Recycling domestic plastic mesh bags for soil reinforcement

Canova, C. A.
Department of Mechanical Engineering, University of Coimbra, Coimbra, Portugal – carolinacanova@gmail.com

Pinto, M. I. M.
Department of Civil Engineering, University of Coimbra, Coimbra, Portugal – isabelmp@dec.uc.pt

Falorca, I.M.C.F.G.
Department of Civil Engineering, University of Beira Interior, Covilhã, Portugal – ifalorca@ubi.pt

Vieira, M.T.F.
Department of Mechanical Engineering, University of Coimbra, Coimbra, Portugal – teresa.vieira@dem.uc.pt

Keywords: recycling, reinforcing elements, micro-reinforcement, shear strength, laboratory tests

ABSTRACT: A current environmental problem results from the large amount of plastic waste daily generated. Therefore recycling of plastics is of great importance to reduce the environmental impact. Reuse of plastic as raw material allows not just for the recovery of economic value, but also for the volume reduction of that material to be disposed in landfills, contributing in this way for the sustainable development. In this context a study on the application of small plastic rescued elements for soil reinforcement was made. The elements are shredded from plastic bags of widespread use as carrying mesh bags for domestic products such as potatoes, onions, garlic, etc. A parametric study of a sandy soil randomly reinforced with these synthetic small rescued elements was performed in order to investigate their influence on the mechanical properties of the sand. By performing Direct Shear Tests it can be concluded that indeed a significant increase of shear strength can be achieved by adding these small elements to the sandy soil. This technique has proved to be technically feasible and also very promising: an increase of about 16% for the shear angle of friction was achieved when just 2% of elements were added as reinforcement.

1 INTRODUCTION

A large amount of waste materials are being produced around the world and their disposal constitutes a very important problem. However, some of these materials have properties very useful for civil engineering applications, especially for geotechnical applications where soil is used as construction material. Fortunately many industrial by-products are already being beneficially used as construction materials and reuse of some other materials are made in a variety of forms.

Micro-reinforcement is a mixture of soil with small elements with tensile strength, randomly oriented. This mixture presents higher shear strength and higher ductility than the unreinforced soil. A list of applications for this composite material was identified (Andrawes et al., 1986), and different types of reinforcing elements are being used: filaments, small meshes, short fibres and fibrillated fibres.

Some experience has been previously acquired for micro-reinforcement with polypropylene fibres of small length randomly distributed in the soil (Falorca and Pinto 2002 and 2004, Falorca et al. 2006 and 2008). The use of small elements shredded from plastic bags of widespread use as carrying mesh bags for domestic products such as potatoes, onions, garlic, etc. might provide an environmental friendly alternative to the referred other micro-reinforcing elements. Even if these rescued elements shows to be of lower quality than the already used reinforcing elements, their low cost makes them a good option, provided that a reasonable performance is obtained.

A parametric study of a sandy soil randomly reinforced with these small plastic rescued elements is underway in order to investigate their influence in the mechanical properties of the sand. Some of the results already obtained by performing Direct Shear Tests (Canova, 2008) are presented herein.

2 TEST MATERIALS AND EXPERIMENTAL PROCEDURE

2.1 *Test materials*

The study was performed in a sandy soil, classified as a poorly graded sand (SP) according to the Unified Classification Soil System (ASTM D2487). The sand was sieved in order to separate the fine, the medium and the coarse fractions. Tests were carried out on the sand (S), the medium fraction (MS) and the fine fraction (FS) of the sand. The main properties of the sand are presented in Table 1 and the granulometric curves of the sand and his two fractions studied are shown in Figure 1.

The reinforcing elements are made of polypropylene, and their main properties are summarized in Table 2. The mechanical properties were measured by performing tensile tests according to EN ISO 5079, for a rate of elongation of 30 mm/min. The reinforcing elements were shredded into the shape shown in Figure 2. This figure shows not just the two types of elements tested (designated as two crosses "2+"and three crosses "3+") but also a piece of a bag from where the elements were shredded. The length of the elements is about 8-12 mm (2+) and 12-15 mm (3+).

Table 1. Soil properties

Property	Sand (SP)
Specific gravity, G_S (-)	2.6
Percentage finer than #200 sieve (%)	0
Mean diameter, D50 (mm)	0.625
Coefficient of uniformity, C_U (-)	3.45
Coefficient of curvature, C_C (-)	0.77
Liquid Limit, LL (%)	-
Plasticity Index, PI (%)	-
Angle of friction, ϕ'_P (^{o})	39.5
Cohesion, c' (kPa)	0

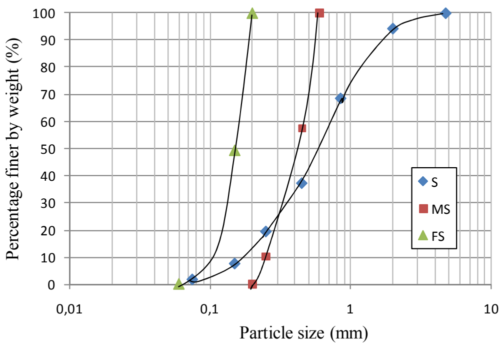


Figure 1. Particle size distribution curves

Table 2. Reinforcing elements properties

Property	PP
Specific gravity, G_f (-)	0.91
Denier (g/9000 m)	6
Maximum tensile strength, T (N)	5.41
Elongation at break, ε_R (%)	780
Moisture absorption (%)	0
Colour	red

2.2 *Sample preparation*

The reinforced samples were prepared by mixing the reinforcing elements randomly with the soil, in a bowl. The quantity of the elements is correspondent to 2% of the dry weight of the soil. For preparing a satisfactory homogeneous reinforced sample, the soil needs to be slightly moistured, otherwise some segregation of the reinforcing elements occurs. The unreinforced samples were also prepared with moistured soil for comparison purposes. Figure 3 a) shows the sand already mixed with the reinforcing elements.

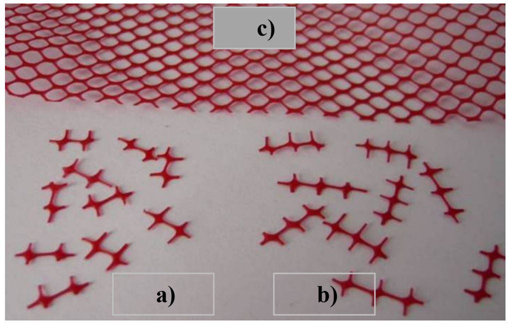
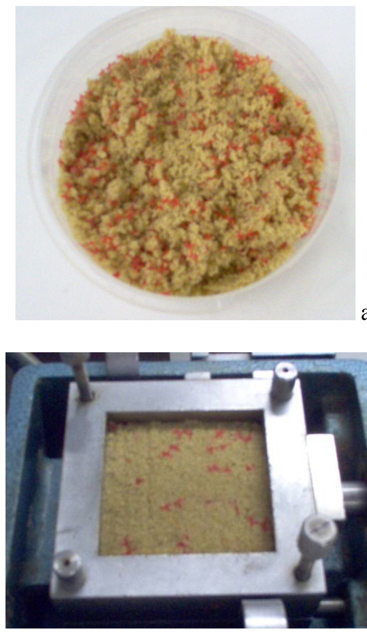


Figure 2. Reinforcing elements: a) 2+ ; b) 3+ and a piece of a bag were the elements were shredded : c)

The prepared samples were then transferred to the shear box (60 x 60 x 20 mm) in three layers, each one being carefully compacted (Figure 3 b)).


a)

b)

Figure 3. Sand mixed with reinforcing elements a) after the mixture; b) inside the shear box, ready to be tested

2.3 *Test procedure*

Shear tests were performed under 4 different vertical stresses. All the tests were carried out at a constant shear displacement ratio of 1mm/min up to a maximum displacement allowed by the shear apparatus (about 12 mm).

Tests were carried out on the sand (S), the medium fraction (MS) and the fine fraction (FS) of the same sand. Two types of reinforcing element were studied and a mixture of these two types was also investigated. Some unreinforced samples were also studied for comparison purposes. A summary of the test program is presented in Table 3.

Table 3. Summary of the test program

Soil	Reinforcing elements		Vertical stress (kPa)			
	Type	% (*)	25	50	100	200
S	-	0	x	x	x	x
MS	-	0	x	x	x	x
	2+	2	x	x	x	x
	3+	2	x	x	x	x
	2+ and 3+ (**)	2	x	-	x	x
FS	-	0	x	x	x	x
	2+	2	x	x	x	x
	3+	2	x	x	x	x

(*) percentage: weight of the dry weight of the soil

(**) these two types of elements were used together, in the same proportion (1% each)

3 ANALYSIS OF TEST RESULTS

In general some scatter was observed in the results. This is most probably due to the difficulty to prepare both good homogeneous mixtures (with soil and reinforcing elements) and samples with the same degree of compaction. Compaction was done manually with a hammer, and, although there was always a tentative to control compaction by the weight of the soil inside the shear box, this type of control might not be enough.

An example of the typical shear stress displacement behaviour of both unreinforced and reinforced samples is shown in Figure 4.

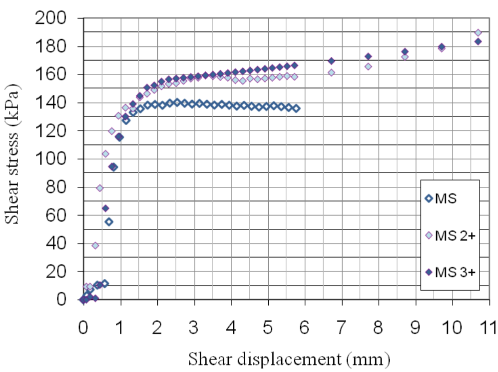


Figure 4. Shear stress displacement for the Medium Sand (σ'_V=200 kPa)

The behaviour shown by the unreinforced sand is a classical behaviour for a sandy soil as it shows a maximum value for the shear stress and then a very slight decrease. For the reinforced soil the behaviour is quite similar to that observed for sand reinforced with short polypropylene fibres (Falorca and Pinto 2002), i.e., a progressive increase of strength with increase of displacement right to the end of the test. However, the increase of shear stress with displacement is not as significant in this study when compared with referred other reinforcing elements.

Reinforced samples show in the great majority of situations higher strength than unreinforced samples. The degree of improvement depends however on the deformation level. The shear strength of both unreinforced and reinforced sand must be therefore be determined by a limiting deformation criterion.

In general, no peak or constant shear stress was identified for the reinforced samples and therefore Mohr-Coulomb failure envelops (Figure 5) were plotted for a deformation of 10%, which is the correspondent to a displacement of 6 mm.

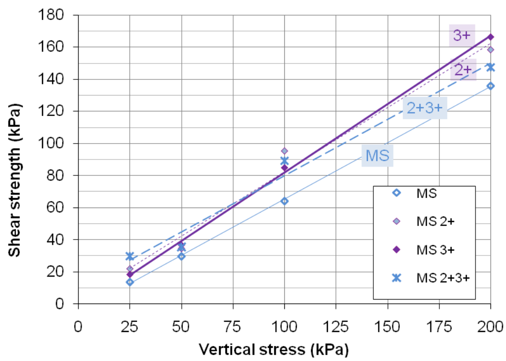


Figure 5. Mohr-Coulomb failure envelops (MS)

Comparing the failure envelops for unreinforced sand (MS) with those reinforced with elements 2+ or 3+, it can be seen that reinforcing elements clearly improve the strength of the soil. Furthermore, reinforcement is more effective for higher vertical stresses.

There seems to be no a huge difference of the improvement capacity for these two types of reinforcing elements. This observation applies both to medium sand (MS) and fine sand (FS) samples. Samples reinforced with elements 2+ show higher cohesion interception and lower angle of friction than samples reinforced with elements 3+.

The advantage of mixing together the two types of elements 2+ and 3+ seems to be small and limited to lower normal stress levels (25-100 kPa).

The improvement achieved with the inclusion of reinforcing elements in the soil is given in Table 4. The highest improvement was obtained when longer reinforcing elements were used with soil of bigger particles. This means that fewer cuts are needed to obtain the reinforcing elements, which is an advantage as far as savings is concern.

The improvement capacity of the small reinforcing elements studied seems to be highly dependent from the size of the soil particles.

Table 4. Improvement due to inclusion of reinforcing elements

Mixture	Angle of friction ϕ' (^{o})	Ratio of Improvement (%) (*)
MS	35	-
MS 2+	38.7	11
MS 3+	40.5	16
MS 2+3+	35.1	3
FS	37	-
FS 2+	40.5	9
FS 3+	40.4	9

(*) defined as $\Delta\phi'/\phi'$

4 CONCLUSIONS

The work described herein demonstrate that small elements shredded from plastic mesh bags of widespread use as domestic carrying bags can certainly be used for soil micro-reinforcement.

By performing Direct Shear tests it can be concluded that a significant increase of shear strength can be achieved by adding the small elements to the sandy soil. This technique has proved to be technically feasible and also very promising: an increase of about 16% for the shear angle of friction was achieved when just 2% of elements were added as reinforcement.

Control of the homogeneity of the samples, and most of all, of their compaction energy, is an important aspect that needs to be improved as a tentative to reduce the scatter observed in the results.

More research is needed concerned the size of the reinforcing elements more suitable for a certain type of soil. Therefore more sizes and more geometries for the reinforcing elements must be under consideration in future studies as well as more different types of soil.

ACKOWLEDGMENT

The authors would like to thanks the financial support from FCT, POCI and FEDER through the research Project POCI/ECM/59904/2004.

REFERENCES

ASTM D2487: Standard Classification of Soils for Engineering Purposes (Unified Classification Soil System).

EN ISO 5079: Textiles - Man-made fibres-Determination of Breaking Strength and Elongation of Individual Fibres.

Andrawes, K. Z., McGown, A., Hytiris, N., Mercer, F. B. & Sweetland, D. B. (1986) "The use of mesh elements to alter the stress-strain behavior of granular soils", *3rd International Conference on Geotextiles*, Vol. 3, Vienna pp. 839-844.

Canova, C.A.C (2008) "Reciclagem de resíduos plásticos para a construção", MSc, University of Coimbra, Coimbra, Portugal, 60 pages. (in Portuguese)

Falorca I.M.C.F.G. & Pinto M.I.M. (2002) "Sand reinforced with short length synthetic fibres randomly oriented", *7th International Conference on Geosynthetics*, Vol. 4, Nice, France, pp. 1237-1240;

Falorca, I.M.C.F.G. & Pinto, M.I.M. (2004) "Silty clay reinforced with short length synthetic fibres randomly oriented", *EuroGeo 3 – Geotechnical Engineering with Geosynthetics*, Vol.2, Munich, German, pp. 565-568;

Falorca, I.M.C.F.G, Pinto, M.I.M. & Ferreira Gomes, L.M. (2006) "Residual shear strength of sandy clay reinforced with short polypropylene fibres randomly oriented", *8th International Conference on Geosynthetics*, Vol 4, Yokohama, Japan, Milpress, Rotterdam, pp. 1663-1666;

Falorca, I.M.C.F.G, Pinto, M.I.M. & Ferreira Gomes, L.M. (2008) "Contribution to the construction method of reinforced soils with geosynthetic fibres", *EuroGeo 4-The 4th European Geosynthetics Conference*, Edinburgh, UK., paper no. 240 (in CD ROM)