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Laboratory Investigation of Recycled Polyethylene Terephthalate (PET) as Soil Reinforcement Material

Etude expérimentale sur le polyéthylène téréphtalate (PET) recyclé en tant que matériau de renforcement des sols

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ABSTRACT: A series of direct shear tests were conducted to examine the effect of recycled plastic waste chips on the engineering properties of Klipheuwel and Cape Flats Sand both locally sourced and predominant in the Western Cape region of South Africa. Polyethylene Terepthalate (PET) plastic chips of 2 mm, 4.75 mm and 5.6 mm sizes were added to the soils at a varying contents from 2.5% - 20 % of dry mass of the soil and mixed randomly to form sand-plastic composite specimen tested in the direct shear test at normal pressures of 2 5 kN/m^2, 50 kN/m^2 and 100 kN/m^2. The experimental results revealed significant improvement in the shear strength parameters, cohesion and friction angle of the sands on addition of PET chips. The highest increase in friction angle of Cape Flats sand and Klipheuwal sand was obtained at plastic contents of 10% and 12.5% respectively for the 5.6mm size plastic chips.

RÉSUMÉ: Une série d'essais de cisaillement direct a été menée pour examiner l'effet des copeaux de plastique recyclé sur les propriétés géotechniques du sable de Klipheuwel et du sable de Cape Flats, produits localement et prédominants dans la région du Cap Occidental en Afrique du Sud. Des copeaux de plastique de polyéthylène téréphtalate (PET) de tailles 2 mm, 4,75 mm et 5,6 mm ont été ajoutés aux sables avec des teneurs variant de 2,5% à 20% de la masse sèche des sables, et mélangés de manière aléatoire pour former des échantillons composites sable-plastique soumis à des essais de cisaillement direct réalisés à des contraintes normales de 25 kN/m^2, 50 kN/m^2 et 100 kN/m^2. Les résultats expérimentaux ont révélé une amélioration significative des paramètres de résistance au cisaillement, cohésion et angle de frottement des sables, lors de l'ajout des copeaux de PET. La plus grande augmentation de l'angle de frottement du sable de Cape Flats et du sable de Klipheuwel a été obtenue avec des teneurs en plastique de 10% et 12,5% respectivement pour les copeaux de plastique de taille 5,6 mm.

Keywords: Polyethylene Terephthalate, Plastic bottles, Recycling, Soil Reinforcement

1 INTRODUCTION

According to International Bottled Water Association (IBWA), plastic bottles consumption increased by 500% over last 10 years and more than 1.5 million tons of plastic are used for bottling water every year (Babu, GL Sivakumar 2011). As a result, a large amount of plastic bottles waste ends up in landfills, ocean, lakes and streams. It is estimated that a total of

10,198,000 tons of waste is received at landfill sites across South Africa per annum (Department of Water Affairs and Forestry, 2005). There is therefore a need to find alternative uses for the plastic bottles waste as a means of resource recovery for environmental sustainability.

Waste material is increasingly being explored as soil reinforcement in civil engineering and several studies have been conducted on inclusion of the material in soil to improve the strength properties. Benson and Khire (1994) investigated the inclusion of reclaimed high density polyethylene (HDPE) from milk jugs; Zornberg et al (2004), Hataf and Rahimi (2006), Naeini and Sadjadi (2008) studied the use of shredded tires; Wang Y. (2006), Miraftab and Lickfold (2008), Anyiko et al. (2011) used carpet fibre waste, Kalumba and Chebet, (2013) utilized plastic shopping bags waste. The studies on soil reinforcement using shredded polyethylene plastic strips reported improvement in the shear strength of soil due to interaction between plastic waste and soil during the loading process as well as the tensile strength and ductility of the plastic material (Babu & Chouksey, 2011). A reliable secondary market for reclaimed plastic waste is essential to promote re-use of the abundant plastic material manufactured from non-renewable petroleum resources. Reinforcement to improve engineering properties of construction soil is a possible means to put to use the plastic waste resource as opposed to disposal into landfills. This could be particularly useful since soil reinforcement is widely used in many geotechnical applications that include backfill for retaining structures, landfill liners and covers, road embankments and sub-grade stabilization. This study therefore sought to explore the use of postconsumer plastic bottles made from polyethylene terephthalate (PET) as soil reinforcing material in ground improvement schemes. It investigated the effect of inclusion of chips from waste plastic bottles on the shear strength parameters of soil.

2 MATERIALS AND LABORATORY TESTING

2.1 Soil Material

Cape Flats sand and Klipheuwel sand were used in the study. These soils are predominant in the Western Cape region of South Africa and were selected for their range of grading, angularity and grain sizes. Both sands were clean and consistent which enabled repeatability of results. Table 1 gives the engineering properties of the soil.

Cape Flats sand is a medium dense, light grey, clean quartz sand, with larger sub rounded grains while Klipheuwal sand contains medium and smaller sized sub angular particles. Figure 1 shows photographs as well as micrographs of the sands observed under a scanning electron microscope (SEM) and Figure 2 gives the grading curves for the sands.

Table 1. Engineering properties of the soils

Soil Property	**Cape Flats Sand**	**Klipheuwel Sand**
Specific gravity, Gs	2.66	2.64
Particle Range (mm)	0.075-1.18	0.075-2.36
Mean Grain Size, D_{50}	0.5	0.72
Coefficient of uniformity, C_u	3.0	4.21
Coefficient of curvature, C_c	0.85	1.05
Angle of friction (°)	38.5	41.6
Cohesion (kN/m^2)	9.4	4.8

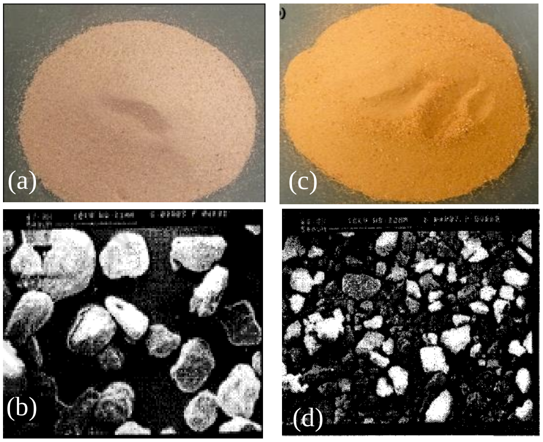

Figure 1. (a) Cape Flats sand b) Cape Flats sand micrograph c) Klipheuwal sand d) Klipheuwal sand micrograph

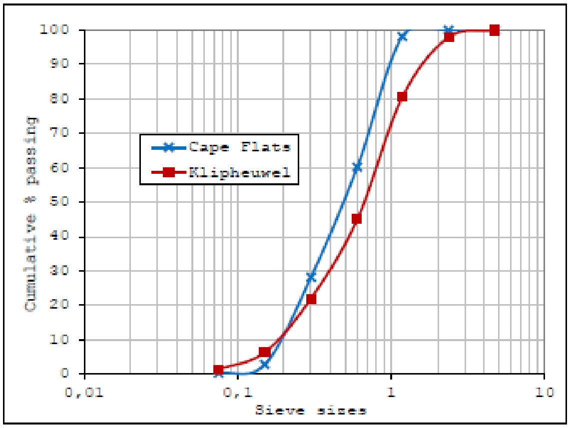

Figure 2. Grading graphs for Cape Flats Sand and Klipheuwal Sand

2.2 Polyethylene Terephthalate (PET) Plastic Chips

Polyethylene Terephthalate (PET) chips from the plastic bottles used in the study were sourced from Kaytech Ltd, a local manufacturer of geosynthetics from recycled plastic materials. Plastic bottles are manufactured from polymers and a mixed stream of various materials, therefore after shredding at the source, smaller pieces have to be washed and the labels, residue and other contaminants removed.

The plastic chips of various sizes were then separated through a stack of sieves sizes ranging of 2.0-4.75mm, 4.75-5.6mm, and >5.6mm. Figure 3 shows the PET plastic chips graded according to the different sizes.

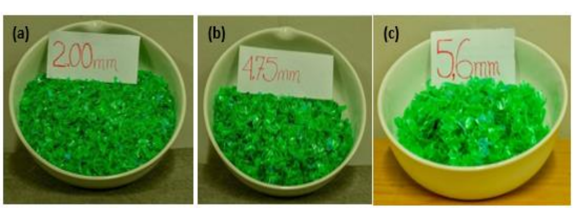

Figure 3 (a) 2.0mm, (b) 4.75mm and (c) 5.6mm

2.3 Test Equipment

The test equipment used in the study was the automated Geocomp ShearTrac II direct shear testing system with a 100 mm x 100 mm x 30 mm shear box (Figure 4). The system comprises a loading frame containing two embedded control systems and components that generate the vertical and horizontal forces fitted with transducers to apply the vertical and horizontal forces and measure the displacements in real time. The equipment has a maximum axial load capacity of 4.4 kN and maximum horizontal and vertical displacements of 12.5 mm and 24.45 mm respectively.

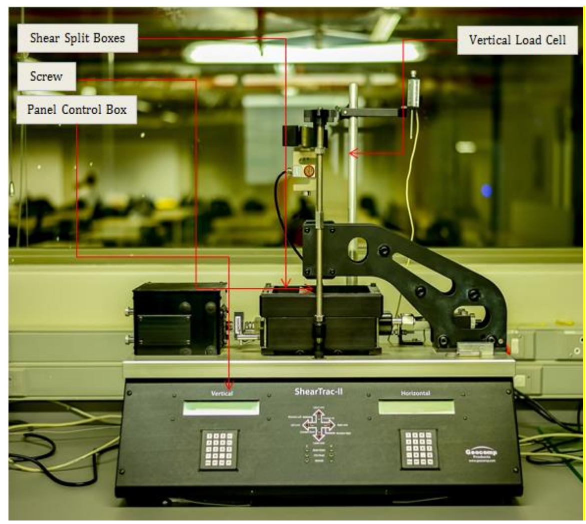

Figure 4. Direct Shear Test Equipment (ShearTrac-II)

2.4 Direct Shear Tests

PET plastic chips were added to the soils at varying contents of 2.5% - 20 % of dry mass of the soil and mixed randomly to form soil-plastic composite specimen that was tested in the direct shear test according to the British Standards (BS 1377-7: 1990). The tests were conducted at normal pressures of 25kN/m^2, 50kN/m^2 and 100kN/m^2. The peak shear stresses for the soil plastic composite specimen were obtained from each of 135 direct shear tests carried out: 72 tests were performed on Cape Flats sands, and 63 tests were conducted on Klipheuwel sand with similar concentrations of shredded plastic.

Figure 5. Soil-Plastic Composite placed in the 100 mm by 100 mm direct shear box

3 RESULTS AND DISCUSSIONS

3.1 *Stress-strain graphs*

The results from the direct shear test presented in Figures 6 and 7 show the stress-displacement graphs at vertical pressures of 50 kPa, 100 kPa and 200 kPa for soil-plastic composites with different size plastic chips of 10% content for the Cape Flats sand and 12.5% for Klipheuwel Sand, which are plastic contents at which the highest strength improvements were observed.

As seen in Figure 6, the peak shear stress values increased with higher plastic chip sizes added to the soil. For a plastic content of 10%, the peak stress value recorded for a normal stress value of 200 kPa was 205 kPa for 2.0 mm plastic chip sizes, 220 kPa for 4.75mm chips sizes and 240 kPa for the 5.6 mm sizes in Cape Flats sand. The same trend is observed for the Klipheuwal sand with peak shear stress values of 225 kPa on addition of 2.0 mm plastic chip sizes, 240 kPa for 4.75 mm sizes and 275 kPa for 5.6 mm sizes at a 200 kPa normal stress (Figure 7).

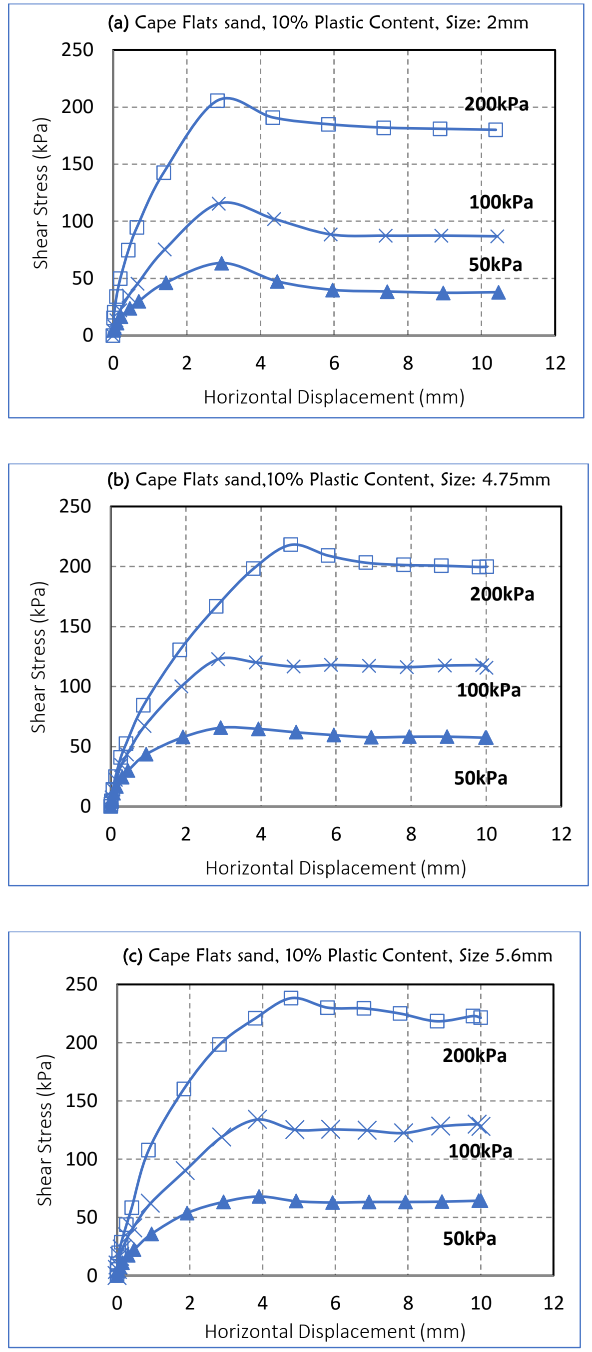

Figure 6. Shear stress-horisontal displacement curves for Cape Flats sand with 10% plastic content of sizes 2.0mm (a), 4.75mm(b) and 5.6mm(c).

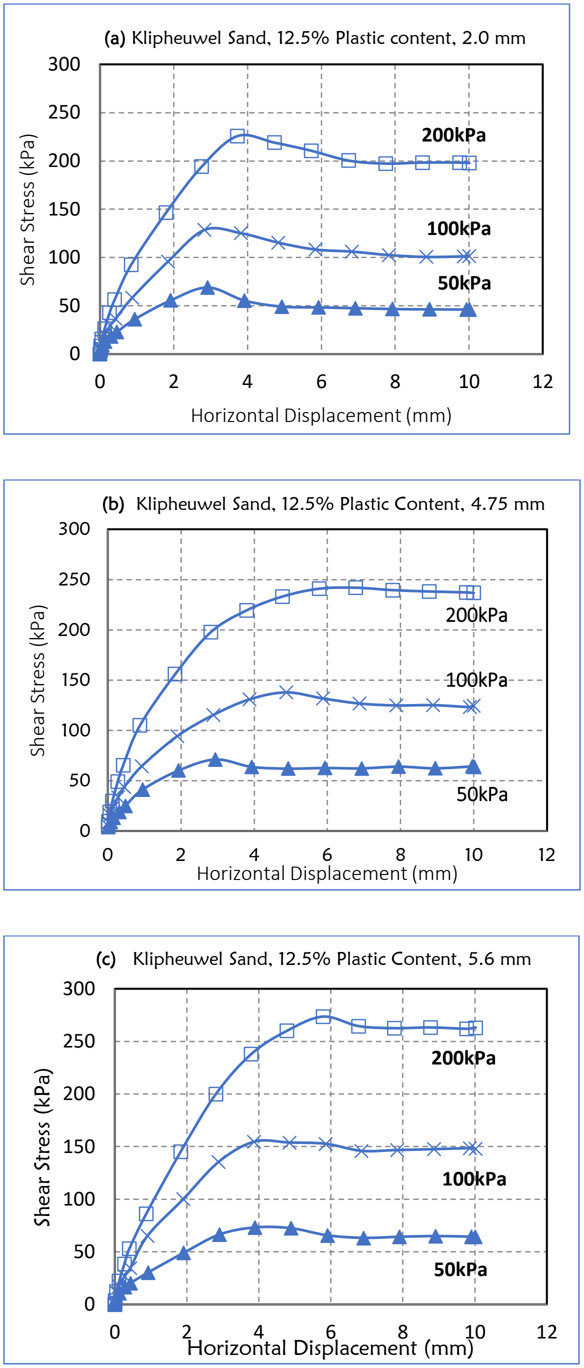

Figure 7. Shear stress – displacement curves for Klipheuwel with 12.5% of (a) 2.0mm, (b) 4.75mm and (c) 5.6mm Plastic content.

3.2 Cohesion and Friction Angle

The values of cohesion and friction angle for the different specimen in the direct shear tests were obtained from the stress-strain graphs by plotting the Mohr-Coloumb failure envelopes. The results for the soil-plastic composite specimen were then compared with the sand only specimen. The inclusion of the PET plastic chips to the Cape Flats and Klipheuwel sands at different plastic contents increased both the cohesion and angle of friction the soil. As shown in Figure 8 (a), addition of the 2.0 mm plastic shreds at contents of 10% and 12.5% in the gave a maximum cohesion value of 18.42 kPa and 20.43 kPa for Cape Flats and Klipheuwel sands respectively. The increases in friction angle for different plastic contents for the 2mm size plastic chips were up to 43.5° in Cape Flats sand and 46° in Klipheuwal sand.

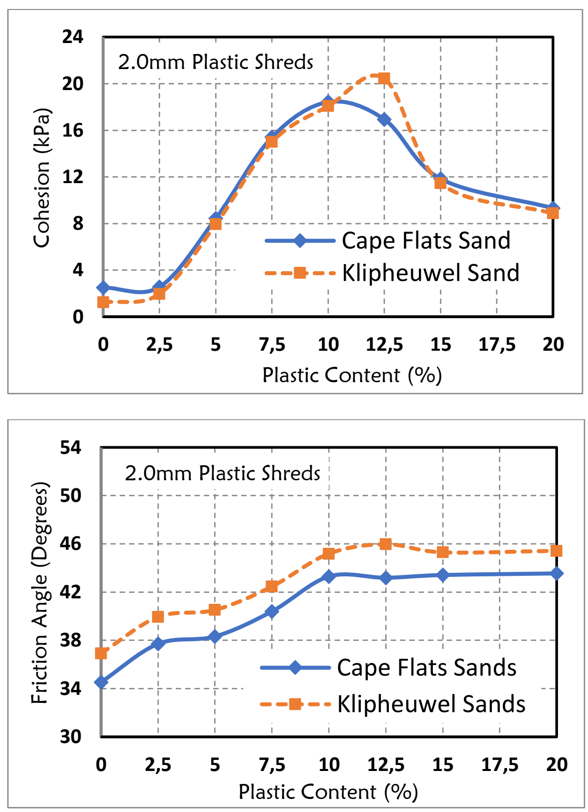

Figure 8. (a) Cohesion and (b) friction angle from 2.0 mm shreds Cape Flats Sand and Klipheuwel Sand

Inclusion of larger average diameter chips to the sand increased the friction angles of the sands, however, higher cohesion values were obtained for all plastic chip sizes at all plastic percentage contents. The highest value of friction angle obtained for the mixture of 4.75 mm plastic chips in Cape Flats sand was 45.2˚ at a plastic content of 10% and for Klipheuwal, the maximum value was 48.3 at 12.5 % plastic content (Figure 9). The highest cohesion values for the 4.75 mm sizes attained were 18 kPa and 19 kPa for Cape Flats sand and Klipheuwal sand respectively.

The results for addition of 5.6 mm plastic chip sizes in the sands are presented in Figure 10 (a) and (b). Increases in the plastic content for the 5.6 mm size chips resulted in progressive inmprovement in shear strength parameters up to optimum content of 10% for Cape Flats sand with maximum cohesion of 15.8 kPa and friction angle of 48.3º. The highest values of cohesion for Klipheuwel sand was 13.8 kPa and friction angle of 52.7º for a plastic content of 12.5%, indicating significant improvements in the shear strength of the sands on inclusion of the plastic material.

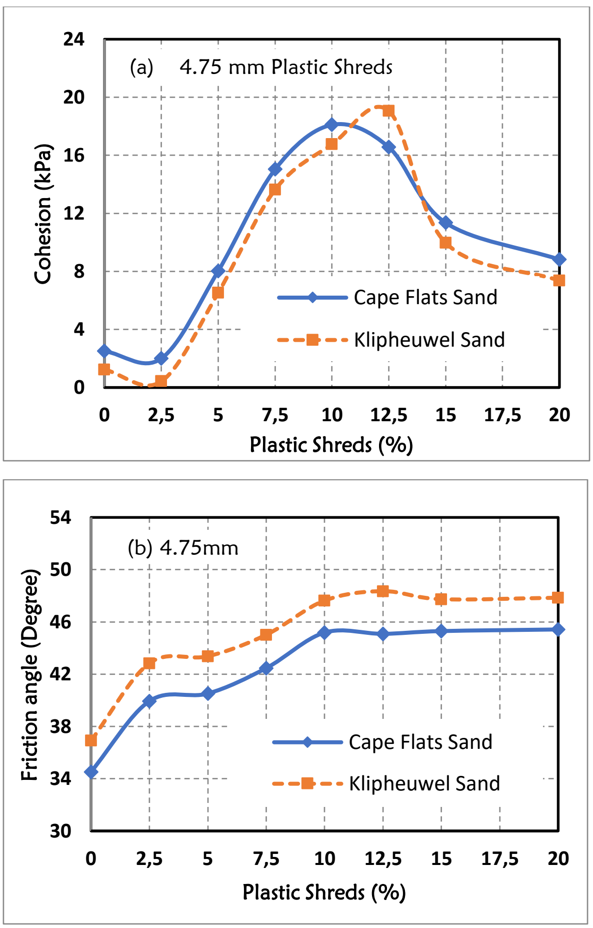

Figure 9 (a) Cohesion and (b) Friction angle for 4.75 mm shreds in Cape Flats Sand and Klipheuwel Sand

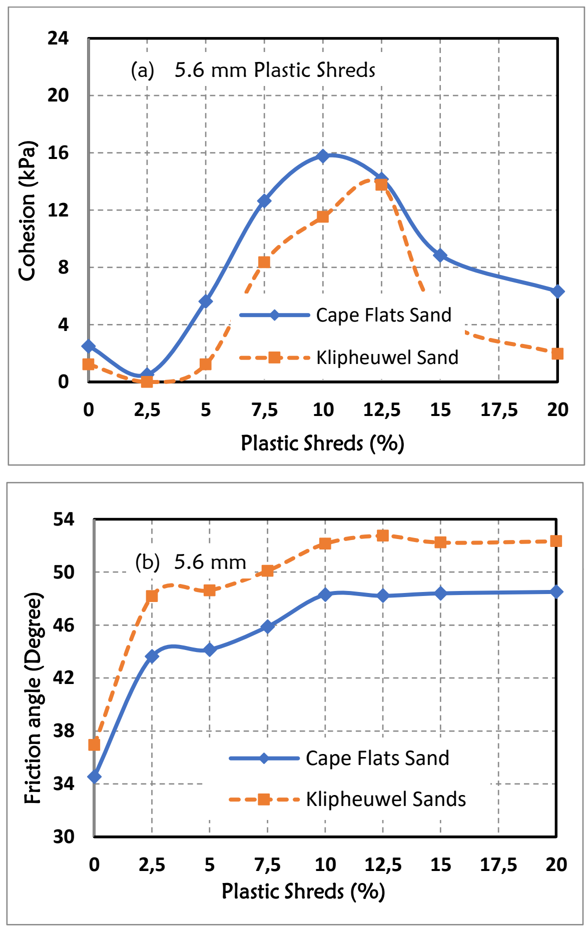

Figure 10 (a) Cohesion and (b) Friction angle for 5.6 mm shreds in Cape Flats Sand and Klipheuwel Sand

3.3 Results Comparison for different PET chip sizes

Figure 11 (a) and (b) shows comparisons of the increases in angle of internal friction for all plastic contents in both Cape Flats and Klipheuwel sands. A plastic content of 10% for the 5.6 mm chips size was observed as the optimum for the angle of internal friction of Cape Flats sand as indicated in Figure 11 (a). The friction angle of Klipheuwel sand improved progressively up to a plastic content of 12.5% for both 4.75 mm and 5.6 mm sizes (Figure 11b).

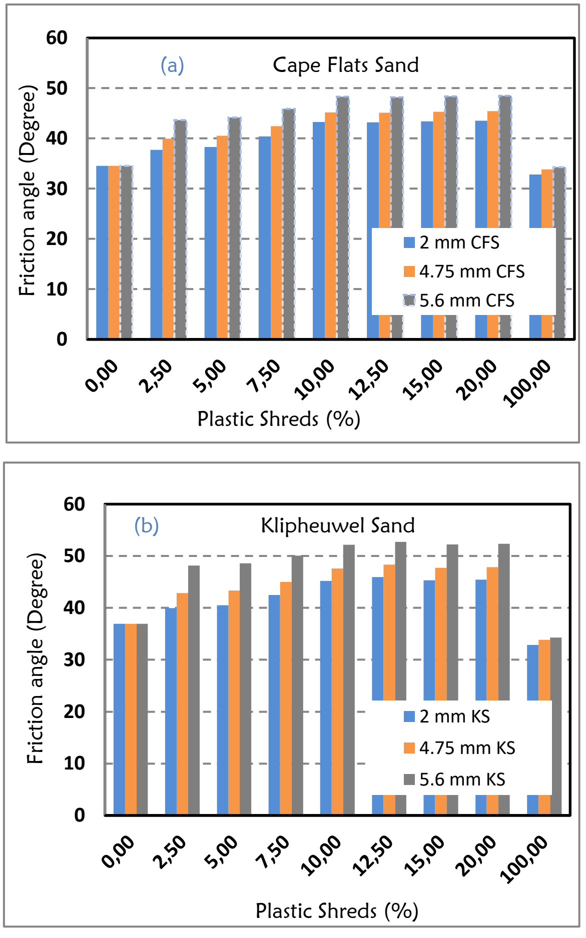

Figure 11. Comparison results for the different plastic shred sizes on (a) Cape Flats sand (b) Klipheuwel sand.

4 CONCLUSIONS

A series of direct shear tests were conducted on soil-plastic composite specimen prepared using two sandy soils and random inclusions of chips obtained PET plastic bottle waste supplied by a local recycling factory. The influence of the plastic inclusions on the shear strength parameters of the soil was investigated by examining the effect of the plastic content and size of the plastic chips on the friction angle and cohesion of the sand. The chips were added to the soil samples at concentrations from 2.5%. to 20% by weight, and the plastic chip sizes were 2 mm, 4.75 mm and 5.6 mm. The test results from the 3 different PET plastic chip sizes mixed with sand generally showed that the angle of friction of sand improved on additions of the plastic chips up to an optimum content of 10% and 12.5% by dry mass for Cape Flats sand and Klipheuwal Sand respectively. The cohesion reached the maximum value for both sands at a content of 30% by dry mass of the soil.

The results from the study suggest a possibility of using recycled PET plastic waste as reinforcement material to improve strength properties of soils in geotechnical works. Further studies into the use of the material for soil reinforcement will provide more information on the behaviour of sand-plastic composites including;

- Chemical tests on plastic chips for potential leaching into the ground.
- The effect of plastic chips longer than 5.6 mm to observe the maximum friction angle that can be achieved with the inclusions.
- Larger scale tests on a wider range of course grained soils to broaden the understanding on the engineering properties of the composite material.

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