

Geotechnical Application for Expanded Polystyrene Waste

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ABSTRACT

Expanded polystyrene (EPS) packaging consumes landfill space when discarded. Reusing this waste product would relieve landfill pressures and provide geotechnical benefits. Previous studies of waste materials for soil reinforcement highlighted the potential for EPS waste to be used similarly. EPS beads of varying diameters and concentrations were tested for their influence on friction angles and dry density of sandy soils. Results showed decreases in the friction angle under heavier loads with larger beads at higher concentrations. Lower concentrations of smaller beads affected soil strength minimally, allowing them to possibly be used in foundations. The inversely proportional ratio of weight to volume of EPS bulked up soils without increasing mass. The lower dry density of the composite made it viable for backfill soils. Should waste EPS be employed in fill and foundation soils, the amount of polystyrene destined to landfills would be reduced, alleviating the environmental burden of this type of plastic.

1. INTRODUCTION

With the rapid rate of globalisation and urbanisation, plastic has become predominant in everyday life as an inexpensive, convenient and reliable way of packaging goods. Consequently, it is one of largest contributors to pollution and landfill waste as it is often discarded after only one use. The waste issue is exacerbated by the chemical make-up of plastic products as a result of the manufacturing process, which renders it unbiodegradable (Wolchover, 2011). Large quantities of throw-away plastic products, such as grocery bags, are produced every year, 96 percent of which are destined for landfills (Ellis *et al*, 2005). These bags and other plastic items, such as polystyrene, can last for up to 1,000 years unaffected by microorganisms, taking up valuable space in the limited-capacity landfills (Adane & Muleta, 2011).

The pressures of inadequate waste management and resulting water and soil contamination, gas emissions, and over-full landfill sites (Shah, 2007) compound the environmental burden. Promoting the recycling of materials is critical to traditional waste management. With only a quarter of municipal solid waste being recycled worldwide, when a 350 percent increase in recycling and organic material recovery is required globally to make the waste industry environmentally efficient, this option is a long way from being feasible (Waste Management World, 2012). Combating the global waste issue requires innovative thinking and viable solutions.

Despite polystyrene being 100 percent recyclable, of the 44,500 tonnes of polystyrene products produced in South Africa in 2005, only 9 percent was recycled (Raubenheimer, 2009). Instead of filling up landfills and littering cities, this often single-use material could become a practical soil reinforcement solution within the construction industry. In this investigation, the option of material re-use was further explored by conducting studies on the use of beads of expanded polystyrene (EPS) waste in sandy soils to improve their geotechnical engineering properties.

2. POLYSTYRENE

2.1 Origin, Manufacturing and Applications of Polystyrene

Styrene is the liquid monomer derived from petroleum that, when polymerised, forms a solid, clear and rigid plastic called polystyrene. Two main types of polystyrene are produced depending on the polymerising process used. Extruded polystyrene (XPS or XEPS) is a strong, lightweight, smooth material generally blue in colour, used extensively for insulation. Blow moulding yields the more common white foamed, lightweight, odourless expanded polystyrene that was used in this study. A simple representation of the blow moulding process is displayed in Figure 1.

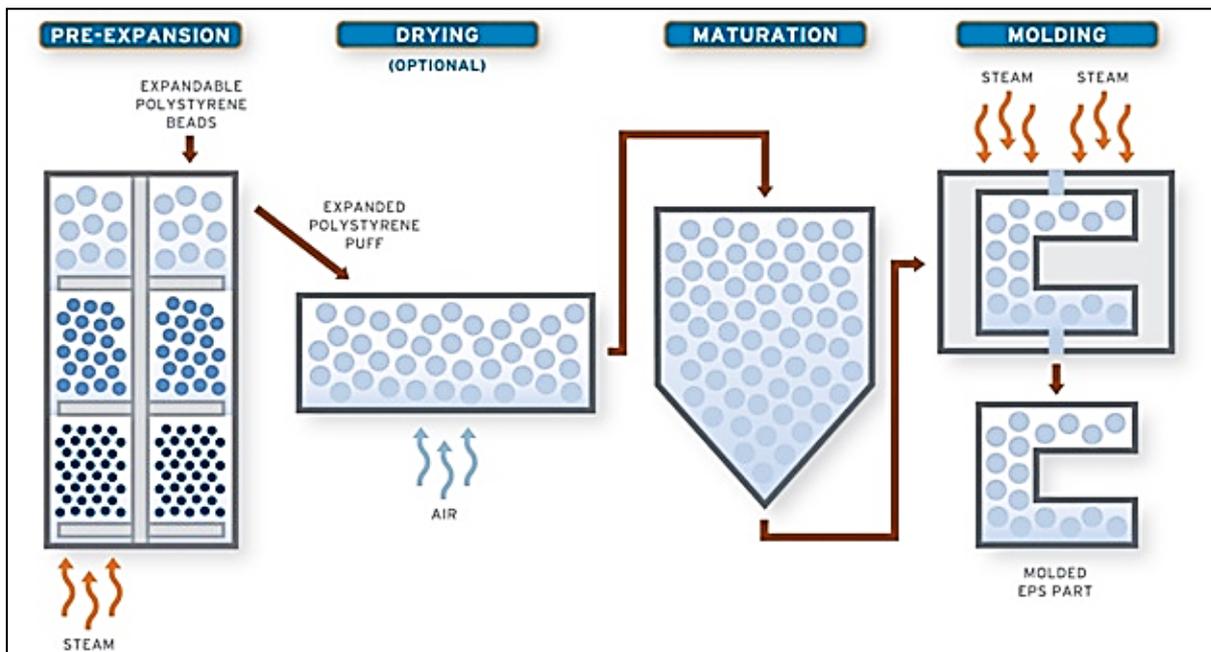


Figure 1: The process of manufacturing EPS (STYRO, 2012)

EPS products are used in multiple industries, including packaging, transport and construction among others, examples of which can be seen in Figure 2. EPS's inherent high energy absorption index makes it suitable for protecting fragile items such as food and electronics. Furthermore, its closed cell structure made up of 95-98 percent air, provides good thermal insulation by restricting the transmittance of heat or cold (EPS Packaging Group, 2012).



Figure 2: Examples of various EPS applications (Esko, 2014; Plotts, 2012; Suttmoller, 2013)

The lightweight, rigidity, compressive resistance, non-aging, and resistance to water of EPS are not only suitable for packaging but have been exploited in the construction industry as well. EPS has been used for bridge support, soil fill, gas ventilation, insulation, soundproofing, lateral force reduction, retaining structures, vibration dampening, decorative finishes and weight reduction of concrete slabs (Hanekom, 2013). EPS is so successful in the construction industry because it is inert to otherwise harmful materials such as cement, plaster and saltwater (EPS Packaging Group, 2012).

2.2 Properties of Polystyrene

Polystyrene is a chemically inert material, but it does dissolve in some organic solvents that contain acetone. Extended exposure to the sun results in photo-oxidation, degrading the material by weakening the Van der Waals forces between polymer chains (Deshpande, 2013). The physical and mechanical properties of general purpose polystyrene are tabulated in Table 1 below.

Table 1: Properties of general purpose polystyrene (Deshpande, 2013)

PHYSICAL PROPERTIES		
Property	Unit	Value
Specific Gravity	g/cm ³	1.03-1.06
Apparent Density	g/cm ³	0.6-0.65
Water Absorption	%	0.03-0.1
MECHANICAL PROPERTIES		
Young's Modulus	MPa	3000-3600
Tensile Strength	MPa	30-60
Tensile Elongation	%	1.0-5.0
Shear Modulus	MPa	1400
Flexural Modulus	MPa	3200

2.3 Methods of Reducing and Recycling Polystyrene

The movement to ban the use of expanded polystyrene in certain cities has had varied results. San Francisco has managed a 36 percent reduction in EPS litter as a result of this enforcement, whereas New York City is having to justify the \$91.3 million per annum cost to businesses and consumers by way of higher priced alternatives (American Chemistry Council, 2013). China lifted its ban on 'white pollution' in May 2013 due to maladministration of enforcement and a push by lobbyists to improve recycling management and technology instead (Kao, 2013).

Although polystyrene in all forms is 100 percent recyclable, it can be uneconomical as a result of its high volume-to-weight ratio and 96 percent air content, making it inefficient to transport and yielding minimal plastic outcome (Plotts, 2012). Efficient waste management and recycling of any material is a challenge faced by developing countries such as South Africa (Nahman, 2010). By finding alternative ways of minimising environmentally detrimental and visible waste, the pressure on waste management systems could be eased. The testing of the effect of EPS on the geotechnical properties of sandy soils aimed to find a viable method of reducing the plastic waste.

3. RESEARCH MATERIALS AND METHODS

3.1 Expanded Polystyrene

The EPS material used in this study was obtained from a discarded geyser, and ranged in size and shape. Three diameters of approximately 2.065 mm, 3.407 mm and 4.772 mm (labelled D2, D3 and D4 respectively, Figure 3) were sieved from the batch as variables for the study to determine the possibility of an optimum size, and the effect on shear strength. The respective EPS bead diameters were found to have densities of 73.7 kg/m³, 33.8 kg/m³ and 25.0 kg/m³. The bigger EPS beads have lower densities due to the volume of the larger particles being made up of more air.

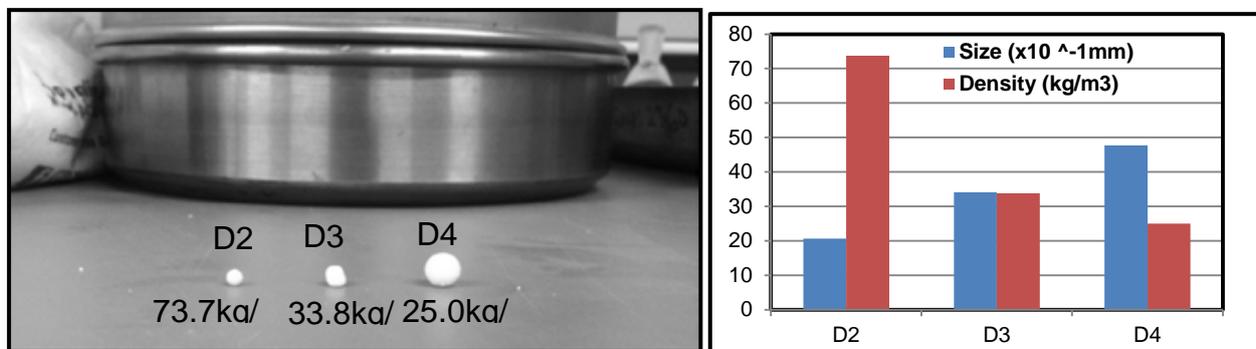


Figure 3: D2, D3 and D4 EPS bead sizes used and respective densities

3.2 Selected Soil Material

The locally available Klipheuwel and Cape Flats sands were particularly used for testing as they provided two similar mediums with which to compare results and assess more thoroughly the potential of the soil reinforcement technique. The consistency of the sands produced repeatable results, verifying the outcomes. The mechanical properties of the sands were determined in accordance with BS 1377:1990, where Klipheuwel sand was found to be uniformly graded, medium dense and reddish-brown in colour and Cape Flats sand was considered a medium dense, light grey quartz sand. Further properties found are tabulated in Table 2 below.

Table 2: Mechanical properties of Cape Flats and Klipheuwel sands

Characteristics	Unit	Cape Flats Sand	Klipheuwel Sand
Specific Gravity, G_s	Mg/m ³	2.50	2.59
Natural Moisture Content	%	3.09	3.65
Average Densest Dry Density	kg/m ³	1728	1801
Average Loose Dry Density	kg/m ³	1620	1692
Optimum Moisture Content (Proctor)	%	13.9	7.8
Maximum Dry Density* (Proctor)	kg/m ³	1601	1805
Particle Range	mm	0.063-1.18	0.063-2.00
Mean Grain Size, D_{50}	mm	0.29	0.24
Coefficient of Uniformity, C_u	-	2.07	2.15
Coefficient of Curvature, C_c	-	1.04	1.10
Angle of Friction, ϕ' (Peak)*	degrees	40.5	39.0
Apparent Cohesion, c' (Peak)*	kN/m ²	0	5.0

*Determined using drained direct shear tests

3.3 Methodology

In order to eliminate the influence of moisture in the soil samples, the sands were first dried in an oven at 105°C for 24 hours, cooled and stored in airtight containers. The EPS beads were sieved, as shown in Figure 4, obtaining three sample diameters of approximately 2.065 mm, 3.407 mm and 4.772 mm. In this way, the effect of different diameters on the shear strength of the soil could be assessed. The consequence of the concentration of EPS beads was also investigated by weighing out samples of respective diameter beads as a proportion of the soil mass and testing the composite samples (Figure 5a). The limited volume of the shear box and lightweight nature of the EPS beads resulted in concentrations of 0.1, 0.2, 0.3 and 0.5 percent by soil mass being tested. The effect of normal load, a third variable, was also examined by testing samples under pressures of 25, 50 and 100 kPa in order to assess the possible peaking of the shear stresses of the EPS-sand samples compared to plain sand.

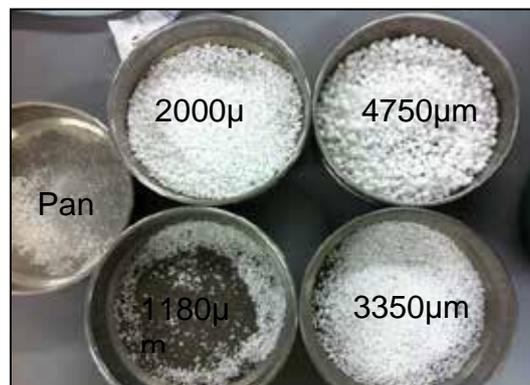
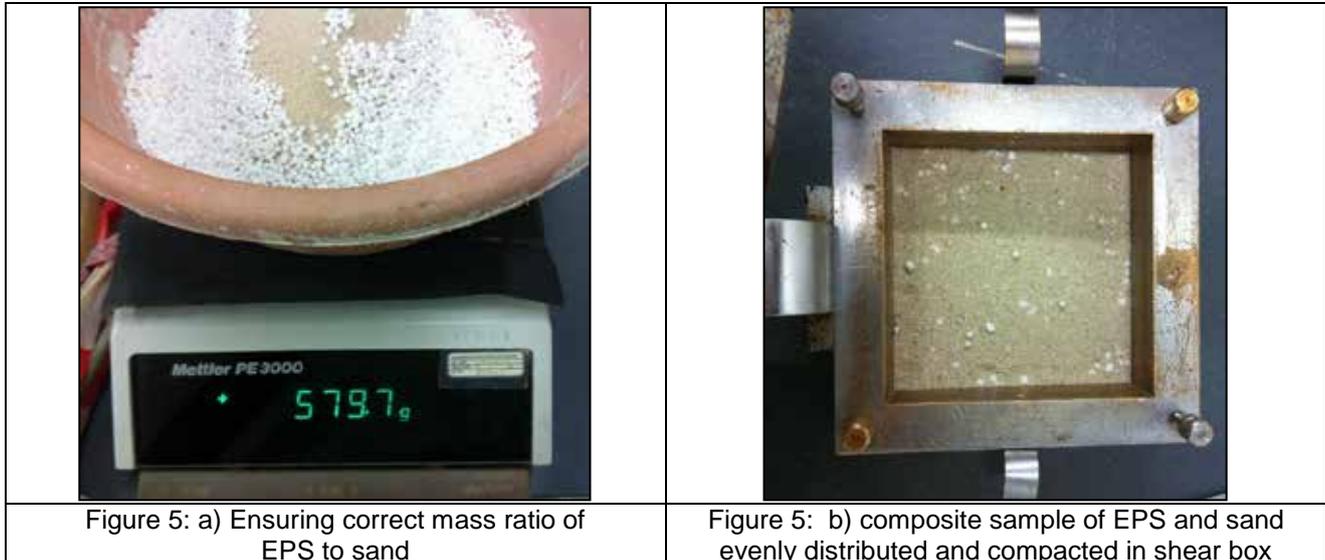


Figure 4: Sieves used for separating EPS beads into required diameters

Each combination of sand and EPS was thoroughly mixed and poured into the 100 mm square Wykeham-Farrance SB1 shear box apparatus in three compacted layers of approximately 1 cm (Figure 5b) using a 10 cm square steel tamper. The method outlined in the British Standards 1377-7: 1990 was followed by applying strain at a constant rate of 1.2 mm/min. The peak and residual shear strength of each sample was then determined under each normal pressure using the readings taken every 10 seconds from the dial gauge on the shear box apparatus.



4. TEST RESULTS AND DISCUSSION

Values recorded of the peak shear strength of the composite samples were plotted against the normal pressures of 25, 50 and 100 kPa under which they were tested. From these graphs the friction angles for each sample were determined and plotted against the varying concentration and size EPS reinforcement parameters. Details of the results from this study were presented by Donald (2013).

4.1 Effect of EPS Diameter on the Friction Angle

The angles of internal friction plotted against EPS diameters in Figure 6 and Figure 7, for the Cape Flats and Klipheuwel sands, show a clear downward trend. The unreinforced samples of the respective sands achieved internal angles of friction of 40.5° and 39°. Analysing the graphs, it is clear that the D2 EPS beads at 0.1 and 0.2 percent concentrations for the Klipheuwel and Cape Flats sand had marginal effects of less than 2 percent decrease on the angles of internal friction. As the diameter of beads increased to D3 and D4, all samples of varying concentrations showed a more substantial decrease in angle as compared to the sand-sand samples. The combination of the largest diameter beads at the highest concentration showed the most significant decline in strength, reducing the angle of the Klipheuwel sand by 14 percent to 33.0° and Cape Flats sand by 22 percent to 31.5° from 40.5° and 39° respectively.

This phenomenon could be attributed to the fact that an increase in particle angularity increases soil shear resistance (Crum, 1989), making the converse true in that EPS is a less angular material than the sand. Thus, when added in higher concentrations, the EPS beads reduced the natural frictional resistance between the sand particles.

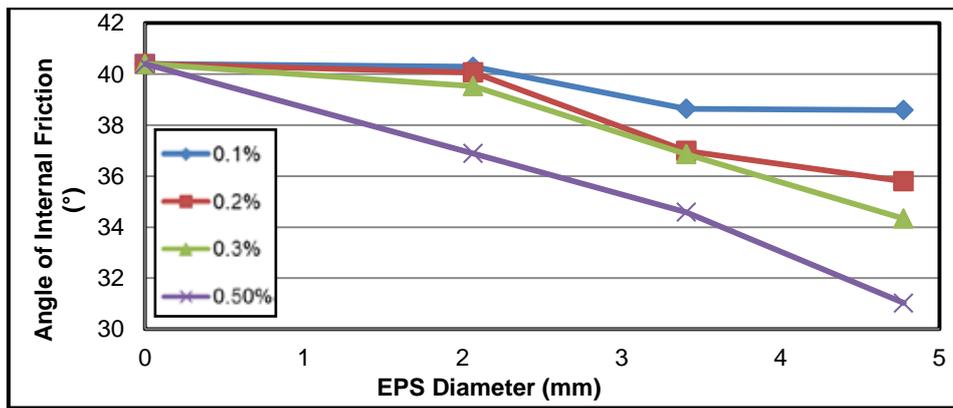


Figure 5: The angle of internal friction vs EPS diameter for Cape Flats sand

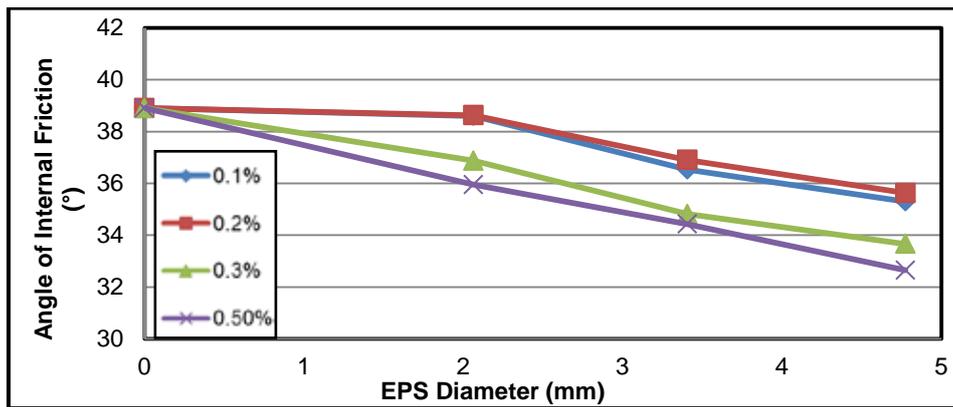


Figure 6: The angle of internal friction vs EPS diameter for Klipheuwel sand

4.2 Effect of EPS Concentration on the Friction Angle

By assessing the influence of the concentration on the angle of internal friction, the effect of EPS on the soils' characteristics was further understood. From Figure 8 and Figure 9, the addition of D2 EPS beads at 0.1 and 0.2 percent for Klipheuwel and Cape Flats sands once more resulted in minor decreases (less than 2 percent) of the internal angles of friction. Larger concentrations, however, indicated more significant reductions once again.

In the Cape Flats sand, the D3 and D4 diameter beads showed the same initial decrease in angle at a concentration of 0.1 percent. However, the two curves diverged when the concentration was increased to 0.2 percent, with D4 beads resulting in a sharper decline in angle. Increasing the concentrations to 0.3 and 0.5 percent continued the general decrease for all three diameters, with D4 beads at 0.5 percent dropping the angle of internal friction for plain Cape Flats sand from 40° to 31°, or by 22.0 percent.

The curves displayed in Figure 9 for Klipheuwel sand show a similar trend to those for the Cape Flats sand. It was evident that the D2 EPS beads, as opposed to the D3 and D4 beads, had little effect on the angle of internal friction when used at concentrations of 0.1 and 0.2 percent. All other data points indicated a decrease in the angle of internal friction from that obtained for the Klipheuwel sand-sand sample. The D4 beads decreased the angle of friction the most as higher concentrations were added. The largest percentage reduction of angle of internal friction from the sand-sand sample was 14 percent, from 39° to 33°.

Plotted against concentration, the angle of internal friction was seen to reduce more quickly for the larger diameters of EPS. This was because the larger, smoother EPS beads did not bond well with the soil samples, replacing the shear resistance between sand particles per unit volume, thus affecting the angle of internal friction (Crum, 1989).

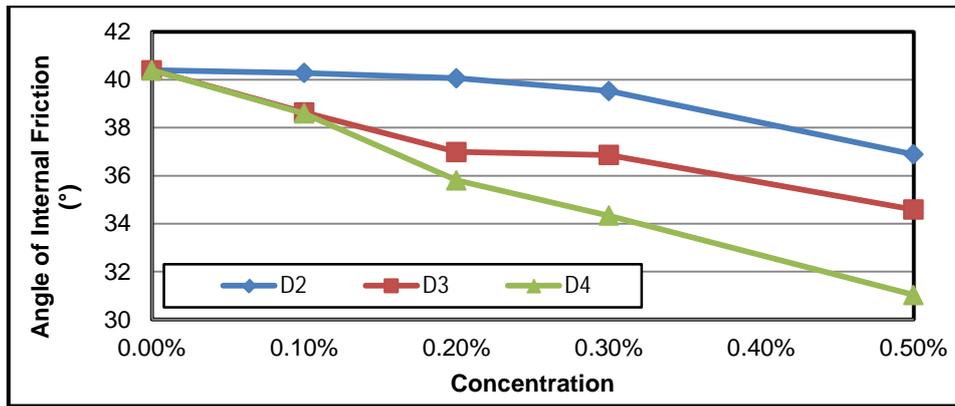


Figure 7: Angle of internal friction vs concentration for Cape Flats sand

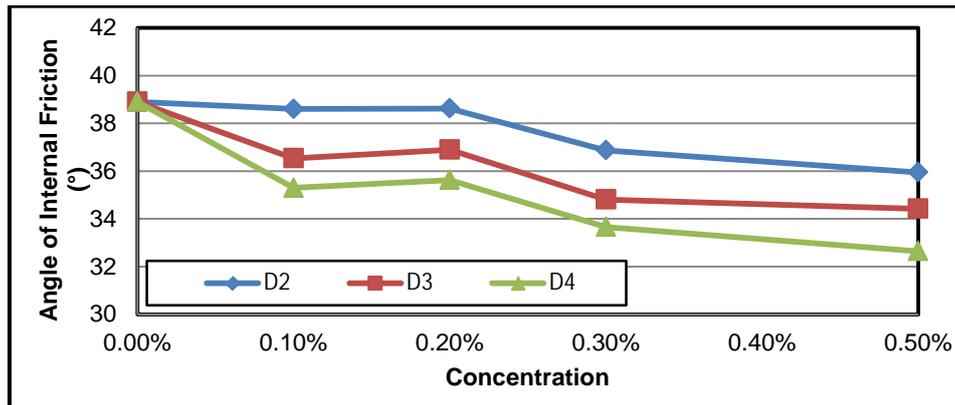


Figure 8: Angle of internal friction vs concentration for Klipheuwel sand

4.3 Effect of EPS on Dry Density

As the experiments were conducted, the densities of the composites were determined. The shaded region in Figure 10 highlights the densest and loosest states of the sand-sand samples and shows that an increase in the diameter of the beads used in the soil reduced the sands' dry densities to below their loosest conditions. This result was supported by the linear relationship which shows that an increase in concentration of EPS beads also decreased the dry density of the samples tested.

It was also noted that, although the natural dry density of the Cape Flats sand was lower than that of the Klipheuwel sand, the EPS decreased the dry density by similar amounts. The maximum percentage decrease in dry density for the Cape Flats sand was 32 percent and 33 percent for the Klipheuwel sand.

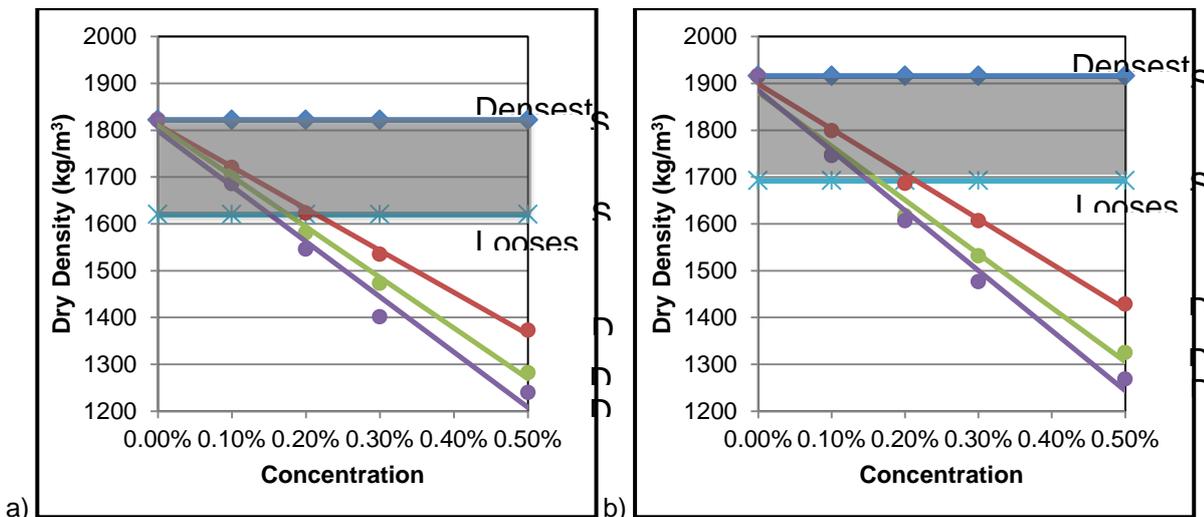


Figure 9: The dry density vs the concentration of EPS inclusions of a) Cape Flats and b) Klipheuwel sands

The results displayed for the dry density versus diameter and concentration is clearly explained by the nature of the reinforcement material being included. Expanded polystyrene is an extremely lightweight material that consists predominantly of voids. As a result of the manufacturing process, larger diameter EPS beads contain more blowing agent, thus larger voids, than those with smaller diameters, making them lighter than the larger ones.

When comparing EPS to the soil materials used, the relative densities were very different. The EPS used in these experiments had densities of 73.7, 33.8 and 24.9 kg/m³ for the D2, D3 and D4 diameters respectively. Whereas the average loosest densities of the Cape Flats and Klipheuwel sands were 1,619 and 1,692 kg/m³, each with particle sizes no larger than 2 mm. By including EPS of different diameters at different concentrations, the polystyrene's size bulked up the soil sample and increased its volume, despite the mass remaining constant. The higher the concentration and larger the diameter of the EPS used, the greater the effect on the soil volume, and the lower the dry density became.

5. APPLICATIONS

Finding an alternative use for expanded polystyrene waste in the construction industry, particularly in the soil improvement sector, is a viable and efficient way of reducing litter and landfill volumes. The material's inert nature means it is not harmful to ground conditions and its longevity, although a problem in landfills and as litter, would be adequately suited to the long life required of contemporary infrastructure. EPS is also widely available, manufactured in South Africa and, if obtained as a waste product, extremely economical.

Unfortunately, the material, when used in beaded form at high concentrations, was detrimental to the shear strength of sandy soils. However, the use of EPS in fill soils, used for embankments and behind retaining walls, is a viable alternative. As polystyrene is lightweight it would add very little to the soil's mass but would increase its volume significantly. Thus, an ideal use of expanded polystyrene waste would be to include it in fill material. The polystyrene itself is non-toxic and would not leach harmful chemicals into the soil, allowing plants to thrive as they would otherwise. Furthermore, EPS is resistant to water and could improve the drainage capabilities of the soil, as well as reduce the risk of erosion.

6. SUMMARY AND CONCLUSIONS

This study looked into the effect of expanded polystyrene beads on the shear strength of sandy soils. Thorough testing was completed on two types of locally available sands by interspersing them with different concentrations of various size EPS beads as a means of reinforcement. Concentrations of 0.1, 0.2, 0.3 and 0.5 percent were tested in conjunction with average bead diameters of 2.065 mm, 3.407 mm and 4.772 mm in order to determine the possibility of an optimum combination. By conducting shear box tests on each sample, the shear parameters of the composites were determined and analysed.

Having compared the angle of internal friction to the different concentrations of EPS inclusions, it was evident that there was little effect when D2 beads were used at 0.1, 0.2 and 0.3 percent in Cape Flats and Klipheuwel sands. The deviations in angle from the plain sand samples were slight for all three concentrations tested, although shear strength was affected the least at 0.1 percent. Thus EPS beads of approximately 2 mm mixed at a mass ratio of 0.1 percent with Cape Flats and Kliphuewel sands yielded the best possible results.

The dry density of the samples was progressively decreased with the presence of EPS at higher concentrations and larger diameters. The significance of this outcome was that although the inclusion of EPS did not improve shear strengths, it could still be used to increase the volume of the soil when required. The density of the pure sand samples was found to be approximately 1,822 kg/m³ and was reduced by 32 percent to 1,239 kg/m³ for the Cape Flats sand with D4 EPS beads at a concentration of 0.5 percent. The Klipheuwel sand showed a similar decrease in dry density of 33 percent from 1,916 kg/m³ for the sand-sand sample, to 1,268 kg/m³ for the sand-polystyrene sample of D4 beads at 0.5 percent concentration.

It is recommended that further studies of this nature be completed using different soils and EPS variables in order to gain further insight into the effect EPS has on shear strength and drainage. Should results be promising, expanded polystyrene waste could be effectively reduced through use in the construction industry, alleviating the pressures on landfill space considerably.

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