Shear strength behaviour of plastic-reinforced sand soil under triaxial compression

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ABSTRACT: This paper investigates the reinforcing effect of high-density polyethylene plastic strips on sand soils. Plastic strip lengths of 7.5 mm, 15 mm and 30 mm, and contents of 0.1 % to 0.3 % by weight of the dry sand were utilised. The plastic strips were randomly included in Cape Flats sand to form a homogeneous mixture compacted to attain target average relative densities. Consequently, a comprehensive triaxial testing regime was undertaken on the samples at confining pressures of 50 kPa, 100 kPa, 200 kPa, 300 kPa and 400 kPa. Laboratory results indicate a significant increase in the shear strength parameters of the reinforced soil due to the plastic inclusions at different lengths and concentrations. A bilinear failure envelope was also reported on tests conducted on soil-plastic composites. Therefore, the research findings indicate that plastic bags can find potential use in geotechnical engineering projects such as cost-effective embankment construction for low volume roads in rural areas.

1 INTRODUCTION

The discovery of plastic material led to its increased usage for various applications such as packaging in commercial establishments. The use of plastic material such as grocery bags has resulted in environmental concerns. The single use of the plastic bags has led to an increase in disposal of the wastes in landfills whose holding capacity reduces drastically. Thus, the concept of environmental geotechnics has attracted great interest in the reuse of waste materials in various engineering applications. Polyethylene plastic wastes have been identified as potential alternative materials for use in ground improvement. This technique has been explored because of the abundance and affordability of grocery bag wastes. Moreover, the associated environmental benefits due to a reduction in the disposal of wastes is immense.

2 BACKGROUND INFORMATION

Soil reinforcement is an ancient technique that utilised tensile inclusions to improve the engineering properties of in-situ soil. The placement of the reinforcement elements is either through the use of randomly discrete inclusions such as plastic fibres, or the insertion of continuously oriented reinforcing elements like geosynthetics (Yetimoglu et al. 2005). Conventional mechanical stabilisation using some of these reinforcing materials is expensive and thus the need to identify alternative economic techniques.

Previous research has been conducted on the use of plastic material for strengthening soil (Benson & Khire 1994, Consoli et al. 2002, Neopaney et al. 2012). It has been reported that plastic strips randomly included in soil reported improved peak shear strength and a decrease in the post-peak strength loss (Maher & Gray 1990, Benson & Khire 1994, Yetimoglu & Salbas 2003, Falorca & Pinto 2011), increased soil stiffness, compressive strength and ductility (Maher & Gray 1990, Santoni et al. 2001, Dutta & Rao 2007). Consequently, plastic reinforced soils have been investigated for use in various geotechnical engineering applications such as airport and road pavements (Santoni & Webster 2001), embankment construction (Yoon et al. 2006) and the design of shallow foundations to improve the bearing capacity of the soil and limit settlements (Hataf & Rahimi 2006, Babu & Chouksey 2011).

The current study investigated the improvement in the geotechnical parameters of Cape Flats sand on varying the plastic strip length, strip content and the confining pressure. Locally obtained high-density polyethylene (HDPE) grocery bags were reused in the research.

3 METHODOLOGY

3.1 *Soil material*

The soil type used in the study was Cape Flats sand predominant in the Western Cape, South Africa. Cape Flats sand is a light grey quartz sand with sub-rounded to sub-angular particles (
Figure 1). The soil is classified as poorly graded as shown in
Figure 2 while Table 1 summarises the engineering properties of the sand.

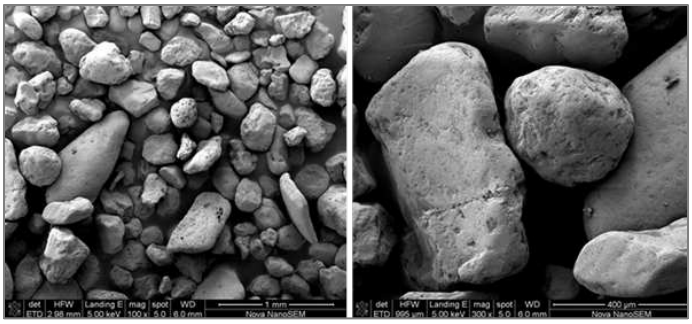

Figure 1. Cape Flats sand photomicrographs under 1 mm and 400 μm levels of magnification

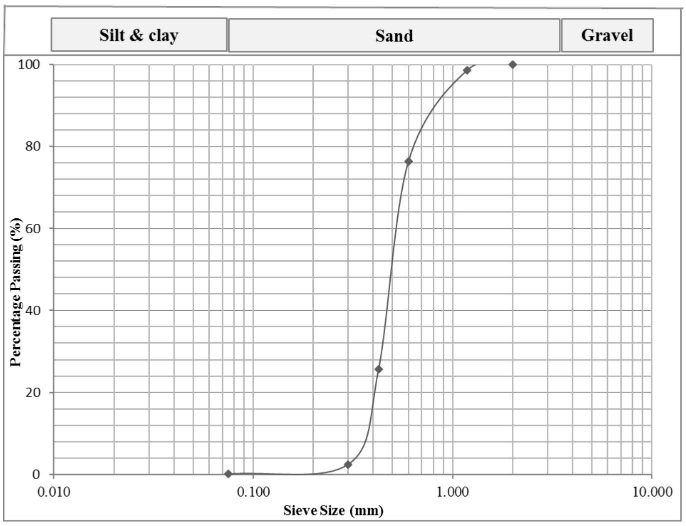

Figure 2. Grading curve for Cape Flats sand

Table 1. Mechanical properties of Cape Flats sand

Property	Unit	Value
Specific gravity, G_s	Mg/m^3	2.64
Maximum dry density	kg/m^3	1803
Minimum dry density	kg/m^3	1552
Mean grain size, D_{50}	mm	0.50
Coefficient of uniformity, C_u	-	1.42
Coefficient of curvature, C_c	-	1.10
Unified soil classification	-	SP

3.2 *Plastic material*

The plastic material chosen for this study were grocery shopping bags obtained from the local Pick 'n Pay supermarket in Cape Town, South Africa (Figure 3a). The bags are medium sized and manufactured from high-density polyethylene. The tensile strength of the plastic material was found to be isotropic and averaged 17 MPa in the transverse and longitudinal directions while the average thickness and density was measured as of 20 μm, density of 1265 kg/m^3respectively. A laser cutting machine was utilised in shredding the bags into the required sizes.

Figure 3. a) Plastic bag b) Laser-cut plastic strips

3.3 *Test procedures*

The sample preparation for the soil and testing of the soil-plastic composites were conducted as per ASTM D7181-11, the Standard Test Method for Consolidated Drained Triaxial Compression. 360 g of oven-dried soil was mixed with plastic strips in varying lengths of 7.5 mm to 30 mm and concentrations of 0.1 % to 0.3 % (by weight). The soil-HDPE was mixed homogenously by hand, divided into equal masses of 72 each and compacted in 5 lifts by dry tamping. The steel tamper utilised had a drop mass of 800 g with a base plate of 35.5 mm diameter and a drop height of 150 mm. The number of blows applied per layer were varied to obtain the target relative densities in the medium dense state. A test specimen of 50 mm diameter and 100 mm height was prepared in a split mould (Figure 4) and positioned in a triaxial cell chamber. Triaxial compression tests were then undertaken on the Geocomp LoadTrac-II/FlowTrac-II apparatus (Figure 5), at confining pressures of 50 kPa to 400 kPa at a constant shear rate of 0.075 %/min.

4 RESULTS AND DISCUSSIONS

The peak deviator stresses at failure for each soil-plastic composite sample was recorded for the applied confining pressures (50 kPa to 400 kPa). Shear strength parameters were obtained from Mohr's circle and the mechanical behaviour explained by the variation in plastic concentration, strip length and confining pressure.

4.1 *Effect of length and concentration on shear strength parameters*

Results indicate that an increase in the strip length (7.5 mm to 30 mm) resulted in improvement in the peak friction angle. This shear strength component improved from 30.0° to 33.8° corresponding to 11.5 % enhancement. The maximum friction angle was obtained at 15 mm strip length (Figure 6). The cohesion part also increased upon inclusion of plastic strips in the soil. The cohesion of the composite sample improved from 21.5 kPa for the unreinforced soil to 49.7 kPa at the 7.5 mm length. In comparison, variation of the strip content realised almost similar trends where the friction angle increased from 30.0° to 32.9° at 0.2 % concentration (Figure 7). The cohesion of the composite soil increased from 21.5 kPa to 59.1 kPa (from 0 % to 0.2 % strip content).

The mechanical behaviour of the Cape Flats sand was influenced considerably by the inclusion of the HDPE strips. The improved soil properties are due to the tensile reinforcement which led to increased cohesion (49.7 kPa and 59.1 kPa) upon attaining optimum strip length and content respectively. Furthermore, the reduction in the shear strength parameters beyond the maximum threshold could be due to sub-angular particles of the sand that led to perforation of the plastics reducing the reinforcing effect. Moreover, at higher concentrations and longer lengths of the plastic strips, entangled of the reinforcement leads to slippage and thus the decrease in cohesion and friction angle.

Figure 4. Specimen prepared in a split mould

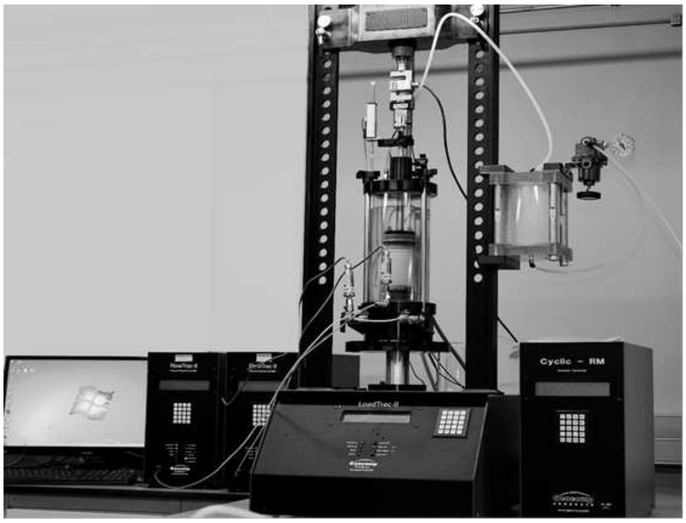

Figure 5. Test specimen in triaxial cell chamber mounted on platen ready for testing

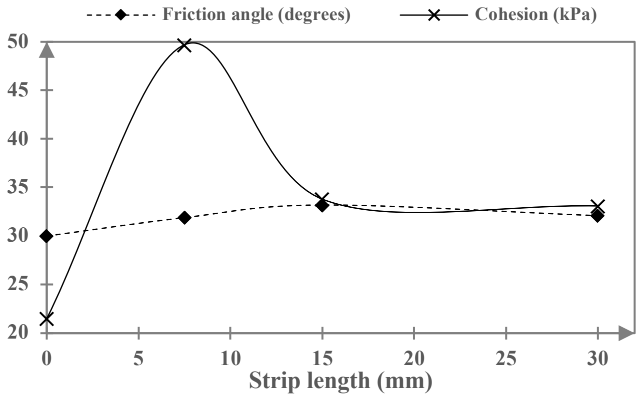

Figure 6. Variation of friction angle and cohesion with plastic strip length

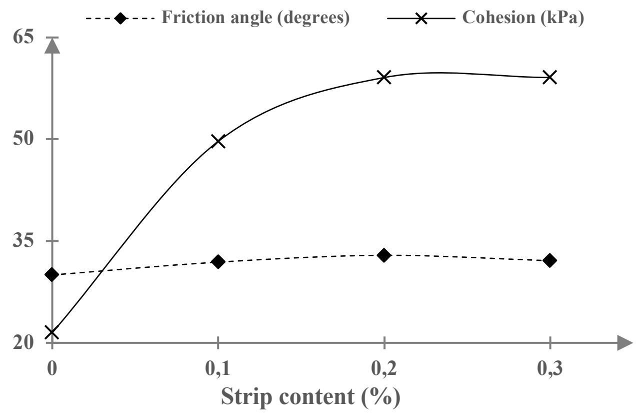

Figure 7. Variation of friction angle and cohesion with plastic strip length

4.2 *Effect of confining pressure*

The mechanical behaviour of the soil-plastic composite sample was also affected by varying confining pressure from 50 kPa to 400 kPa. The Mohr-Coulomb failure envelopes for the Cape Flats sand and the soil-plastic composite samples were analysed and results presented in

Figure 8. The results indicate shear stress-normal stress relationships of the Cape Flats sand without plastic strips (Figure 8a), the composite soil sample at the optimum plastic strip length of 15 mm (Figure 8b), and the composite soil sample at the optimum plastic strip concentration of 0.2 % (Figure 8c).

The analysis reported a linear failure envelope was observed in the unreinforced soil as shown in Figure 8a. In contrast, the soil-plastic composites reported a bilinear envelope, Figure 8b and

Figure 8c. The bilinear failure envelope is attributed to the variation in the confining pressure of the test. Consequently, a threshold confining pressure was found beyond which the bilinearity was observed. This was reported to be between 300 kPa and 400 kPa. At a lower confining pressure, the strength of the soil-plastic composites was governed by plastic slippage while at higher stresses, the tensile strength of the reinforcement governed the strength of the reinforced soil. The results are consistent with findings from previous research (Benson & Khire 1994, Consoli et al. 2002).

5 CONCLUSION

Triaxial compression tests were undertaken on Cape Flats sand reinforced with randomly discrete HDPE plastic strips at varying strip contents, strip length and confining pressure. The study was aimed investigating the shear strength behaviour of plastic reinforced soil. Laboratory results indicate that the tensile inclusions in soil result in increased peak friction angle and cohesion. The maximum friction angle was obtained at a strip length of 15 mm and concentration of 0.2 % while the highest cohesion was at a length and concentration of 7.5 mm and 0.2 % respectively. A linear and bilinear failure envelope was observed in the unreinforced and reinforced samples respectively. This was attributed to the low and high applied stresses as well as the plastic inclusions.

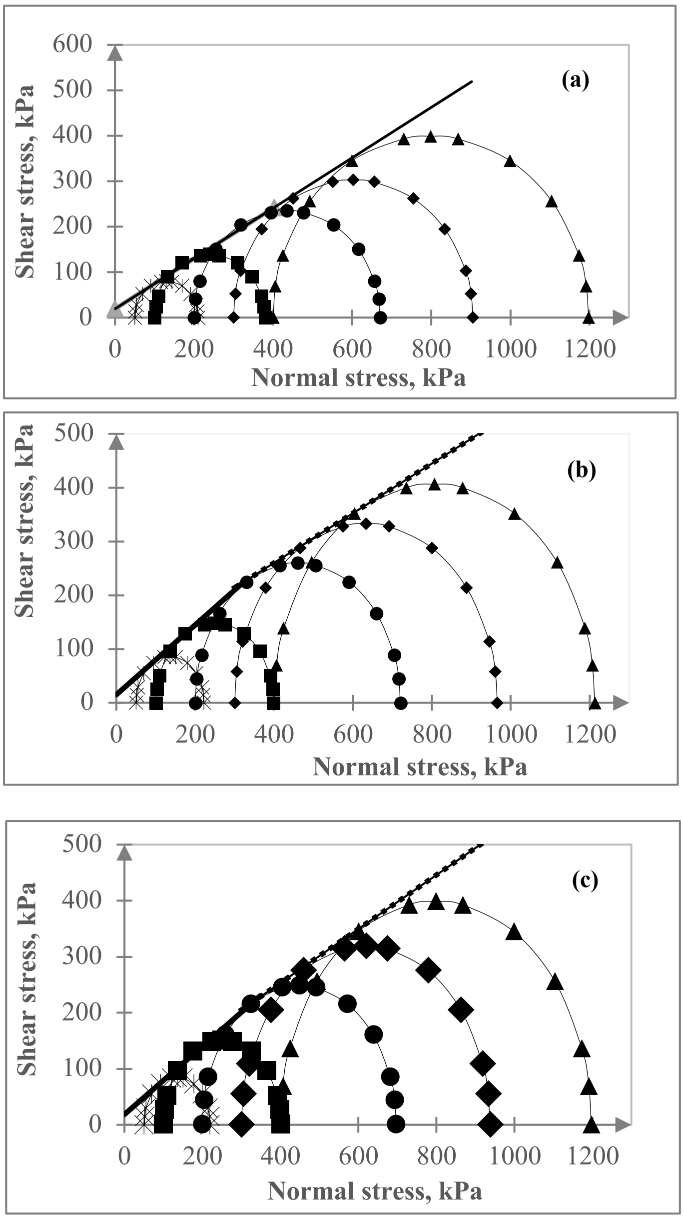

Figure 8. Mohr-Coulomb failure envelopes; a) unreinforced Cape Flats sand, b) composite sample at optimum length of 15 mm, and c) optimum content of 0.2 % respectively (Wanyama et al. 2017)

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