# Experimental investigation on shear strength properties of polyethylene (plastic) reinforced sand under triaxial compression

## Etude expérimentale sur les propriétés de résistance du sable renforcé de polyéthylène (plastique) sous compression triaxiale

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ABSTRACT: A series of laboratory triaxial tests were undertaken on samples of sand mixed with strips of polyethylene material to investigate the effect of the inclusions on the strength properties of the soil. The aim of the study was to explore the feasibility of re-using discarded plastic bags as a soil reinforcement material for geotechnical engineering applications. Plastic material were cut into strips and randomly added to Cape Flats sand to form soil-plastic composite specimens that were tested under triaxial compression to obtain the shear strength parameters. The effect of varying parameters of the plastic material was investigated by using strip lengths of from 7.5 mm to 30 mm and plastic contents from 0.1 % to 0.3 % by weight of the dry sand. The composite samples were compacted to variable relative densities of 52 % and 57 %, and tests conducted at confining stresses from 50 kPa to 400 kPa. Laboratory results positively indicate the improvement in the engineering properties of the soil due to these inclusions. Based on the findings, the proposed technique could find potential practical applicability in low-cost embankment or road construction.

RÉSUMÉ : Une série de tests triaxiaux de laboratoire a été effectuée sur des échantillons de sable mélangés à des bandes de polyéthylène pour étudier l'effet des inclusions sur les propriétés de résistance du sol. Le but de l'étude était d'explorer la faisabilité de réutiliser des sacs en plastique mis au rebut comme matériau de renforcement de sol pour des applications d'ingénierie géotechnique. Les matières plastiques ont été coupées en bandes et ajoutées aléatoirement au sable de Cape Flats pour former des échantillons composites sol-plastique qui ont été testés sous compression triaxiale pour obtenir les paramètres de résistance au cisaillement. L'effet des différents paramètres de la matière plastique a été étudié en utilisant des longueurs de bandes de 7,5 mm à 30 mm et des teneurs en matières plastiques de 0,1% à 0,3% en poids du sable sec. Les échantillons composites ont été compactés à des densités relatives variables de 52% et 57%, et des essais réalisés à des contraintes de confinement de 50 kPa à 400 kPa. Les résultats de laboratoire indiquent positivement l'amélioration des propriétés d'ingénierie du sol en raison de ces inclusions. Selon les résultats, la technique proposée pourrait trouver une application pratique possible dans les remblais à faible coût ou la construction de routes.

KEYWORDS: Triaxial compression tests, Polyethylene, Soil reinforcement, Geotechnical engineering, Shear strength

## 1 INTRODUCTION

### 1.1 *Introduction*

Over the past few years, a rise in usage of plastics for various domestic and industrial applications such as packaging has led to an increase of these materials in the waste stream. Plastic materials such as grocery bags are abundant, low-priced, readily available, and are non-biodegradable which has encouraged their disposal into the environment after only single usage. A large quantity of the total volume of these wastes particularly polyethylene plastics is destined to landfills whose capacity is steadily declining leading to challenges in municipal solid waste management. Consequently, there is a need to find an alternative, innovative and sustainable uses of the reclaimed plastic shopping bag wastes. Numerous researchers have proposed techniques that can utilise the abundant plastic waste resource as a soil reinforcement material (Benson & Khire, 1994; Dutta & Rao, 2007; Choudhary et al., 2010; Kalumba & Chebet, 2013; Chebet & Kalumba, 2014).

In this study, a laboratory experimental investigation was undertaken to explore the feasibility of using strips of reclaimed polyethylene shopping bags to reinforce a locally sourced sandy soil. The effect of varying plastic strip length and content in the sand prepared at different relative densities over a range of confining pressures on the shear strength parameters of the soil-plastic composites was investigated.

### 1.2 *Background*

Ground improvement through the inclusion of reinforcing elements in soil seeks to improve engineering parameters of soil such as the shear strength, permeability, density, compressibility (Hejazi et al., 2012), tensile strength, rigidity (Maher & Gray, 1990), material strength and ductility (Consoli et al., 2007). Soil reinforcement has widely been used for geotechnical engineering applications such as earth retaining walls, embankment slopes and subgrade stabilisation in road construction (Gray & Ohashi, 1983).

Studies into the random addition of plastic strips in the soil for reinforcing purposes have reported improved peak shear strengths and reduced the post-peak shear strength loss (Gray & Ohashi, 1983; Benson & Khire, 1994; Consoli et al., 2002). Moreover, the tensile inclusions contribute to enhancement in soil stiffness (Gray & Al-Refeai, 1986; Maher & Gray, 1990; Dutta & Rao, 2007), and increased compressibility of the soil (Santoni et al., 2001; Babu & Chouksey, 2011). Consequently, soil-plastic composites have been explored for use in various engineering applications such as low-cost road or embankment construction (Santoni et al., 2001; Mishra et al., 2013), and airfield pavements (Santoni & Webster, 2001).

Prior studies reported an increase in the friction angle of the compsites upon inclusion of polyethylene strips in the soil (Kalumba & Chebet, 2013; Chebet & Kalumba, 2014). The current study was therefore intended to contribute to the better understanding of the mechanical behaviour of soil-plastic composites.

## 2 MATERIALS AND EXPERIMENTAL PROCEDURES

### 2.1 *Soil Material*

The soil selected for the study was Cape Flats sand, which is locally available in the Western Cape Province, South Africa.

Cape Flats is a medium dense, light grey, clean quartz sand with sub-rounded to sub-angular particles (Figure 1). Table 1 gives a summary of the mechanical and physical properties of the sand.

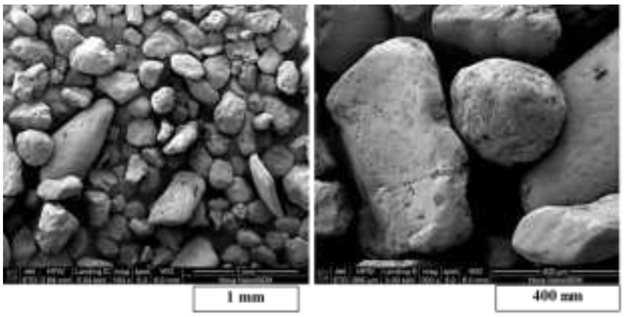



Figure 1: Photomicrographs of Cape Flats sand particles under different levels of magnification

Table 1. Engineering properties of Cape Flats sand.

| Soil Property | Unit | Value |
|---|---|---|
| Specific gravity, Gs | $Mg/m^3$ | 2.64 |
| Average densest dry density | $kg/m^3$ | 1803 |
| Average loosest dry density | $kg/m^3$ | 1552 |
| Particle size | mm | 0.075-1.200 |
| 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 |
| Angle of friction, $D_r = 52\%$ | ° | 29 |
| Angle of friction, $D_r = 57\%$ | ° | 30 |

### 2.2 *Plastic Material*

The plastic bags used in the experiments were 24-litre grocery shopping bags sourced from a local supermarket in South Africa. Each bag was labelled high-density polyethylene, HDPE, with a recycling number 2 (Figure 2a) in accordance with the American Society of the Plastics Industry (SPI) polymer identification code. The material average properties were measured as thickness of 20 $\mu$m, density of 1265 $kg/m^3$, and average tensile strength of 17 MPa. A laser cutting machine with a bed size of 965 mm x 610 mm and a laser cartridge of 40 W, was used to cut the plastics to the required dimensions (Figure 2b).

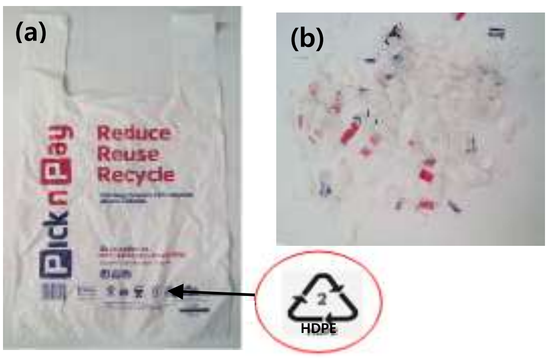



Figure 2: Plastic bag a) Before cutting, and b) Laser cut strips

### 2.3 *Experimental Procedures*

The soil-plastic composite specimens were prepared according to the dry tamping technique recommended in ASTM D7181. For each test, 360 g of oven-dried Cape Flats sand was used in order to eliminate any effects of moisture. The polyethylene strips used were of lengths 7.5 mm to 30 mm while the width was kept constant at 6 mm. The requisite mass of plastic strips for each experiment was computed as a percentage of the weight of dry sand and ranged from 0.1 % to 0.3 %. The HDPE strips were randomly mixed by hand in the soil to form a homogenous soil-plastic composite specimen (Figure 3a). The composite sample was compacted by use of a steel tamper in 5 layers, in a membrane stretched tightly in a triaxial test split mould (Figure 3b), in order to achieve target relative densities of 52 % and 57 % respectively. The densities corresponded to the medium dense state of the sand. The test specimen measuring 50 mm in diameter and 100 mm in height was assembled in a triaxial cell (Figure 3c), and triaxial tests conducted using the LoadTrac-II/FlowTrac-II Geocomp triaxial apparatus at confining pressures of 50 kPa,100 kPa, 200 kPa, 300 kPa, and 400 kPa at a shear rate of 0.075 %/min.

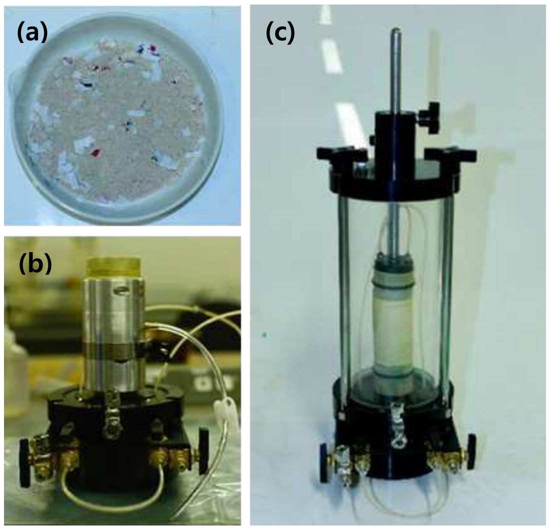



Figure 3: Test specimen preparation a) Soil-plastic matrix, b) Assembled split mould, and c) Specimen ready for triaxial testing

## 3 RESULTS AND DISCUSSION

The peak deviator stresses of the composite samples from the triaxial compression tests were recorded on varying the strip length (7.5 mm to 30 mm), plastic content (0.1 % to 0.3 %), relative density, $D_r$ (52 % to 57 %), and confining pressure (50 kPa to 400 kPa). Mohr's circles were plotted and shear strength parameters obtained from which the influence of the variables on the soil friction angle was determined.

### 3.1 *Effect of Confining Pressure*

The effect of confining stresses was illustrated by plotting graphs of the deviator stresses from the triaxial tests against the respective normal stresses for both unreinforced and reinforced Cape Flats sand at $D_r = 52$ % (Figure 4). The graphs defined the Mohr-Coulomb failure envelopes from which shear strength parameters ($c'$, $\emptyset'$) were obtained. A maximum strain of 10 % was adopted because beyond this value strain hardening was observed in all the tests.

Based on the results, a linear relationship was observed in unreinforced soil (Figure 4a). However, there exists a critical confining stress at which the failure envelope ceases to be linear for soil-plastic composites (Figure 4a and b). Shear strength failure was governed by plastic slippage below this threshold stress, while at higher stresses it was governed by the tensile strength or pull-out of the plastic strips. Maher & Gray (1990) indicate that the critical confining stress is influenced by the specific soil-plastic parameters including; plastic strip length, angular shape and gradation of Cape Flats sand while relatively no influence is attributed to the strip contents. This explains the clear deviation from the linear relationship in Figure 4 (b) on varying the strip length, and slight change in slope in Figure 4 (c) on varying the plastic strip length. The critical confining pressure was found to be in the range of 300 to 400 kPa.

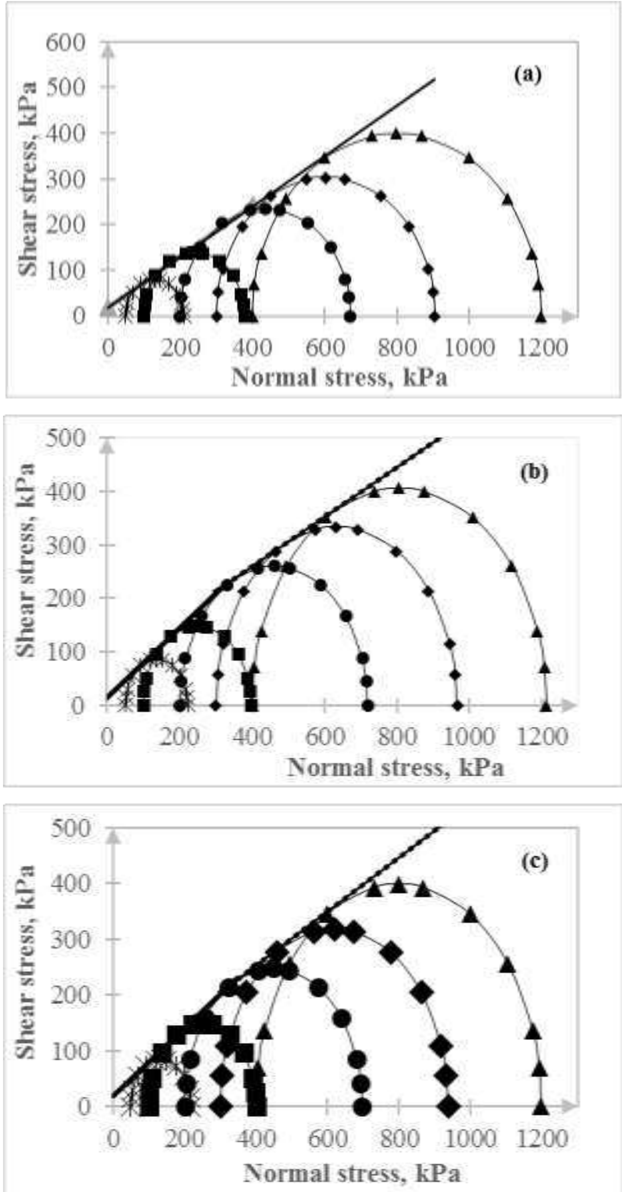



Figure 4: Shear strength envelopes a) Unreinforced sand, b) Reinforced sand (optimum length, 15 mm), and c) Reinforced sand (optimum content, 0.2 %) (Wanyama, 2016)

For all the results, an increase in the frictional resistance angle at lower confining stresses was observed upon addition of plastic material. This improved with increasing strip length which is consistent with test results reported from previous research (Gray & Ohashi, 1983; Maher & Gray, 1990; Consoli et al., 2002). Furthermore, the failure envelope for reinforced sand at normal stresses greater than the critical confining stress was almost parallel to that of the unreinforced sand, as predicted in previous studies (e.g., Maher & Gray, 1990; Benson & Khire, 1994; Consoli et al., 2002).

### 3.2 *Effect of Strip Length and Plastic Content*

Laboratory results indicate that varying the strip length from 7.5 mm to 30 mm at a Dr = 52 % led to an enhancement in the peak friction angle of the Cape Flats sand (Figure 5a). The friction angle increased from 29.0° to 33.0° representing approximately 14 % strengthening. The results indicate that the maximum friction angle was recorded at 15 mm length. Beyond this optimum value, a decrease in the shear strength was observed. In comparison, a similar trend was observed on inclusion of plastic reinforcement in the soil at concentrations of 0.1 % to 0.3 % (Figure 5b). The peak friction angle improved from 29.0° to 31.3°, equivalent to 8 %. The optimum friction angle was obtained with 0.2 % plastic content beyond which further increase in concentration had no significant effect. Moreover, the soil stiffness (ratio of deviator stress to vertical strain) improved significantly due to the tensile inclusions.

The improvement in the shear strength properties of the soil may be attributed to the plastic reinforcement angular gradation of the soil. The soil particles adhere and interlock tightly which results in increased frictional resistance at the soil-plastic interface. Furthermore, longer plastics are less likely to undergo slippage due to the soil-plastic interaction which enable the soil to bear tensile stresses.

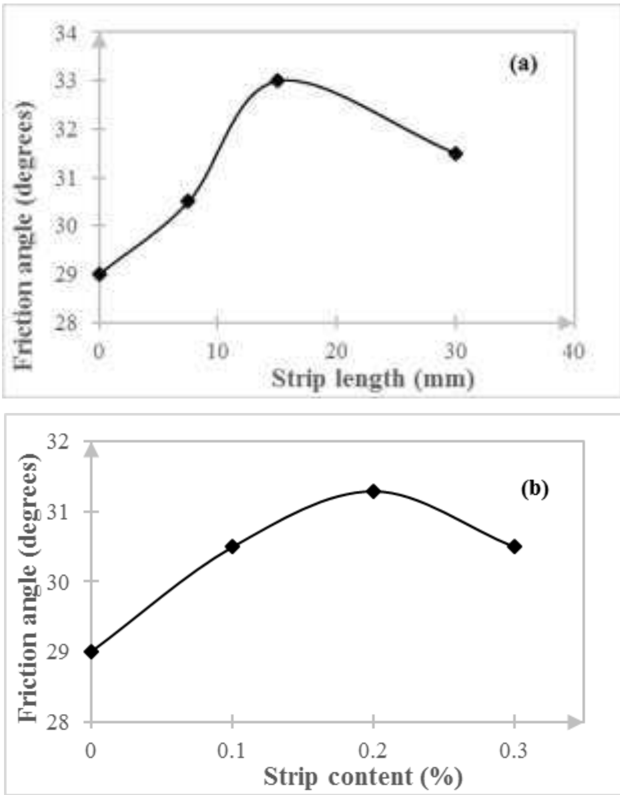
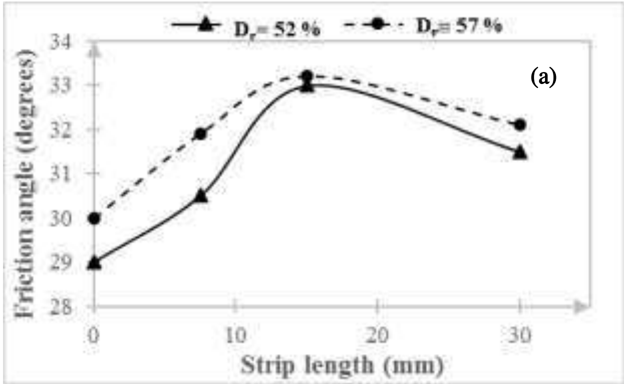



Figure 5: Variation of friction angle with plastic parameters a) Strip length, and b) Strip content (Wanyama, 2016)

### 3.3 *Effect of Relative Density*

The effect of relative density on peak friction angle with varying plastic parameters is shown in Figure 6. It can be observed that the optimum friction angle improved on addition of plastic strips at concentrations 0 % to 0.3 %, and increasing the relative density from 52 % to 57 % (Figure 6a). The optimum soil friction angle increased from 31.3° to 29.0° corresponding to 5 %. Nevertheless, variation of the strip length from 7.5 mm to 30 mm resulted in the optimum friction angle increasing slightly 33.0° to 33.2° (Figure 6b). This is equivalent to approximately 1 %. The strengthening of the soil may be attributed due to denser packing of the soil-plastic composites as the compaction density was increased. The reinforcing action was greater on varying HDPE content as compared to varying the strip length. The relative density also affected the failure mode of the triaxial specimens. A planar shear failure plane predicted by the Mohr-Coulomb theory was observed on specimens prepared at a Dr = 52 %, and tested under low confining stresses (50 kPa to 200 kPa), while bulging failure was reported for test samples tested whose Dr = 57 %, and tested at high confining pressure (300 kPa to 400 kPa).



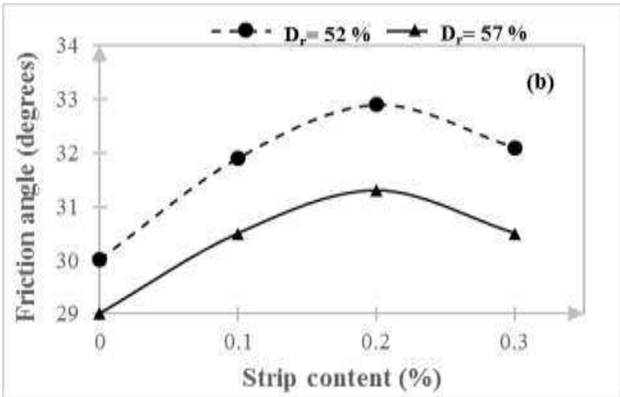




Figure 6: Effect of relative density on friction angle with plastic parameters a) Strip length, b) Strip content (Wanyama, 2016)

## 4 CONCLUSION

Triaxial compression tests were conducted on dry Cape Flats sand with random inclusions of HDPE plastic strips at different concentrations and lengths. Moreover, different relative densities and confining pressures were used in the study. The test parameters were systematically varied to investigate their effect on the shear strength properties of the soil-plastic composites.

The laboratory results indicate that the addition of plastic strips in soil increased its peak shear strength and stiffness. In addition, the post-peak strength loss was reduced in the reinforced soil. A linear failure envelope was observed in tests on unreinforced samples while a bilinear failure envelope was observed in soil-plastic composites. An increase in the plastic content and strip length, and relative density caused an improvement in the friction angle of the soil-plastic composites. A linear increase was observed up to a maximum value beyond which a decrease in the friction angle was reported. The optimum strip length and plastic content was 15 mm and 0.2 %.

The research findings from the current study favourably suggest the possibility of using plastic shopping bag material in improving the shear strength of sandy soils. Consequently, the method could be considered for practical applications in geotechnical engineering projects such as lightweight fill material for road construction. This would lead to reduction of overall project costs and provide a sustainable way of reducing plastic wastes destined for landfills.

## 5 ACKNOWLEDGEMENTS

The authors wish to thank Commonwealth Scholarship in low and middle income countries for availing funds for the research. The geotechnical engineering laboratory staff at the University of Cape Town are also appreciated for the assistance offered during the laboratory investigation stage.

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