Utilisation of polyethylene (plastic) shopping bags waste for soil improvement in sandy soils

Utilisation des déchets de sacs en polyéthylène (plastiques) pour l'amélioration des sols sableux

Kalumba D., Chebet F.C.
University of Cape Town, South Africa

ABSTRACT: This study investigated the possibility of utilising polytheylene shopping bags waste to reinforce soils to pave way for its use in civil engineering projects such as in road bases, embankments and slope stabilisation. A series of direct shear tests was undertaken on soil-plastic composites of two selected sandy soils: Klipheuwel and Cape Flats sands. Strips of shredded plastic material were used as reinforcement inclusions at concentrations of up to 0.3% by weight. The effect of varying dimensions of the strips was investigated by using strip lengths from 15 mm to 45 mm and strip widths from 6 mm to 18 mm. Shear strength parameters were obtained for composite specimen from which analyses were done to identify the extent of soil improvement. The testing programme involved addition of solid strips as well as perforated strips with varied diameter of perforations to examine the effect of the openings on the strips. Laboratory results obtained favourably suggest that inclusion of this material in sandy soils would be effective for ground improvement in geotechnical engineering.

RÉSUMÉ : Cette étude a examiné la possibilité de l'utilisation des déchets des sacs d'épicerie en polyéthylène pour renforcer les sols afin de promouvoir son intégration dans les projets de génie civil tels que les couches d'assise des routes, les remblais et la stabilité des pentes. Une série d'essais de cisaillement direct a été réalisée sur des composites plastique-sols sur deux sols sableux sélectionnés : sable de Klipheuwel et de Cape Flats. Des lamelles de matériau plastique déchiqueté ont été utilisées comme intrants de renforcement à des concentrations allant jusqu'à 0,3% du poids. L'effet de la variation des dimensions des lamelles a été apprécié en modifiant leurs longueurs de 15 à 45 mm et leurs largeurs de 6 à 18 mm. Les paramètres de la résistance au cisaillement obtenus pour les spécimens de composites ont servi à faire des analyses pour l'estimation du degré d'amélioration des sols. Le procédé scientifique a été fait avec des lamelles pleines et des lamelles perforées à divers diamètres afin d'observer l'effet des interstices dans les lamelles perforées. Les résultats de laboratoire obtenus confirment favorablement que l'ajout de ce matériau dans les sols sableux serait efficace pour l'amélioration des sols dans les applications d'ingénierie géotechnique.

KEYWORDS: Plastic bags, Polyethylene, Waste minimisation, Soil reinforcement, Ground improvement, Shear strength

1 INTRODUCTION

Increased use of plastics in day to day consumer applications has resulted in municipal solid waste containing an ever growing fraction of plastic material used for a short time and discarded. Ever since their invention over 60 years ago, plastics have taken centre stage in daily life due to favourable attributes such as low weight, durability and lower cost as compared to other material types (Thompson et al. 2009, Andrady and Neal 2009). These attributes make plastics convenient and therefore highly demanded by consumers with production increasing substantially from about 0.5 million tonnes in 1950 to over 260 million tonnes by 2008 with higher projections expected in the future (Thompson et al. 2009). A large percentage of plastics produced are used for disposable applications like packaging and therefore reach the waste stream more quickly since their usage life is shorter than that of plastics used in the construction or automotive industry (Azapagic et al. 2003). Consequently about 10% by weight and 20% by volume of the municipal waste stream is composed of plastics destined for landfills (Barnes et al. 2009, Azapagic et al., 2003). Of the plastic material discarded, 50% is from packaging, a third of which consists of plastic shopping bags (Nhamo 2008).

Plastic shopping bags are water resistant materials mostly made of polyethylene, a non-biodegradable polymer produced from non-renewable petroleum and natural gas resources. The linear consumption patterns of plastic bags involving single usage and then disposal has led to environmental challenges such as diminishing landfill space, marine and urban littering. There is therefore a growing need to find alternative uses of reclaimed plastic bag waste to lengthen the usage time of the plastic material. This is so as to tap into the abundant plastic resource that possesses a great extent of versatility and yet in the same vein poses a danger to the environment if not well managed in terms of responsible disposal that involves resource recovery vital in contributing to sustainable development.

Chen et al. (2011) maintain that new approaches on the reuse of plastic waste in cities as alternative materials for urban developmental programs, referred to as urban symbiosis, could help reduce green house gas emissions and fossil fuel consumption. This study explored the possibility of utilising reclaimed plastic material from polyethylene bags as tensile inclusions to reinforce soil for ground improvement schemes in geotechnical engineering applications such as retaining walls, road bases, embankments and slope stabilisation.

Research into random inclusion of discrete polypropylene fibres in soil as reinforcement material have reported increases in peak shear strengths and reductions of post peak losses in soils (Zornberg 2002, Consoli *et al*., 2007, Falorca and Pinto 2011). Furthermore, these fibres have been found to improve compressive strength and ductility of soils (Maher and Ho 1994, Santoni *et al*., 2001, Miller and Rifai 2004). As a result, fibre reinforced soil consisting of polypropylene fibres have been successfully used on embankment slopes in the US (Gregory and Chill 1998) and in applications such as foundations for sport pitches, horse racing tracks and access for secondary roadways (Ibraim and Fourmont 2006).

The main objective of this study was therefore to investigate the effect of including plastic strips from polyethylene shopping bags on the shear strength of two locally sourced sandy soils. Additionally, perforations were introduced on selected strips to examine if increased bonding and interlocking of soil in the soil-plastic composite through the openings in the plastic material provided an additional effect on the shear strength parameters of the soil-plastic composite.

2 MATERIALS AND METHODS

2.1 *Soil Material*

The soil types used in the study were Cape Flats sand and Klipheuwel sand, both predominant in the region of Cape Town, South Africa. Cape Flats sand is a medium dense, light grey, clean quartz sand with round shaped particles while Klipheuwel sand is a medium dense, reddish brown sand with angular particles. Table 1 gives a summary of the physical properties of the sands.

Table 1. Engineering properties of the selected soils.

Soil Property	Cape Flats Sand	Klipheuwel Sands
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

2.2 *Plastic Material*

The plastic bags (Figure 1a) were sourced from a local supermarket and shredded into strips of varying lengths and widths using a laser cutting machine. The bags were labeled as high density polyethylene (HDPE) according to the plastics identification code by the American Society of the Plastics Industry (SPI). The density was measured as 743 kg/m^3 with an average thickness of 40 μm and a tensile modulus of 389.7 MPa. The tensile strength obtained for the plastic material varied between 15 MPa and 20 MPa. Both the solid strips and perforated strips were included in the testing regime. For perforated strips, the laser cutting machine was used to make perforations of different diameters on the strips (Figure 1b).

Figure 1: a) Plastic Bag b) Shredded and perforated strips

2.3 *Experimental Work*

Soil samples for the tests were oven dried in order to eliminate any effects of moisture and the plastic strips mixed with the soil in a bowl to form a composite (Figure 2a). The plastic strips used were of lengths 15 mm, 30 mm, 45 mm, and widths of 6 mm, 12 mm, 18 mm. Perforations of diameter 1 mm and 2 mm were made on strips of width 6mm while their lengths varied. The strips were added to the soil at concentrations of 0.1% 0.2% and 0.3% by weight and the composite material placed into a 100 mm x 100 mm shear box for direct shear testing (Figure 2b). The specimen in the shear box was compacted to an average density of 1700 kg/m^3 and the tests performed for normal stresses of 25 kPa, 50 kPa, 100 kPa at a shear loading rate of 1.2 mm/min. The peak stress for each soil specimen was noted including the results obtained for the control experiment in which no strips were added to the soil.

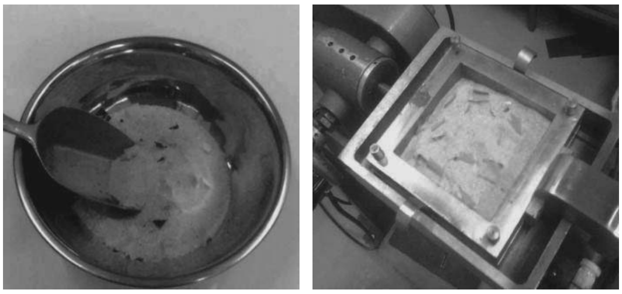

Figure 2: a) Soil-plastic composite b) Composite specimen placed in shear box for testing

3 RESULTS AND DISCUSSION

The peak shear stresses obtained from the direct shear tests were recorded and plotted against the respective applied normal stresses to determine the friction angles for each soil specimen tested. The results revealed a general increase in peak friction angles for both Klipheuwel and the Cape Flats sands on addition of both the solid and perforated plastic strips. The plastic parameters yielded a distinct effect on the soils as they were varied with both soils showing a unique response to each parameter. The relationship between the peak friction angle and the different strip variables of length, width, concentration and perforation diameter are presented in Figures 3 and 4.

3.1 *Solid Strips*

The results indicate that the peak friction angle for both Cape Flats and Klipheuwel sand is enhanced on addition of solid plastic strips (Figure 3a). An increase in friction angle from 38.5^o to 42.4^o was observed for the Cape Flats sand and from 41.6^o to 44^o in Klipheuwel sand. The higher values obtained for Klipheuwel sand was due to the better grading and thus giving a higher initial shear strength. The results reveal that maximum friction angles were obtained with 15 mm strips for Klipheuwel and 45 mm strips for Cape Flats sand. Therefore, there could be a limiting plastic strip length for the soil-plastic composite beyond which further lengthening results in a decrease in the shear strength on addition of the solid strips.

Further testing indicated that beyond the reinforcement width of 6 mm, the peak friction angle decreased which suggested that the soil strength decreases as the reinforcement strips widen (Figure 3b). This may be due to an increased interaction between the plastic strips caused by more overlapping for the case of wider strips in the test specimen resulting in reduced soil-plastic interaction in the composite.

An almost linear increase in the initial friction angle was observed for Cape Flats sand on increasing the strip content with a progressive improvement from 38.5^o at 0.1% to 42.4^o at 0.3% concentration (Figure 3c). Klipheuwel sand on the other hand responded with an increase on addition of 0.1% plastic and a decrease at higher concentrations. Higher plastic content seemed to affect the particle interlocking in the more angular shaped Klipheuwel sand resulting in a lower friction angle at greater strip concentrations.

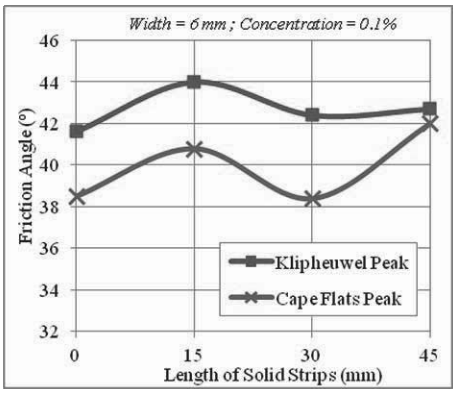

Figure 3a: Friction angle vs Solid strip length

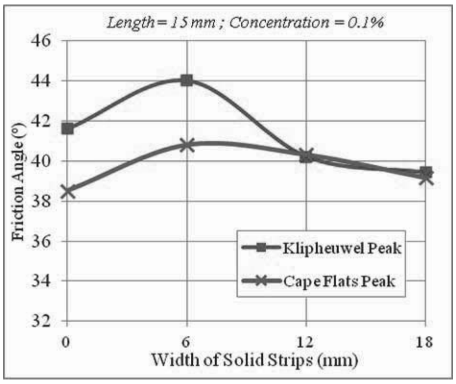

Figure 3b: Fiction angle vs. Width of solid strips

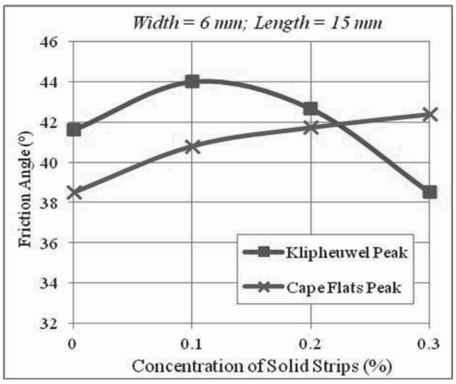

Figure 3c: Friction angle vs. Concentration of solid strips

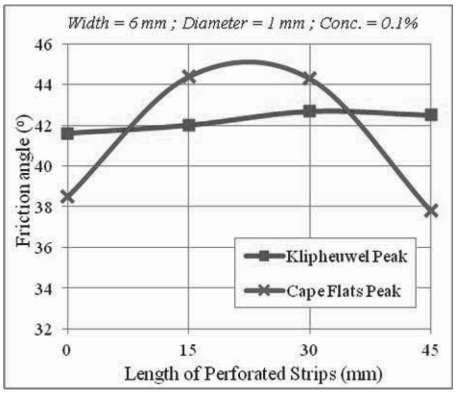

Figure 4a: Friction angle vs Perforated strip length

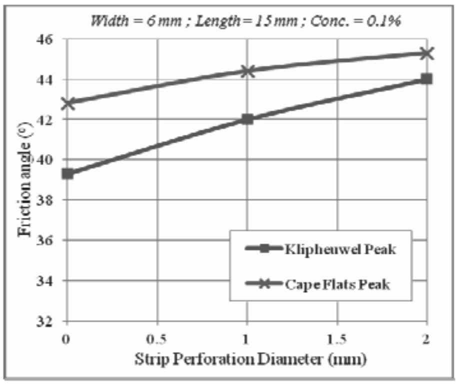

Figure 4b: Fiction angle vs. Perforation diameter

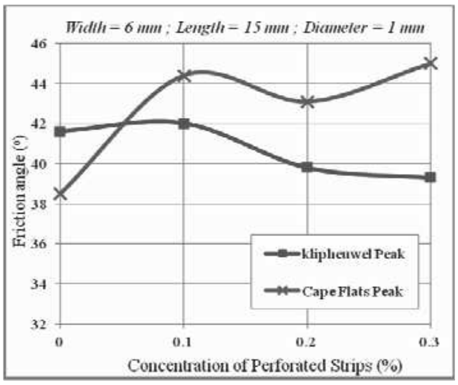

Figure 4c: Friction angle vs. Perforated strip concentration

3.2 *Perforated Strips*

Introducing perforations on the strips achieved higher friction angles with additional increases of 3.5% and 18.0% on inclusion of the perforated strips in Klipheuwel and Cape Flats sand respectively. This was represented by improvements from 41.6^o to 44^o for Klipheuwel sand and 38.5^o to 45.3^o for the Cape Flats sand (Figure 4a). The effect of varying the length of the perforated plastic strips was more significant in Cape Flats sand. Addition of the reinforcement generally had a bigger impact as regards improvement of the shear strength parameters for the more round shaped Cape Flats sand than for angular shaped Klipheuwel grains. This indicates an inherent requirement for reinforcement of the more poorly graded Cape Flats sand so as to enhance its strength properties.

Varying the strip perforation diameter provided an increase of up to 14.7% in Klipheuwel sand compared to using solid strips and for Cape flats sand a further increase of 8.5% was recorded (Figure 4b). This result indicated increases of 2^o for every additional mm in perforation diameter.

The improvement in friction angle with perforation diameter may be attributed to interaction between the soil and the plastic in the composite as well as better bonding and interlocking between the soil particles through the perforations in the plastic strips.

An increase in the peak friction angle from 38.5^o to 44.5^o for Cape Flats sand was obtained when perforated plastic strips were added to the soil at a 0.1% concentration as shown in Figure 4c. A concentration of 0.2% resulted in a slight decrease and a further increase in concentration to 0.3% provided a higher friction angle of 45.0^o. The pattern in Klipheuwel composites however indicated that addition of the perforated strips at a 0.1% concentration caused a slight improvement in friction angle but a decrease was observed for concentrations of 0.2% and 0.3%. This demonstrates that the influence of strip concentration could be soil specific due to the difference in soil properties like particle shape and size. Different soils would therefore require specific testing to determine the parameters particular to the soil type in order to obtain an optimal increase in the shear strength parameters on inclusion of the plastic strips.

3.3 *Deformation of Strips during Shear*

The plastic strips used in the composite specimen for the direct shear tests were assessed for physical deformations such as dents or rupture at the end of each experiment. The nature of deformations of the plastic strips was examined with respect to their location in the shear box. Visual inspections revealed that most of the elements that deformed were within or close to the shearing zone. The indentations on some of the strips may have been caused by soil particles as they pressed in to form surface attachments with the plastic strips (Figure 5a). This was mainly due to the particle shape and grading of the sandy soils used in the study that enhanced the frictional bonding between the soil and the plastic material. Other strips in the specimens were stretched and compressed due to the shearing action at or near the shear plane (Figure 5b). The stretched strips were located parallel to the shearing direction. This indicated that as the plastic strips were strained relative to the shearing direction, they improved the soil tensile strength by enabling transfer of forces arising from the loading conditions. None of the reinforcements in the composite were severely indented or ruptured during the shearing since the tensile strength of the plastic strips was greater than 15MPa compared to the generated shear forces in the test specimen under for a maximum applied normal stress of 100kPa.

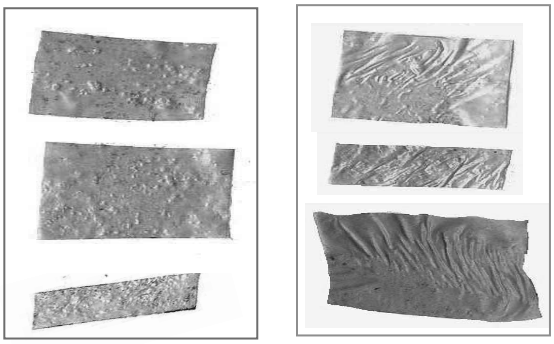

Figure 5 a): Dented Strips b) Stretched and Compressed Strips

4 CONCLUSION

A comprehensive laboratory direct shear testing programme was undertaken on composite specimens of sandy soils mixed with random inclusions of plastic strips obtained from high density polyethylene shopping bags. Two locally sourced soils, Klipheuwel and Cape Flats sands were selected for the research and the influence of plastic strips on the shear strength parameters of the sandy soils were studied. The effect of introducing perforations on the plastic strips was further examined. Parameters of the plastic strip inclusions such as length, width, concentration and diameter of perforations were varied to investigate the effect on the peak friction angle. The plastic strip lengths used in the study were 15 mm, 30 mm and 45 mm, strip widths 6 mm, 12 mm, 18 mm and perforation diameters of 1 mm and 2 mm made on the 6mm wide strips. The strips were added to the soil samples at concentrations of 0.1%, 0.2% and 0.3% by weight.

Results indicate an improvement in peak friction angle on addition of the solid strips and perforated strips of varied lengths and concentrations for the both sands. For the scope of experiments conducted, maximum values for the peak friction angles were obtained for strips of length 30 mm, concentration 0.1% and perforation diameter of 2 mm. Addition of perforations on the strips resulted in a further enhancement of the friction angle as compared to results obtained using specimens prepared with solid strips. An increase in the diameter of perforations resulted in higher values of friction angle at an average of 2^o for each mm in perforation diameter.

The laboratory results presented in the study favourably suggest the possibility of utilizing plastic material as tensile inclusions in sandy soil to increase the resistance to shear. As demonstrated in Chebet et al. 2012, the plastic inclusions can also improve the load bearing capacity and settlement characteristics of the sand. Additionally, introduction of perforations on the plastic material further aids in the interaction between the soil and plastic thereby boosting the soil's strength properties. However, a better understanding of the interaction mechanism in soils reinforced with the plastic material would be essential to properly document the engineering behaviour of the soil-plastic composite.

The influence of the soil physical properties, plastic properties and scale effects would need to be further investigated through more comprehensive testing in a wider range of stresses using larger scale tests to eliminate boundary effects. This could in turn contribute in the development of design methodologies for projects that may opt to incorporate this type of reinforcement material resulting in a reduction in project costs. Furthermore, successful application in the field could permit a reduction of plastic waste disposed of to landfills bringing along environmental benefits as a result of more efficient use of natural resources and reduction of CO_2 emissions.

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