Laboratory investigation on shear strength characteristics of soil reinforced with recycled linear low density polyethylene

Etude de laboratoire sur les caractéristiques de résistance au cisaillement du sol renforcé par du polyéthylène basse densité linéaire recycle

L. Nolutshungu, D. Kalumba

Department of Civil Engineering, University of Cape Town, South Africa, nltlit001@myuct.ac.za)

ABSTRACT: In South Africa, approximately 20% of plastic waste is recycled, increasing marginally each year (Plastics Federation of South Africa, 2015). The aim of this research was to investigate the viability of using the recycling output material, which are plastic flakes and pellets, as soil reinforcement in geotechnical applications. Triaxial tests were conducted on composite samples of Cape Flats sand mixed with randomly distributed flakes and pellets of low density polyethylene (LDPE) to investigate their effect on the shear strength parameters. The effect of varying the concentration of the pellets (1% to 7.5%), flakes (0.1% to 1%) according to the dry weight of the sand, was investigated. Consolidated drained tests were conducted on dry composite samples under confining pressures of 75kPa, 150kPa and 300kPa. The results showed that the inclusions improve the engineering properties of the soil as evidenced by increases in the shear strength parameters. According to the outcome of this study, the potential exists for use of this material in applications such road sub-layer and embankment construction.

RESUME: En Afrique du Sud, environ 20% des déchets plastiques sont recyclés, augmentant légèrement chaque année (Plastics Federation of South Africa, 2015). Le but de cette recherche était d'étudier la viabilité de l'utilisation du matériau de sortie du recyclage, qui sont des paillettes de plastique et des granulés, comme renforcement du sol dans des applications géotechniques. Des essais triaxiaux ont été effectués sur des échantillons composites de sable de Cape Flats mélangés à des flocons et des pastilles de polyéthylène basse densité (LDPE) distribués de façon aléatoire pour étudier leur effet sur les paramètres de résistance au cisaillement. On a étudié l'effet de la variation de la concentration des pastilles (1% à 7.5%), des flocons (0,1% à 1%) en fonction du poids sec du sable. Des essais de drainage consolidés ont été réalisés sur des échantillons composites secs sous des pressions de confinement de 75 kPa, 150 kPa et 300 kPa. Les résultats ont montré que les inclusions améliorent les propriétés d'ingénierie du sol comme en témoigne l'augmentation des paramètres de résistance au cisaillement. Selon les résultats de cette étude, le potentiel existe pour l'utilisation de ce matériau dans des applications telles que la sous-couche de route et la construction de remblais

KEYWORDS: Triaxial tests, Polyethylene, Recycled plastic waste, Shear strength, Soil reinforcement, Geotechnical engineering

1 INTRODUCTION

Since the development of plastics in the 1930's, plastics have increasingly become widely used for packaging in the commercial marketplace. With this application being for immediate disposal, the amount of plastic waste generated presents a challenge in the disposal thereof. The risks associated with non-biodegradable products, pressure on existing landfills and the increasing costs thereof have necessitated the development of alternative options for waste management over the years. Research has resulted in various forms of treatments and recycling processes adopted and implemented as environmentally and economically viable solutions. These plastics, most of which is polyethylene (low density/linear low density), are reduced in size during the recycling process into pellets, flakes or powder (Al-Salem, Lettieri & Baeyens, 2009) ready for reuse in the manufacturing of various products.

Identifying different applications for this material increases demand thereof, leading to lower volumes of waste reaching landfill sites. One such application could be the use of the recycled product as soil reinforcement for ground improvement purposes. This offers a multifaceted engineering solution that is environmentally friendly; economic, in that is uses an existing process in creating a new market; and equitable as it is an unbiased approach to an environmental and geotechnical issue, thus making it sustainable

2 BACKGROUND

Soil can be reinforced with the use of continuous reinforcement (steel bars, sheets or strips) in predetermined patterns, or could be with the inclusion of discrete elements randomly distributed in the soil mass (Yetimoglu, Inanir & Inanir, 2005). The use and methodology of some of these materials can be quite costly and as a result warrant the need for more economical and easy to use reinforcement methods and techniques. Studies have been conducted on various forms of plastics, including plastic waste (Benson & Khire, 1994; Consoli et al., 2002) with some more focussed on the shear strength characteristics (O'rourke, Druschel & Netravali, 1990; Falorca & Pinto, 2011; Pradhan, Kar & Naik, 2012). These various studies showed increases in strength characteristics for various soils with plastic inclusions. This was attributed to the tensile properties and hardness of the reinforcement material. the shored inclusions of the of various soils including. These results showed the potential that exists in using polyethylene (in various forms) to improve soil properties.

Studies undertaken on sand-polyethylene composites, using high density polyethylene, showed increases in friction angle which contributed to improved shear strength. The aim of this study therefore was to investigate the effect of randomly distributed inclusions of recycled LLDPE on the shear strengths characteristics of Cape Flats sand. This was conducted by comparing the two products (flakes and pellets) that are produced during the recycling process.

3 MATERIALS AND TESTING PROCEDURES

3.1 *Soil*

The soil used for the study was Cape Flats sand which is a light grey quartz sand that is readily available in the Western Cape. The particles are mainly sub-angular with some sub-rounded (Figure 1). This is a poorly graded sand with the properties shown in Table 1.

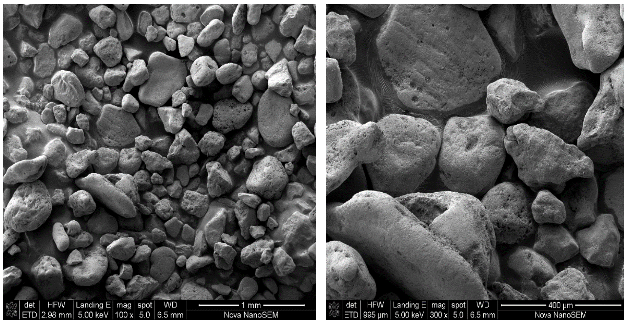

Figure 1: Cape Flats sand photomicrographs at 1 mm and 400 µm magnification

Table 1. Soil properties

Property	Unit	Value
Specific Gravity, G_S	-	2.64
Average minimum Dry Density	Mg/m3	1.554
Average maximum Dry Density	Mg/m3	1.657
Mean grain size, D_{50}	mm	0.32
Maximum grain size, D_{100}	mm	1.15
Particle size range	mm	0.075 – 1.15
Coefficient of uniformity, C_u	-	1.8
Coefficient of curvature, C_c	-	1.176
assification	-	SP

3.2 *Recycled plastic material*

The plastic selected for this study is classified as linear low-density polyethylene (LLDPE), which was a clear plastic used mainly for packaging. The density of the plastic material is 917kg/m3, with tensile strength of 59kPa and elongation of 600% (Westlake Chemical Corporation, (n.d.)). The recycling process reduces the plastic in size into flakes and pellets, as shown in Figure 2.

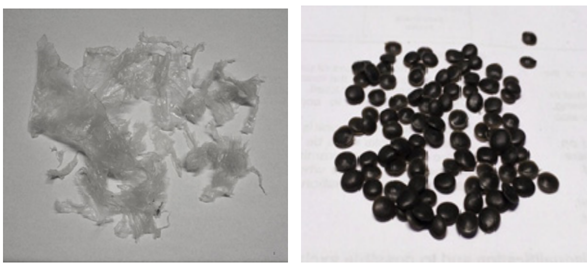

Figure 2: Recycled LLDPE plastic

It is these two forms of plastic that were used as reinforcement material in the test specimen. LLDPE was used particularly for its isotropic tensile strength. Exhibiting the same strength in different directions compensates for the irregularity in size and aspect ratios of the flakes. The pellets had an average diameter of 5.31mm and thickness of 2.10mm.

3.3 *Testing procedures*

All preparations, excluding the reinforcement, were done according to ASTM D7181-11 (2011), the Standard Test Method for Consolidated Drained Triaxial Compression Test for Soils. 360g of oven dried soil was mixed in varying concentrations of 0.1% to 1% for the flakes and a range of 1% to 7.5% for the pellets. This soil-LLDPE composite, which was hand mixed, was divided into masses of 72g each and compacted in 5 layers as per dry tamping method prescribed in section 6.4.4 of ASTM D7181-11. The tamper used had a drop height of 150mm and drop mass of 800g with a 35,5mm diameter base plate. The compaction was done with a minimum 15 drops required to obtain a relative density above the minimum dry density of the sand which was determined as per ASTM D4254-00 (2000). A test specimen of 50mm diameter and 100mm average height was prepared in a split mould (Figure 3a) and placed in a triaxial chamber (Figure 3b) ready for testing. Triaxial compression tests were conducted on Geocomp LoadTrac-II/FlowTrac-II apparatus at confining pressures of 75 kPa, 150 kPa and 300 kPa at a constant shear rate of 0.075%/min.

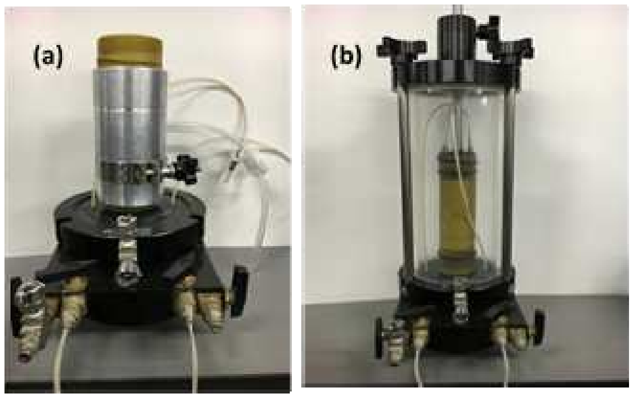

Figure 3: (a) Split mould assembly (b) Composite sample placed in triaxial cell

4 RESULTS AND DISCUSSION

The failure stresses of the test specimen were recorded according to variations in concentration of pellets (1% to 10%) and flakes (0.1% to 1%) at different confining pressures (75 kPa, 150 kPa and 300 kPa). Shear strength parameters were obtained from Mohr's circles, with the behaviour explained by the effects of polyethylene concentration and confining pressures.

1 .2 *Concentration effects on shear strength parameters*

Results indicated that increasing the concetration of pellets (from 1% to 7.5%) leads to an improvement of the peak friction angle. This parameter increased from 30.1° to 32.9° which is a 9.3% improvement in the frictional component of shear strength. The maximum friction angle was obtained at 5% pellet concentration (Figure 4a). The flakes were were varied from 0.1% to 1.0 % , resulting in decreases in peak friction angle. This was a notable decline from 30.9° at a concentration of 0.1% to 22.5° at the highest concentration of 1.0%, representing a 27,2% loss in strength (Figure 4b).

The shear strength behaviour of the Cape Flats sand was affected by the inclusion of the LLDPE flakes and pellets. The introduction of the polyethylene reflected cohesive properties in what is ordinarily a non-cohesive soil. This was evident in the improvement in cohesion with the increase in concentration of the flakes. At 0.1% content, cohesion of approximately 17 kPa was recorded, up to a maximum of 79 kPa at 0.5%. resulting in a 365% increase in the shear strength parameter (Figure 4b). The introduction of pellets in the composite showed an immediate increase in cohesion to approximately 19 kPa at 1% concentration, which decreased to a minimum of 6 kPa at 3% (Figure 4a).

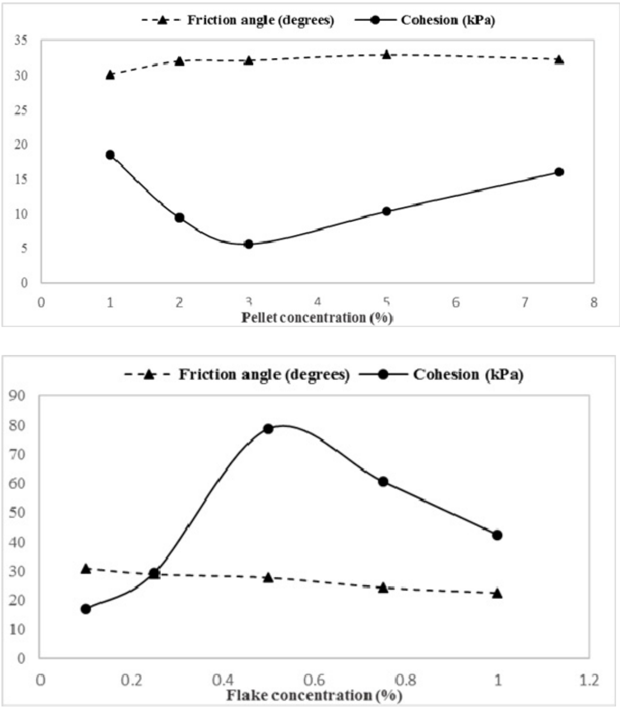

Figure 4: (a) Friction angle and Cohesion parameters at various pellet concentration (b) Friction angle and Cohesion parameters at various pellet concentration

The pellets showed increases in friction angle due to a better interlocking mechanism between the soil particles and the edges of the pellets. The flakes reflect constant decreases in friction angle primarily due to the sub-angular shaped particles which puncture the plastic upon application of deviator stress. The improvement in cohesive properties as a result of the flake inclusions can be attributed to the tensile strength and elongation properties of the material.

1 .2 *Confining pressure effects*

An analysis of the Mohr-Coulomb failure criterion provides insight into the shear mechanism of the composite. It was found that the results show a bilinear stress envelope. This was as a result of the different confining stresses applied in the testing phase. This effect was assessed for the reinforced and unreinforced soil for confining pressures of 75 kPa, 150 kPa and 300kPa (Figure 5). The unreinforced soil showed a linear relationship (Figure 5a). However, this changes in the reinforced soil to a bilinear relationship (Figure 5 (a) and (b)).

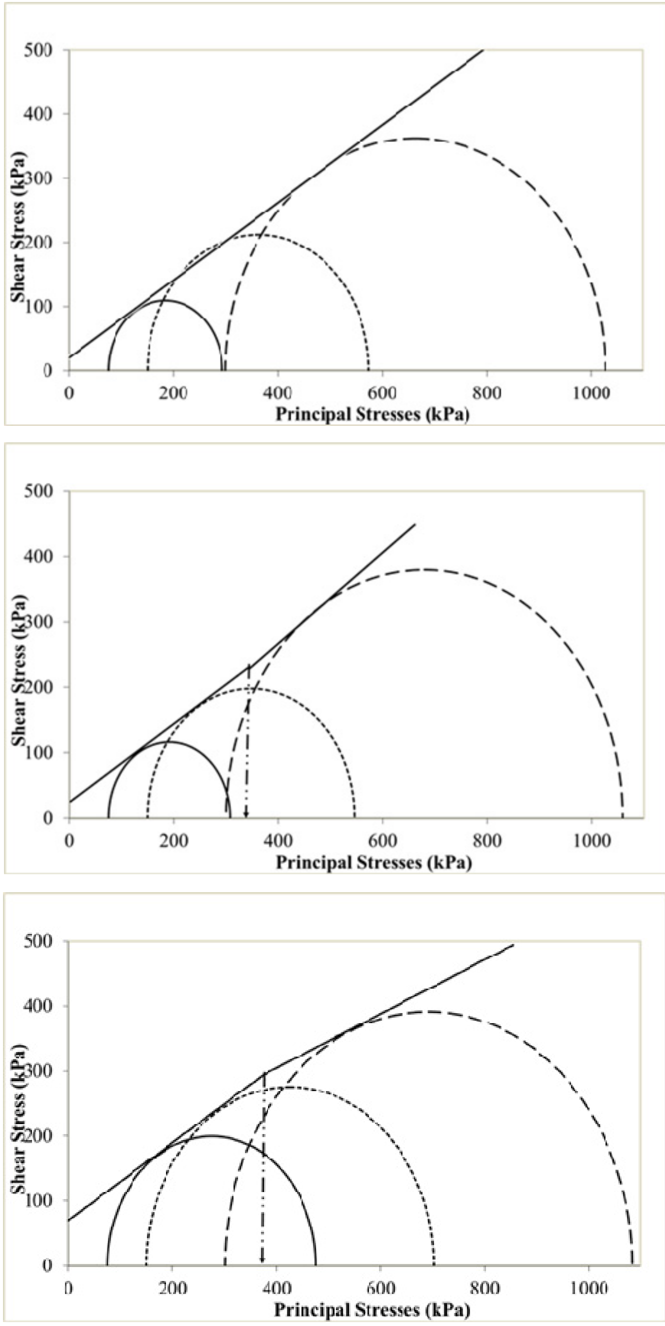

Figure 5: (a) Unreinforced Cape Flats sand (b) Pellets at 5% optimum concentration (c) Flakes at 0.5% optimum concentration

Figures 5 (a) and (b) indicate the existence of a threshold pressure where the behaviour changes. This critical confining pressure was between 300 and 400 for both the pellets and flakes, with the flakes exhibiting a slightly higher pressure. The behaviour of the two materials differs and this is governed by the difference in the failure mechanism at pressures before and after the threshold pressure. This change in behaviour is reflected by the change in slope which is reflected in Figures 5(b) and (c).

Before reaching the threshold confining pressure, the pellet reinforced soil exhibited lower friction angles which can be attributed to the lower degree of interlocking between the soil particles and reinforcement material that occurs at lower confining pressures. The internal frictional angle therefore increases and confining pressures above the threshold. The behaviour of the flakes differed in that higher friction angles which are indicative of improved slip and pull. Before reaching the threshold confining pressure, the reinforced soil exhibited higher friction angles which are indicative of improved slip and pull. It can therefore be said that randomly distributed pellets serve as frictional elements to the principal pressures in the Mohr-Coulomb envelope, whilst the flakes act to resist tension. This is supported by previous research conducted (Lin, 2005; Shukla, Sivakugan & Das, 2009)

5 CONCLUSION

Triaxial tests were conducted on Cape Flats sand with randomly distributed recycled LLDPE in the form of flakes and pellets. The inclusions were at varying concentrations to investigate the effect on the shear strength of the soil. The results show that both forms of these inclusions increased shear strength, by the increase in the internal friction angle parameter due to pellet inclusions and induced cohesion due to the flakes. The pellets showed increases in friction angle due to a better interlocking mechanism between the sub-angular particle shape and the edges of the pellets. The maximum angle friction angle was reached at a pellet concentration of 5% and the highest cohesion recorded at 0.5% flake content.

6 ACKNOWLEDGEMENTS

The authors thank the staff of the University of Cape Town Geotechnical Laboratory for the assistance in the experimental investigation.

7 REFERENCES

Al-Salem, S., Lettieri, P. & Baeyens, J. 2009. Recycling and recovery routes of plastic solid waste (PSW): A review. *Waste Management.* 29(10):2625-2643.

ASTM D4254-00 2000. *Standard Test Method for Minimum Index Density and Unit Weight of Soil and Calculation of Relative Density.* West Conshohocken, Philadelphia: American Society of Testing and Materials.

ASTM D7181-11 2011. *Standard Test Method for Consolidated Drained Triaxial Compression Test for Soils.* West Conshohocken, Philadephia: American Society of Testing and Materials.

Benson, C.H. & Khire, M.V. 1994. Reinforcing sand with strips of reclaimed high-density polyethylene. *Journal of Geotechnical Engineering.* 120(5):838-855.

Consoli, N.C., Montardo, J.P., Prietto, P.D.M. & Pasa, G.S. 2002. Engineering behavior of a sand reinforced with plastic waste. *Journal of Geotechnical and Geoenvironmental Engineering.* 128(6):462-472.

Falorca, I. & Pinto, M. 2011. Effect of short, randomly distributed polypropylene microfibres on shear strength behaviour of soils. *Geosynthetics International.* 18(1):2-11.

Lin, C. 2005. Mechanical reponse of fibre-reinforced soil. PhD. University of Texas.

O'rourke, T., Druschel, S. & Netravali, A. 1990. Shear strength characteristics of sand-polymer interfaces. *Journal of Geotechnical Engineering.* 116(3):451-469.

Plastics Federation of South Africa 2015. It's all about plastic: Material of choice. (Unpublished).

Pradhan, P.K., Kar, R.K. & Naik, A. 2012. Effect of random inclusion of polypropylene fibers on strength characteristics of cohesive soil. *Geotechnical and Geological Engineering.* 30(1):15-25.

Shukla, S., Sivakugan, N. & Das, B. 2009. Fundamental concepts of soil reinforcement—an overview. *International Journal of Geotechnical Engineering.* 3(3):329-342.

Westlake Chemical Corporation (n.d.). *Linear Low Density Polyethylene: MSDS No. SC74853.* Houston, Texas: .

Yetimoglu, T., Inanir, M. & Inanir, O.E. 2005. A study on bearing capacity of randomly distributed fiber-reinforced sand fills overlying soft clay. *Geotextiles and Geomembranes.* 23(2):174-183.