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INVESTIGATION ON RE-USING POLYETHYLENE (PLASTIC) BAG WASTE MATERIAL FOR SOIL REINFORCEMENT IN GEOTECHNICAL ENGINEERING

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Abstract: This paper presents a laboratory investigation into the resultant increase in shear strength and bearing capacity of locally sourced sand due to random inclusion of strips of high density polyethylene material from plastic shopping bags. A series of direct shear tests was undertaken on soil-plastic composites of two selected sandy soils. 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. Soil strength parameters were obtained for composite specimen from which analyses were carried out to identify the extent of soil improvement. The results obtained favourably suggest that inclusion of this material in sandy soils would be effective for soil reinforcement in geotechnical engineering.

Keywords: *Plastic* bags, Polyethylene, Re-use and Recycling, Soil reinforcement, Ground improvement, Soil strength

I. Introduction

The widespread increase of single-use plastics in day to day consumer applications continues to contribute to an ever growing volume of plastic material in municipal solid waste generated across the world. These plastics are used for disposable applications and therefore reach the waste stream more quickly as their usage life is shorter than that of the plastics used in the construction or automotive industry. Landfills are thus continually being filled up by plastic material that has been used for only a short time with more than 50% of the discarded plastics coming from packaging applications, a third of which consists of plastic shopping bags. Manufactured from polyethylene, a non-biodegradable polymer, plastic shopping bags are inexpensive, lightweight, durable and water resistant which make them a convenient and reliable packaging material for consumers worldwide. Owing to the favourable attributes plastics possess compared to other material types, global utilisation of the plastic shopping bags has escalated and is estimated by the United Nations Environment Program (UNEP) at up to one trillion annually. Extensive use and linear consumption patterns whereby the plastic bags are mostly used once and then discarded has resulted in the generation of millions of tonnes of waste leading to environmental challenges such as diminishing landfill space for disposal and marine and urban littering.

A substantial increase in the production of plastic bags as a result of high consumer demand has been reported as from about 0.5 million tonnes in 1950 to over 260 million tonnes by 2008 with higher projections expected in the near future (Thompson et al., 2009). The raw material for production of the plastic bags being from non-renewable petroleum and natural gas resources, the current pattern of consumption of the plastic bags involving only single use and disposal has raised the question of efficient use of natural resources thus inspiring the modern day culture of recycling. However, while many communities have undertaken policies that encourage re-use, the success of any recycling program is ultimately dependent on a secondary market that will consume the reclaimed plastic materials (Benson and Khire, 1994). Large scale re-use of plastic bag waste is therefore essential to counter the production-disposal rate by lengthening the usage time of the plastic material in order to promote environmental sustainability. Chen et al. (2011) maintain that new approaches on the utilisation 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. Reinforcement of soil to improve its strength properties for civil engineering construction is a possible means to put to use the abundant plastic bag waste. This will tap into the plastic resource that possesses great 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 which is vital in contributing to sustainable development.

II. Research Materials and Sample Preparation

II.I. Soil Material

Krishna patnam Port sand collected from Andhra Pradesh and Ennore sand collected from Tamilnadu, were selected for the study. Ennoresand is a medium dense quartz sand with round shaped particles while Krishnapatnam Port sand is made up of angular shaped particles (Figure 1). Both sands were clean and consistent which ensured repeatability of results since identical samples could be reproduced.

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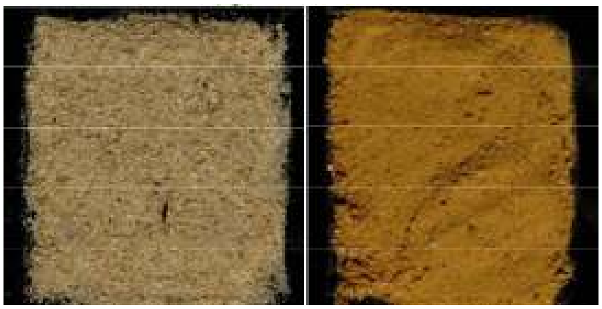


Fig. 1: a) Ennore Sand b) Krishna patnam Port Sand

Classification tests to characterise the sands and obtain the engineering properties presented in Table 1 were undertaken according to the Indian Standard, IS: 1498-1970. The sands were both classified using the IS Soil Classification System as poorly graded and contained little or no fines. Krishna patnam Port sand exhibited better grading with a greater range of particles than Ennore sand which had particles with more uniform grading. Sieve analysis of the sands yielded the particle size distribution curves shown in Fig. 2.

Table 1: Sand physical properties

Property	**Krishnapatnam Port Sand**	**EnnoreSand**
Specific Gravity	2.64	2.66
Natural Moisture content (%)	2.72	2.20
Optimum Mois ture Content (%)	6.7	15.0
Maximum Dry density (kg/m^3)	1985	1710
Particle Range (mm)	0.075-2.36	0.075-1.18
Angle of friction, ^{o}	41.6	38.5
Cohesion, kN/ m^2	4.8	8.4

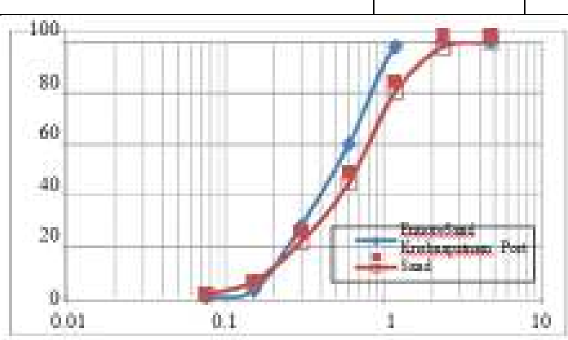


Fig. 2: Grading Curves for Krishnapatnam Port and Ennore sands

II.II. Plastic Material

Polyethylene consumer bags produced by DORA plastics, a manufacturer and distributor of plastic packaging products in Chittoor Dist, Andhra Pradesh were used to obtain the plastic material for the study.

Fig. 3 Plastic bags selected for the study

Tensile strength tests on the polyethylene were carried out using a universal tensile testing machine (Figure 4). A tensile modulus of 389.7 MPa was obtained from the test s while the tensile strength ranged between 15 MPa and 20 MPa. The density of the plastic bag material was measured to be 743 kg/m^3 with an average thickness of 40 µm.

Fig. 4: The universal testing machine used for tensile testing of polyethylene

II.III. Plastic Strips

Using a laser cutting machine, the plastic material was sliced into strips of distinct rectangular dimensions and mixed with the soils to form composite samples for which the soil tests were conducted (Figure 5).

Fig. 5: Randomly mixed sand-plastic composite for testing

2.3.1 Perforated Plastic Strips

Perforations of varied diameter were introduced on a portion of the strips added t o the soil in order to examine the effect of the holes in the reinforcement on the soil strength parameters. The laser cutting machine used to slice the plastic material was also used to make perforations of diameters 1 mm and 2 mm on strips of constant width with lengths of 15 mm, 30 mm and 45 mm (Fig. 6).

Fig. 6: Plastic strips with perforations

III. Experimental Investigation

A testing program consisting of direct shear tests was undertaken to determine the soil strength parameters of the soil-plastic composite and establish the effect of randomly including the plastic strips in the soil as compared with unreinforced soil. Solid strips and perforated strips of varied length and width were added to dried soil samples in varying concentrations. Soil samples were oven dried at 105º C for 24 hours to eliminate the effects of moisture. The influence of the different plastic parameters of length, width, concentration and perforation diameter on the soil shear strength properties was examined.

The laboratory programme consisted of 100 direct shear tests undertaken on composite samples of Ennore sand and Krishna patnam Port sand mixed with plastic strips. The strips were added at lengths of 15 mm, 30 mm, 45 mm, widths of 6 mm, 12 mm, 18 mm and concentrations of 0.1%, 0.2%, 0.3% by weight and each sample compacted into the shear box in 3 layers before testing. For the perforated strips, the widths were kept constant at 6mm and the perforation diameters of 1mm and 2mm. The tests in the study were all conducted according to the Indian Standard, IS2720 – Part13-1986, under normal pressures of 25 kPa, 50 kPa and 100 kPa at a strain rate of 1.2 mm/min applied using a drive unit, shearing the specimen horizontally until failure occurred. The resistance of the sample against the displacement was monitored using the proving ring from which the test data was read off and the peak stress recorded at the point when the value reached the maximum shear load. A plot of the shear load versus displacement was generated from the test data obtained.

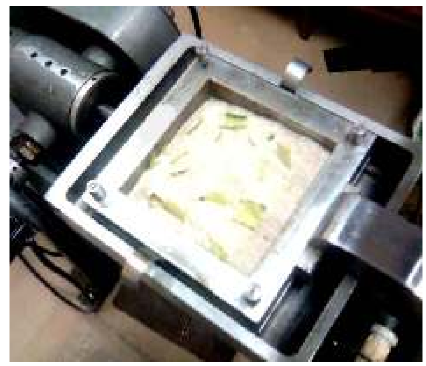


Fig. 7: Soil-plastic composite sample placed in shear box for strength testing

Peak shear stresses from each test were obtained for the respective applied normal stresses and the values plotted against the normal stresses to determine the angles of internal friction from the failure envelope for each composite specimen. The response of the soils reinforced with perforated strips was compared with soil mixed with solid strips. For assurance of repeatability, three similar soil-plastic composites were prepared, subjected to a normal pressure of 100 kPa and the results of the compared for consistency. The average peak stress from the three experiments obtained was 92.5kN/m^3 with a deviation of approximately 1.54kN/m^3. The three composites composed of randomly distributed reinforcing strip elements, attained results of the repeatability tests that indicated consistency and reliability in the testing process. The graphs based on the results from the tests on the reinforced specimens with different plastic parameters of length, width, concentration and perforation diameters are presented in Fig. 8a – 8f.

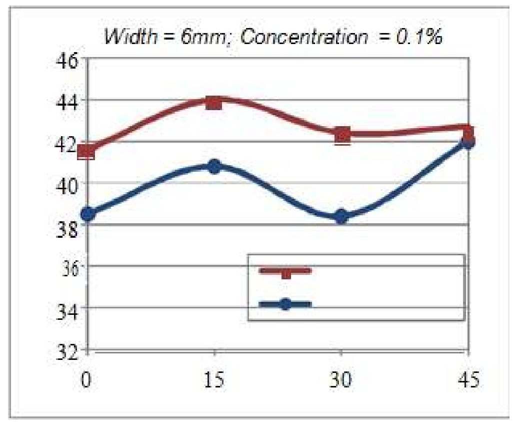
IV. Results and Discussion

The peak stresses of the composite specimen in the direct shear tests were recorded for respective applied normal stresses of 25 kPa, 50 kPa and 100 kPa from which relationships between the friction angle and the plastic parameters of length, width, concentration and perforation diameter were obtained (Fig 8). Analysis of the results revealed an immediate rise in the peak friction angles of the sands on addition of plastic strips with a notable increase from 38.5° to 41° in the Ennore sand and 41.6° to 44° for Krishna patnam Port sand. Increasing the strip lengths and keeping the width constant at 6mm resulted in a non-linear correlation with the friction angle with each of the sands exhibiting a unique response (Fig 8a). In the Ennore sand, the shear strength improved with increased strip length over specified lengths of 15 mm and 45 mm, while the Krishna patnam Port sand showed increases in friction angle peaking when the 15 mm long strips were used. On introduction of perforations in the strips, using lengths of 30 mm increased the peak friction angle for Krishna patnam Port sand from 41.6° to 42.7° and 38.5° to 45.3° for the Ennore sand, an increase of up to 3.5% and 18.0% respectively (Fig 8d). Inclusion of the plastic strips generally had a bigger impact as regards improvement of the shear strength parameters for the more round shaped Ennore sand than for angular shaped Krishna patnam Port sand. Furthermore, the results suggest that the effect of varying the length of the plastic strips was comparatively more significant in Ennore sand. On varying strip widths, results indicate that beyond a reinforcement width of 6 mm, the peak friction angle of the composite decreased (Fig 8c). Due to the smooth texture of the plastic material used, longer and wider strips resulted in more contact and overlapping of the plastic during shearing. The interface friction in the composite was thus increasingly between the plastic strip material leading to a reduction in the effective soil-plastic interaction and a resultant decrease in strength.

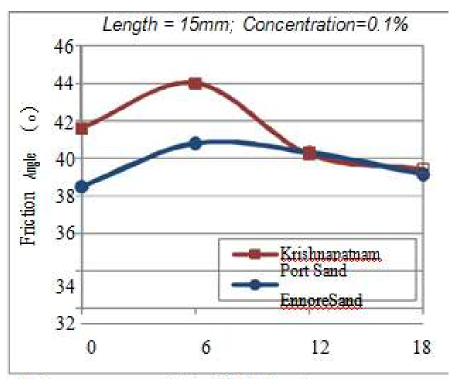
A 0.1% strip concentration added to the Ennore sand initially improved the angle of friction from 38.5° to 41.7° with higher concentrations resulting in an approximately linear response (Fig 8b). In Krishna patnam Port sand, the plastic inclusion resulted in a higher peak friction than the unreinforced soil, however, beyond the reinforcement concentration of 0.1% the strength decreased. On introducing perforated strips, an increase in the peak friction angle of the soil from 38.5° to 45.0° for Ennore sand was obtained when the strips were added to the soil at a 0.1% concentration (Fig 8e). A concentration of 0.2% resulted in a slight decrease and a further increase in concentration to 0.3% provided a higher friction angle. For Krishna patnam Port sand, addition of the perforated plastic 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%. It is apparent that the percentage concentration of plastic strips included had an influence on strength parameters of the sand-plastic composite.

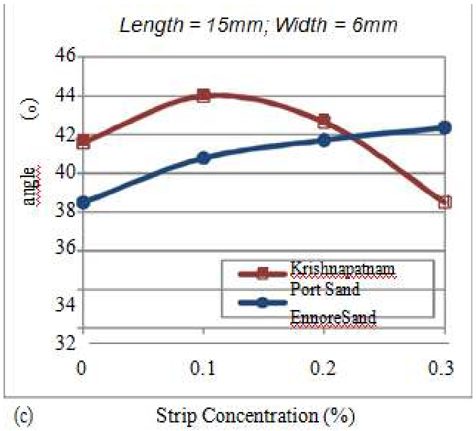
A linear increase in the peak and residual friction angles with strip perforation diameter was observed for both Krishna patnam Port and Ennore sand (Fig 8f). Introducing perforations on the strips achieved higher friction angles of up to 14.7% in Krishna patnam Port sand as compared to using intact strips. For Ennore sand, an increase of 8.5% was obtained representing 2° for a 1 mm enlargement in perforation diameter. The improvement in friction angle with perforation diameter can 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. Krishna patnam Port sand responded better to increases in perforation diameter than Ennore Sand in which the variations in length and concentration had a bigger impact.

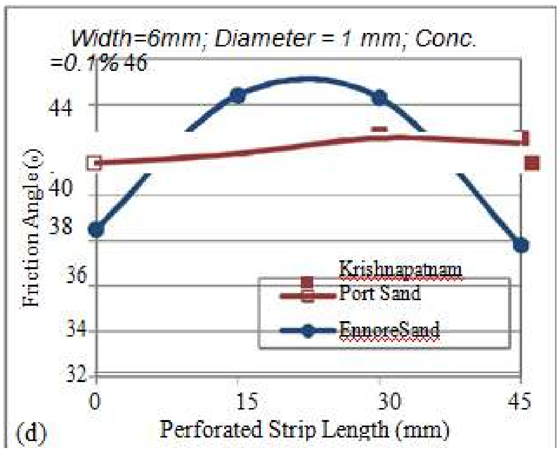


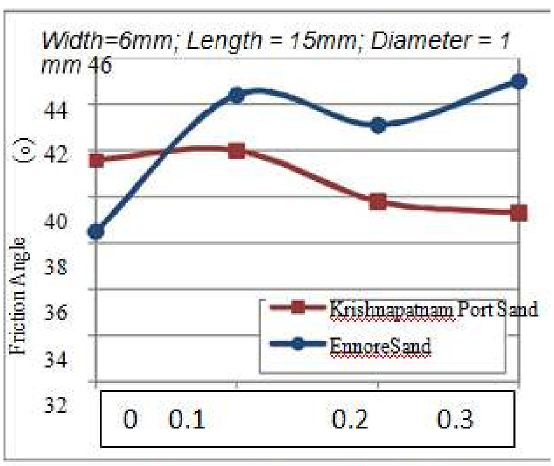
(a) Strip Length (mm)



(b) Strip Width (mm)







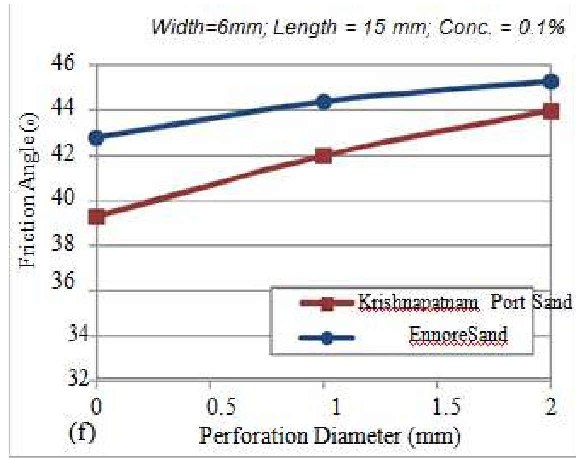


Fig.8:Graphs of Friction Angle against plastic strip parameters of Length, Width, Concentration and Perforation Diameter

V. Conclusion

A laboratory investigation involving a series of direct shear tests was conducted on plastic reinforced soil specimen prepared from two sandy soils mixed with random inclusions of plastic strips obtained from high density polyethylene shopping bags. The effect of the plastic strips on the soil strength parameters was studied by adding strips at concentrations of up to 0.3% by weight and varying the lengths and widths.

From the direct shear test results, an increase of more than 20% in the soil strength parameter of internal friction angle was attained in the sandy soils implying an increase in the shear strength on addition of the plastic strips. Perforations of diameters 1 mm and 2 mm were introduced in the plastic strips to examine any changes or improvements in the shear strength parameters of the soil due to this modification. On addition of the perforated strips of varied lengths and concentrations in the different soils, further improvement in friction angle was observed. From the experiments conducted, optimum results were obtained from plastic strip parameters of length 15 mm, concentration 0.1% and perforation diameter of 2 mm for strip widths of 6mm. Furthermore, increasing the diameter of perforations on the plastic strips resulted in higher values of friction angle with average increases of 2° for every 1 mm in perforation diameter. The results obtained from the testing programme suggested that addition of plastic elements in sandy soils provides an increase in the soil shear strength.

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