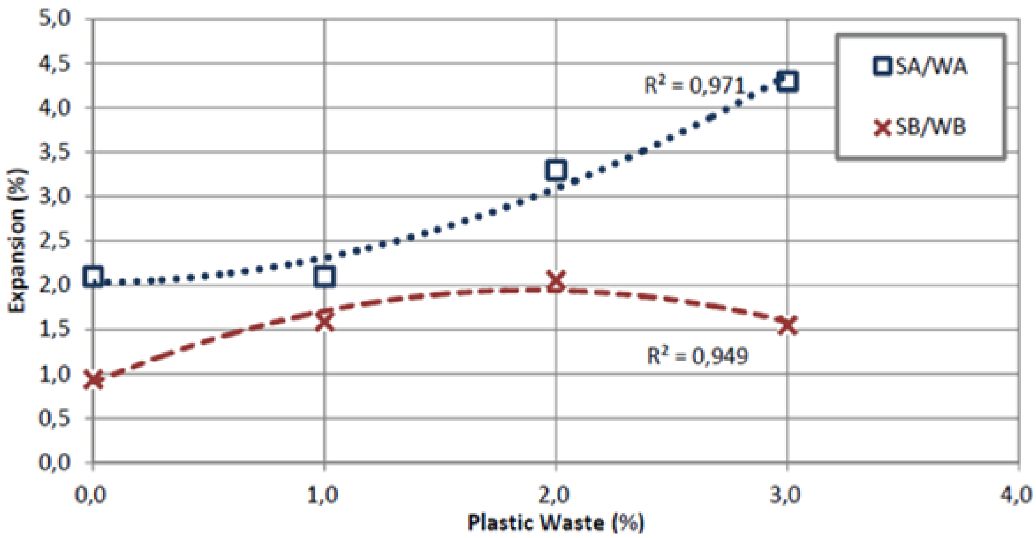

Figure 4: Expansion variation with waste plastic content for SA/WA and SB/WB

California Bearing Rate curves show that the effect of the stabilization with the plastic wastes is more noticeable for higher penetrations, particularly for SA/WA, Figure 5 and Figure 6. For penetrations above 8 mm all WA contents showed higher force values than the original soil. Whilst for penetrations below 2 mm only specimens with 1% content WA showed higher force values than the original soil.

For SB/WB the specimens with 2% content showed in all penetration range force values higher than the original soil. For high penetration values, 1% and 3% WB content showed forces comparable to the original soil.

5. Conclusions

Two different plastic wastes, from shredded package labels and ground bottles, were used for soil stabilization. From the tests results the following conclusion could be drawn:

- CBR values were increased by more than 20% when compared to the original soil. For WA the best results were achieved for 1% content whereas for WB the best results were achieved for 2% content. These optimum waste contents are in

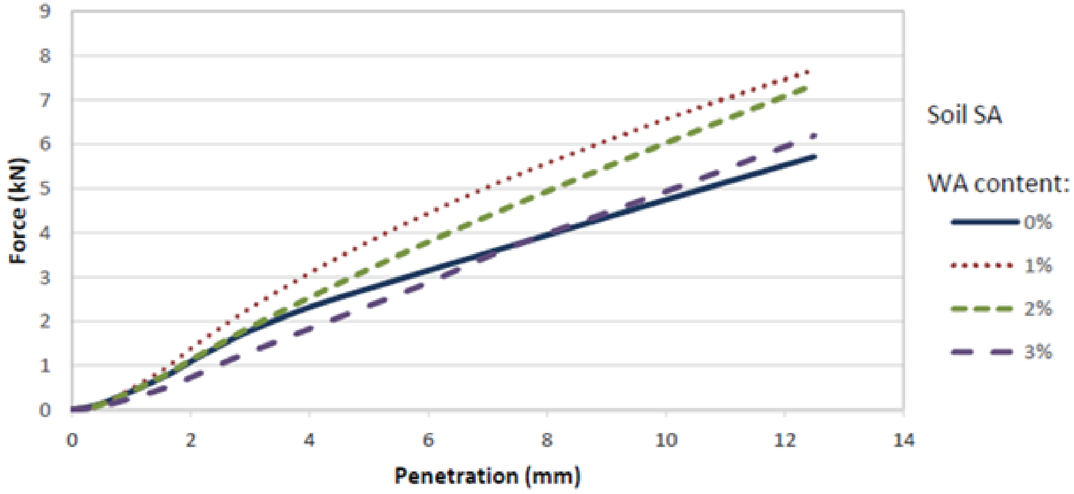

Figure 5: CBR curves for soil SA/WA

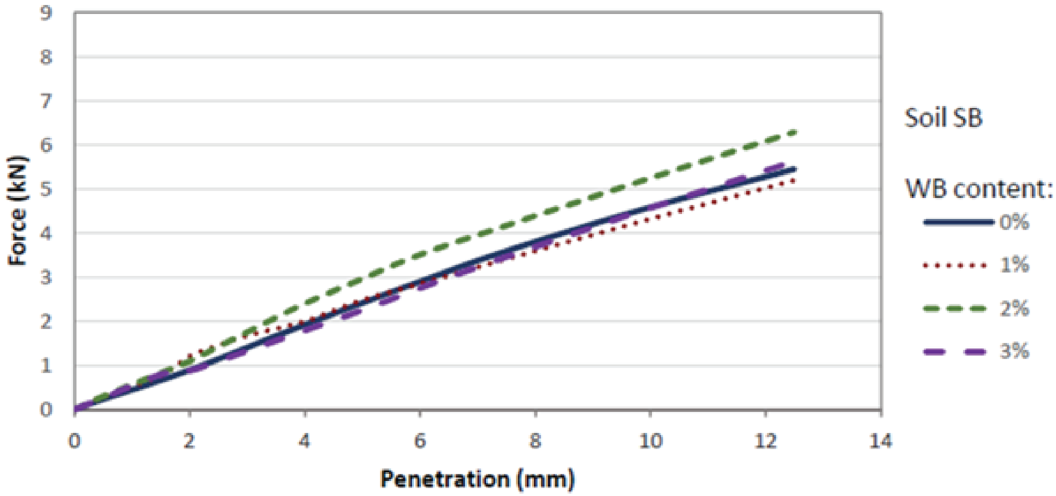

Figure 6: CBR curves for soil SB/WB

the range usually referred in similar studies. CBR values increase with the plastic waste content until an optimum content and decreased subsequently.

- Dry unit weight decreased with the increase in plastic waste content for both plastic wastes used and for both soils. This decrease was uniform and slightly more noticeable for waste WB. This could be explained by the composition and shape of the particles found in the plastic wastes used.
- Better results were achieved with stabilization with flexible flakes, WA, on the bearing capacity of the soil. CBR curves show that for higher penetrations the effect of the stabilization with SA is more effective. Because of the different stiffness of the particles the behaviour of the plastic particles in the soil matrix can be different. However, the stabilized soils were different, and the effect of the plastic particles in the strength parameters differs with the soil properties.

- Stabilized specimens had higher expansions, for WA and WB. The expansion tends to increase with the increase in plastic waste content. The soil stabilized with WA show higher increases in expansion reaching values that could be restrictive to its use. However, high expansion values occurred for plastic waste contents that are higher than the range where there is bearing capacity increase. For optimum waste plastic contents expansion increase was limited.

The use of plastic wastes for soil stabilization can promote their valorisation. It has low costs and can increase the bearing capacity of the soil. It should be stressed that the results obtained are only representative for the soils and plastic wastes used. Nevertheless, the obtained results are coherent with those referred in similar studies.

Environmental issues are not addressed in this paper, although they are of the most relevance when using wastes in soil improvement. The disposal and reuse of waste plastic stabilized soils, when compared to non-modified soils, can show more limitations even if they are classified as non-hazardous.

Acknowledgements

The authors would like to thanks to Ecoiberia - Reciclados Ibéricos, S.A for kindly providing the plastic wastes used and also to the students of the Degree in Civil Engineering of the Polytechnic Institute of Castelo Branco, Miguel Sousa, César Vilarinho and Maria de Fátima Figueiredo for their dedication in carrying out the laboratory work.

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