Investigation of shear strength characteristics of sand reinforced with recycled plastic waste

L. Nolutshungu. Department of Civil Engineering. University of Cape Town, South Africa. nltlit001@myuct.ac.za
D. Kalumba. Department of Civil Engineering. University of Cape Town, South Africa. denis.kalumba@uct.ac.za

ABSTRACT

In 2014, a total of 1.4 million tons of plastic was converted. In an attempt to reduce waste, 20% was recycled (PlasticsSA, 2015). The reuse of this material increases demand thereof leading to lower volumes of waste reaching landfill sites. The aim of this research therefore was to investigate the effect of inclusion of recycled plastics, on the shear strength of sand. Low density polyethylene (LDPE) from packaging was used due to its uniform tensile strength, as opposed to plastic shopping bags where it varies with orientation. Triaxial tests were conducted on sand samples with randomly distributed LDPE flakes and pellets. The effect of varying the concentration of the pellets (1% to 10%), flakes (0.1% to 1%) and confining pressure (75, 150 and 300 kPa) was investigated. The results showed an improvement in the shear strength of sand, with flakes exhibiting significant reductions in density when compared with the pellets.

1. INTRODUCTION

1.1 Background

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 treatment and recycling processes adopted and implemented as environmentally and economically viable solutions. These plastics, most of which is polyethylene (LD/LLD), are reduced in size during the recycling process into pellets, flakes or powder (Al-Salem, SM, 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 (recycling products) as soil reinforcement for ground improvement purposes in the construction industry.

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 et al. 2005). The use and methodology of some of these materials could 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 polymers, including plastic waste by Consoli, et.al (2002) and high density polyethylene by Benson and Khire (1994). These results of these studies showed the potential that exists in using polyethylene to improve certain soil properties.

1.2 Aim of study

The aim of this study was to investigate the effect of randomly distributed inclusions of recycled linear low density polyethylene (LLDPE) on the shear strength characteristics of soil. This was conducted by comparing the two products that are produced during the recycling process. Further to this, the effect of varying concentrations of both products was examined.

2. RESEARCH MATERIALS AND EQUIPMENT

2.1 Materials

2.1.1 Soil material

The soil that was used for the study was obtained from Afrimat quarry in the Phillippi area in the Western Cape. This sand is called the Cape Flats sand and is classified as poorly graded sand (SP) under the Unified Soil Classification System (USCS). The mechanical properties of the sand are summarised in Table 1 and the grading curve shown in Figure1.

Table 1. Characteristics of Cape Flats sand

Characteristics	Unit	Value
Specific Gravity, G_s		2.64
Minimum Dry Density	Mg/m^3	1.554
Maximum Dry Density	Mg/m^3	1.657
Mean grain size, D_{50}	mm	0.32
Coefficient of uniformity, C_u		1.8
Coefficient of curvature, C_c		1.176
Shape		Subangular

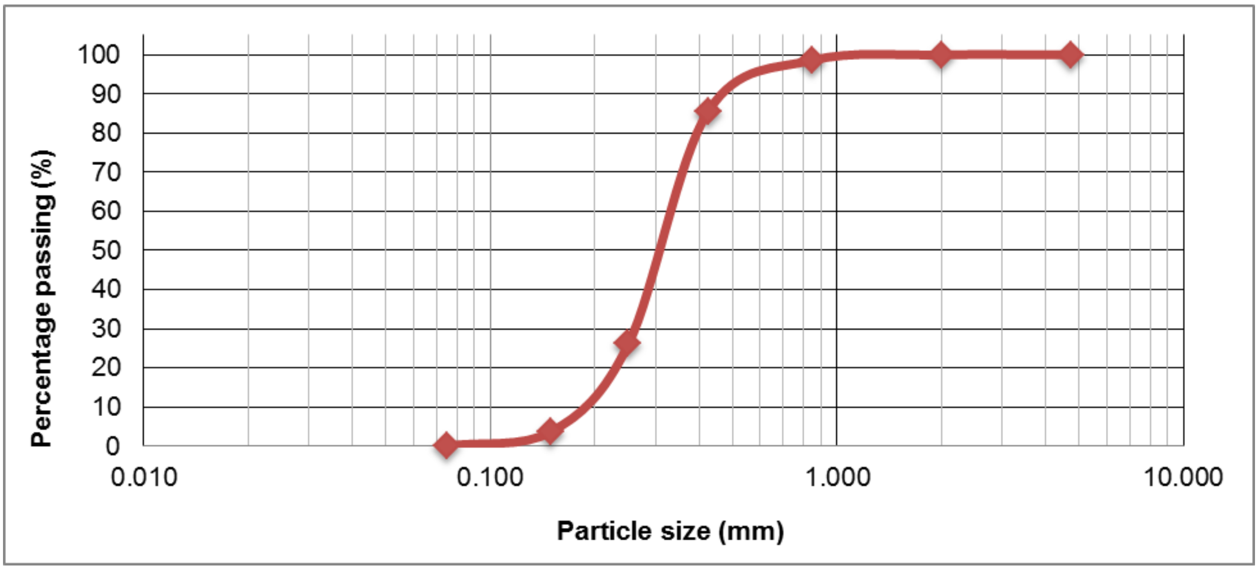
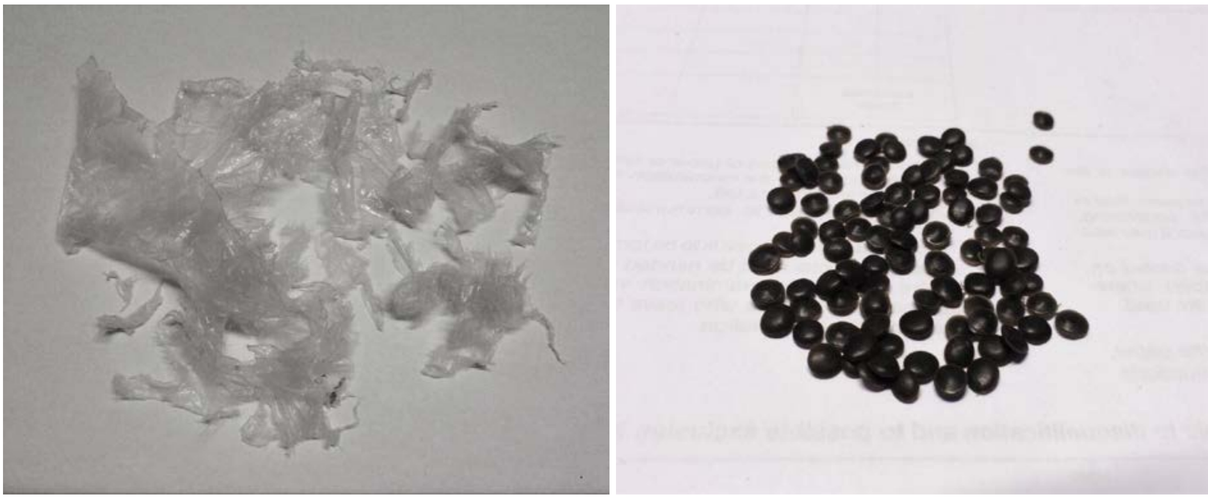


Figure 1. Particle grading curve

2.1.2 Recycled plastic material

The plastic selected for this study is classified as linear low-density polyethylene (LDPE), 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, 2016). The recycling process reduces the plastic in size into flakes, as shown in Figure 2 (a) or pellets in Figure 2 (b).



a) Flakes b) Pellets

Figure 2. Recycled LLDPE products.

2.2 Equipment

The equipment used for the laboratory investigation was the Geocomp LoadTrac-II/FlowTrac-II system (Figure 3) for triaxial testing. This system fully automates the testing process once the soil specimen was prepared and the test conditions selected. It consists of a LoadTrac-II frame, which used a micro stepper motor in applying the vertical load and capable of applying strain rate or stress at a displacement rate range between 0.00003 and 15mm per minute. The second components were two FlowTrac-II flow pumps, which regulated the pressure for the cell and controlled the specimen volume using a micro stepper motor, and electronic valves for direction of flow to the cell or specimen. The FlowTrac-II maintains the desired pressured to within ±0.35kPa. The system uses a computer fitted with a network card and Microsoft Windows applications software called TRIAXIAL to run the test and store data.

Figure 3. Geocomp LoadTrac-II/FlowTrac-II triaxial test system

3. RESEARCH METHODOLOGY

3.1 Sample preparation

The soil was oven dried overnight and cooled in a hygroscopic chamber before being used for sample preparation. Control tests were run on unreinforced sand specimen before the plastic was incorporated. The pellets were mixed with the soil in concentrations of 1%, 2%, 3%, 5%, 7.5% and 10%. On separate samples, the flakes were included in concentrations of 0.1%, 0.25%, 0.5%, 0.75% and 1%. These specimens were prepared by using a pre-calculated quantity of sand mixed with the pellets/flakes and compacted in a latex membrane mounted in a split mould. The compaction was conducted by separating the measured quantity into five sections and applying 15 blows to each of the 5 layers using a tamper weighing 800g from a drop height of 150mm. The completed sample (Figure 4(a)) used for a test measured approximately 51mm in diameter and between 105mm and 110mm in height . The sample preparation was done in accordance with ASTM D7181-11 section 6.3.

3.2 Testing process

The ASTM D7181-11 standard was used to conduct consolidated drained triaxial shear tests. The triaxial cell with the prepared sample was placed in the LoadTrac-II with the loading piston inserted through an opening at the top of the cell and locked in place. The FlowTrac-II was connected to the LoadTrac-II and the system checked for pressure leaks. The complete cell assembly is shown in Figure 4(a). In preparation for the laboratory investigation, three repeatability tests were conducted using samples of pure sand, with a normal pressure of 100kPa, to evaluate the reliability of the equipment to produce consistent results. The internal friction angles attained were 30.5º, 30.3º and 30.6º, which confirmed reproducibility of data.

For each concentration of the pellet and flake samples, normal pressures of 75, 100 and 200 kPa were applied which allowed for the determination of shear strength parameters. The first phase of consolidation was run at the normal confining pressures, with the shearing phrase applied at a rate of 0.075%/min and run to a maximum strain of 10%. TRIAXIAL software was used to monitor the test and create data that was exported to excel for analysis. The total number of shear tests conducted was 45 excluding repeatability and control tests. Figure 4(b) shows a sample that has reached the maximum strain.

a) Sample assembly ready for testing

b) Completed test sample

Figure 4. Testing process

4. RESULTS AND DISCUSSION

4.1 Shear strength and shear parameters

In determining shear strength, there were two parameters taken into account. The first one was cohesion, caused by negative capillary pressure, which is lost upon wetting or pore pressure responses during undrained testing of granular soils such as the sand that was used in this investigation. This parameter was not included in this discussion as it only represented apparent cohesion, due to the soil being dry and tested under drained conditions. The second parameter is the internal friction angle, which is the angle at failure due to shear stress. This is the reference parameter for shear strength investigation of non-cemented granular materials such as the Cape Flats sand used in this study (Jamiolkowski et al., 2003) Figure 6(a) and 6(b) show the internal friction angle plotted against the concentrations for pellets and flakes, respectively.

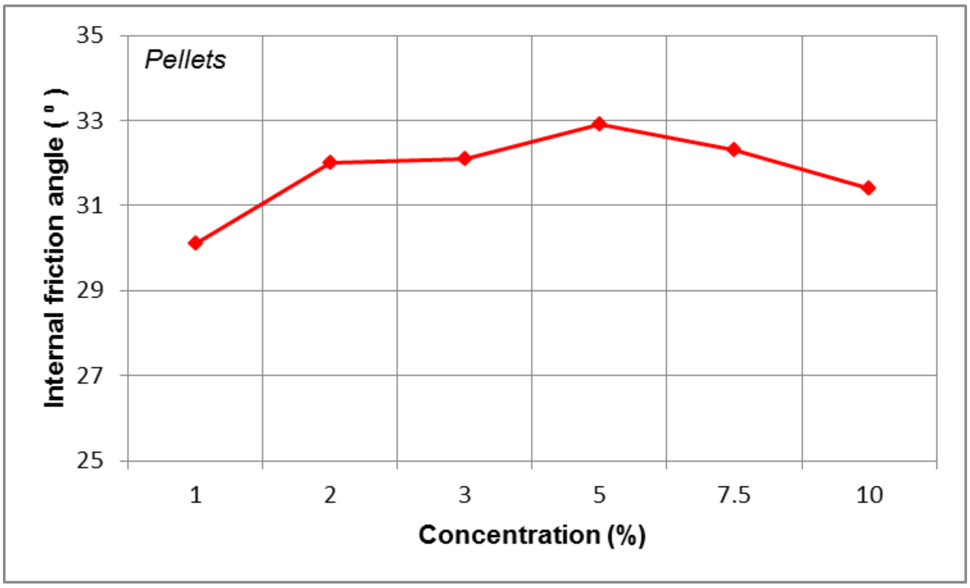


Figure 6a: Internal friction angle versus concentration (Pellets)

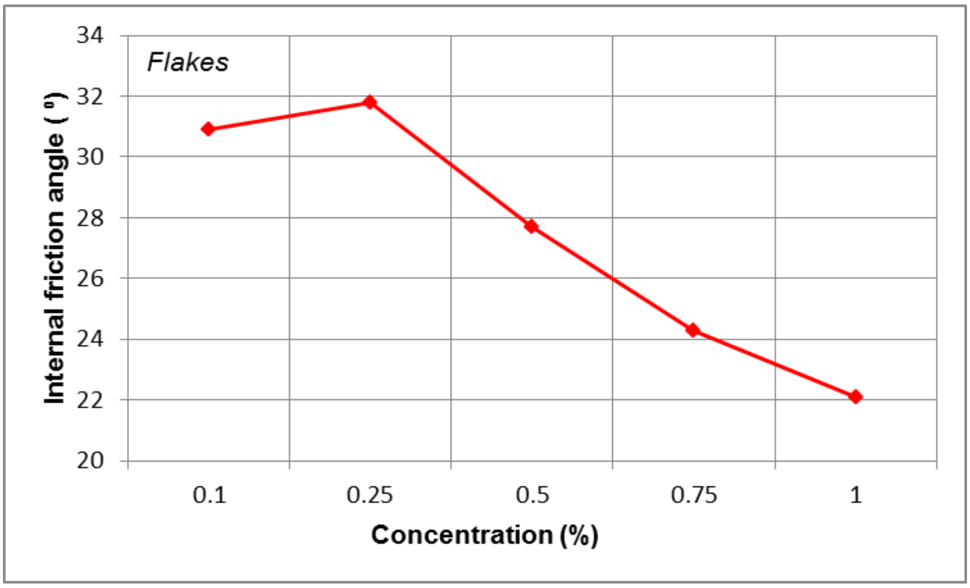


Figure 6b: Internal friction angle versus concentration (Flakes)

From Figure 6(a), it can be seen that an increase in concentration of the pellets resulted in an improvement of the internal friction angle up to a maximum of 32.9º before it begins to decrease again. This was achieved at a concentration of 5%. The increase in the friction angle results in an increase in the shear strength. Figure 6(b) shows the effect of concentration of flakes on the internal friction angle. It is clear from the graph that there was an initial increase at lower concentrations of 0.1% and 0.25%, beyond which there is a definite decrease. The maximum friction angle was attained at 0.25% concentration. This means that shear strength peaks at this concentration.

4.2 Density

Figure 7(a) and 7 (b) shows the density plotted against concentration. Both the pellets and flakes show a constant decrease in density with an increase in concentration. This is because of the relatively low density of LLDPE material that replaced the sand. Further to this, the pellets resulted is notably lower density values with higher concentrations. This is due to the flakes' the ability to deform and wrap around the soil particles allowing for tighter packing and resulting in higher densities at lower concentrations. A comparison of Figure 7(a) and Figure 6(a) reveals that the maximum friction angle was attained at the lowest possible density, without going below the minimum density of the soil.

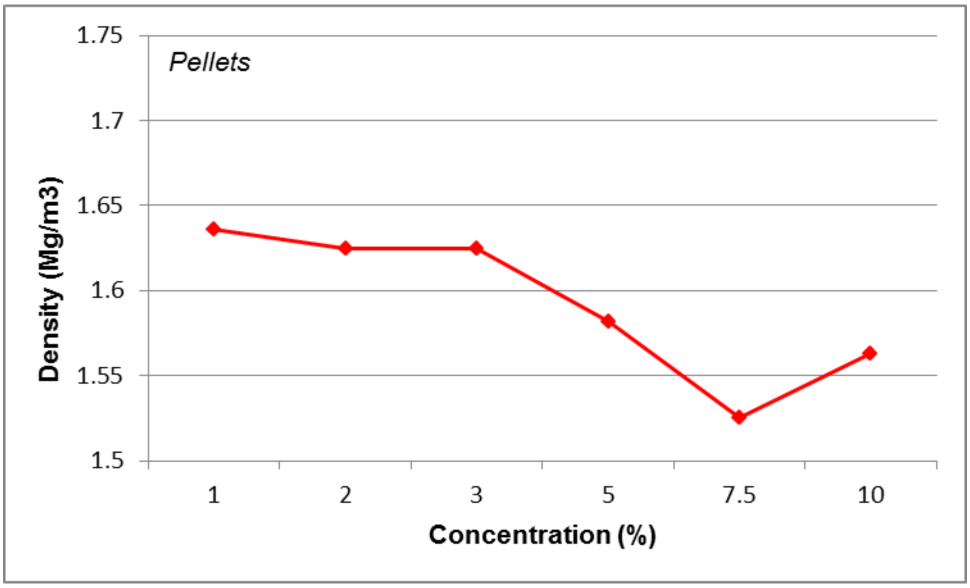


Figure 7a: Density angle versus concentration, pellets

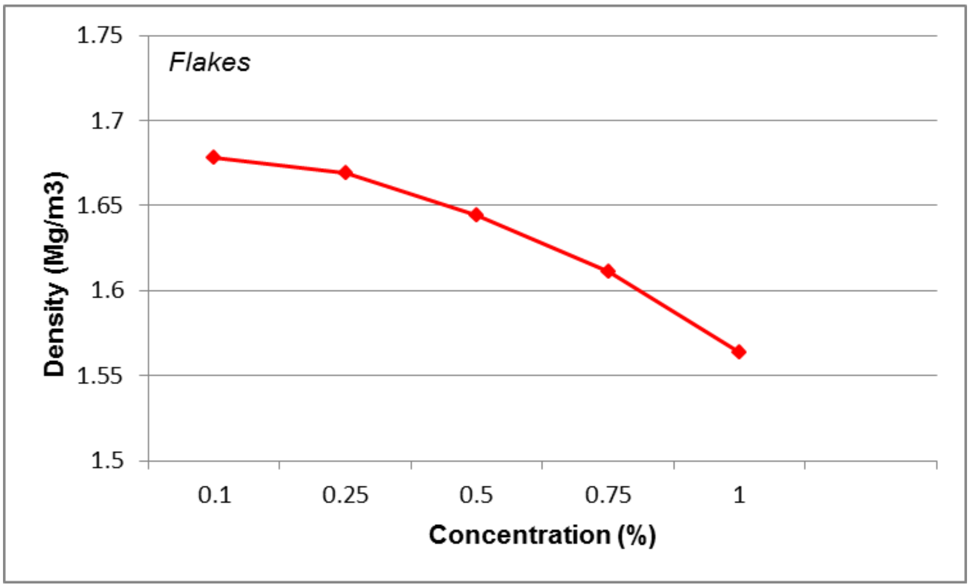


Figure 7b: Density versus concentration, flakes

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 evident increase in the internal friction angle parameter. The pellets showed a higher increase in friction angle due to a better interlocking mechanism between the sub-angular particle shape and the edges of the pellets.

The maximum friction angle for pellets was reached at a higher concentration (5%) and lower average density (1.582 Mg/m^3) when compared with the flakes. A higher concentration meant an increase in the inter-particle friction because of more pellets inter-locking with the sand particles. This continued increase ceased when the density of the composite mixture was close to the minimum density of pure sand (1.55 Mg/m^3), making this the optimum concentration for the pellets. The lower average density was as a result of the low density LLDPE pellets, replacing sand with a higher density. This could also be attributed to the flakes ability to deform with the consequence of tighter packing, leading to higher densities.

The flakes showed an initial increase at a small concentration of 0.25%, with a continuous decrease thereafter. This is because of the soil particles punching through the material as a result of the irregular shape with some sharp points, improving the interparticle friction. However, further increases in concentration mean there is more flake-on-flake interaction, which results in a slip providing not friction. Smaller sized flakes could provide more tensile strength with less flake-on-flake interaction, resulting in higher interparticle friction.

This investigation showed that using the pellets resulted in increased shear strength. This could be useful in applications where improvement is needed in the shear strength properties of sand. The flakes resulted in a minor increase that required further investigation relating to the best size to reach optimum concentration for the highest improvement in friction angle. Successful use of this recycled material in construction and ground improvement applications could lead to a significant reduction in waste material.

ACKNOWLEDGEMENTS

Samuel Juuko is acknowledged for training on the operating of the equipment, Charles Nicholas for the design and fabrication of some apparatus used and Elvino Witbooi for general assistance in the laboratory.

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 D 7181-11. Standard Test Method for Consolidated Drained Triaxial Compression Test for Soils. *American Society for Testing and Materials*, West Conshohocken, Pennsylvania, USA.

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 behaviour of a sand reinforced with plastic waste. *Journal of Geotechnical and Geoenvironmental Engineering*. 128(6): 462-472.

Jamiolkowski, Michele, D. C. F. Lo Presti, and Mario Manassero. "Evaluation of relative density and shear strength of sands from CPT and DMT." *Soil behavior and soft ground construction* 7.119 (2003): 201-238.

Yetimoglu, T., Inanir, M., and Inanir, O.E. (2005). A study on bearing capacity of randomly distributed fibrereinforced sand fills overlying soft clay, Geotextiles and Geomembranes, 23: 174–183.