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The Effect of Plastic Waste as Soil Stabilizer

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Abstract
In recent years, stabilisers such as lime, cement and fly ash have become prohibitively expensive for soil stabilisation. In some circumstances, solid waste production, particularly garbage from plastic products, is increasing uncontrollably and continuously. Given the rapid increase in plastic waste and the rising expense of additives in recent years, the current study focuses on treating the soil with plastic waste as a soil stabiliser to enhance the soil's bearing capacity. This prospective study aimed to determine the index properties, review past research on the engineering properties and develop a hypothesis on the optimum proportion of plastic waste to be employed in the soil for engineering applications. This research paper examines the use of plastic waste from polyethene terephthalate (PET) plastic bottle shreds as a stabiliser, which necessitates a review of previous research studies and several investigations following the British Standard (BS), such as dry and wet sieving, hydrometer test, oven-drying method, density bottle method, Atterberg limit tests, compaction test and finally direct shear test. The study devised a hypothesis for the ideal percentage of plastic waste in the soil, which was 2%. The inclusion of 2% plastic waste was likely to boost soil strength. Furthermore, the shreds acted as reinforcements, helping to enhance the soil structure. Therefore, stabilising residual soil with plastic bottle shreds was a safe solution to the waste disposal problem and a cost-effective approach for stabilising weak soils.
Keywords: - soil stabilisation, plastic waste, polyethene terephthalate (PET) plastic bottle shreds, direct shear test, residual soil.

Introduction

Soils are natural resources vital for human life because they protect the ecosystem and sustain the structures. Soils are the world's oldest and most complicated engineering resources. The forefathers exploited soils as a building material for flood defence and shelters to better grasp the significance of soils in building stability. Roman architects and engineers, particularly Vitruvius, who worked during Emperor Augustus' reign in the first century before Christ (B.C.), were fascinated by soil kinds and nature and the construction of well-built foundations.

In Malaysia, land traits may spoil. For example, Bentong Lipis Road was undertaken by the JKR in November 2001 and completed in October 2004. It was acknowledged that the foundation soil was clayey and was built without proper treatment. Hence, consolidation occurred. As a result, the maintenance cost took five million Malaysian Ringgit per year though the initial contract cost was RM140 million. The repair cost each year was higher compared to the initial construction cost of the project. This issue highlighted that soil settlement is a significant problem for Malaysian roads [1]. Other than soil settlement issues, damages from seismic hazards, inappropriate soil materials, slope collapse, cavities and fractures are also labelled as land characteristics of Malaysia. Due to various issues arising from land characteristics, soil stabilisation has been introduced to the world.

Soil stabilisation is broadly described as the treatment of soils to improve their physical or index properties to satisfy an engineering objective. Furthermore, soil stabilisation entails combining and mixing materials to boost soil's strength parameters and bearing capacity by utilising various additives [2]. Furthermore, soil stabilisation encourages the utilisation of waste geo-materials in construction [3].

Malaysia has just been named one of the world's polluters of plastic. Most plastics are discarded, a tiny percentage is burned, and a very small rate (2% in 2013) is recycled [4]. In this research study, plastic waste was employed as an option to replace available additives such as lime and cement, which have gotten pricey in recent years. Using plastic wastes for stabilisation conserves natural resources and lays the way for improved plastic waste disposal [2]. Similarly, another previous study claimed that this unique approach to soil stabilisation could be utilised efficiently to meet societal concerns and reduce the volume of plastic waste that contributes to a recyclable and harmless ecology [5].

Due to the rapid growth in plastic waste and the rising cost of additives in recent years, the current study focused on treating the soil sample with plastic waste as a soil stabiliser to improve soil bearing capacity by adding waste into the compacted soil to increase the carrying capacity of the compressive force and then as the final product of the soil, it will become more stable.

Literature Review

To assess the effects of plastic waste as a soil stabiliser, Nouri [6] conducted a study specifically on the behaviour of plastic reinforcement in the sand under triaxial monotonic drained conditions. The sand used in this study was obtained from the Chlef River. The maximum and minimum dry unit weights were at 15.7 and 129 kN/m^3 respectively. Dry samples were prepared at 60% relative density to conduct all triaxial tests. A series of laboratory triaxial compression tests were accomplished to find out stress and strain, volumetric change behaviour and shear strength parameter, besides approximating the strength ratio at various strain levels in sand reinforced with plastic layers. The plastic used in this study was plastic sheeting. This geo-synthetic is made of green low-density polyethene obtained from Chef plastic manufacturers. One to five plastic layers were involved; one, two, three and five. They were positioned at vertical spacing within the sand [6].

Triaxial consolidated drained (CD) tests were executed on soil samples to determine strength in both unreinforced and reinforced scenarios. The experiments were carried out at three confining pressures: 50, 100, and 200 kPa. Consequently, adding plastic layers increased the maximum deviator stress, shear strength parameters, and flexibility, corresponding to the five layers of plastic. To put it another way, adding plastic layers to sand reduced dilation and improved the strength ratio, with the percentage improvement being more remarkable at higher strain levels.

Ilies [7] conducted a study that examined two ways to improve soil characteristics. The first strategy was to improve soil with plastic garbage, and the second was to improve soil with cement. This study employed polyethene plastic waste as its source of plastic waste. This study examined how shear strength parameters change when cement or polyethene is added at different rates of 2%, 4%, 6%, and 8%. The experiment was carried out on silty clay.

Based on the [7] study, employing leftover polyethylene material for soil stabilisation can be considered an environmentally benign strategy. The carbon footprint of producing polyethene grains as a stabilising substance is lower than cement or other hydraulic binders. By combining the soil with 4% polyethene, remarkable findings were noted. When a soil sample with 4% polyethene admixture was compared to a soil sample with 4% cement, the polyethene sample had a lower cohesiveness of 52% and a lower internal friction angle of 63%. Even though the perfection in cement was greater, the traditional approach has a higher carbon footprint than plastic admixture and is thus less ecological.

The experiment conducted by Peddaiah [5], showed that a rise in the engineering properties of silt sand was obtained at 0.4% of the plastic bottle strips between 0.2%, 0.6% and 0.8% with a strip scale of 15 mm x 15 mm. The compaction test at 0.4% plastic content yielded the maximum dry unit weight (MDU) for 15 mm x 15 mm plastic strips. MDU values continue to fall with increased proportions of plastic composition; 0.6% and 0.8%, respectively, and for larger plastic strip sizes, 15 mm x 25 mm and 15 mm x 35 mm. It was also noted that the optimum moisture content (OMC) values for reinforced plastic soil show the opposite pattern as the MDU values. Direct shear test results revealed that cohesion and internal friction angle improve by up to 0.4% of the plastic content. Shear characteristics decreased as the percentage of plastic components increased. However, shear strength measurements revealed the best gain at 0.4% of the plastic part for smaller strip sizes; 15 mm x 15 mm.

It is critical to design the surfaces of plastic strips to maximise the strength of the soil plastic mass. The plastic strips utilised in this investigation featured undulated surfaces, improving cohesion and the internal friction angle. The augmentation of both shear strength characteristics is not achievable if the surface of the plastic strip is clear, plain, flat and smooth. Peddaiah [5] for example, determined that the effects of plastic reinforcement in soil mass were crucially reliant on the nature of the surface, whether it is plain, flat, corrugated, or undulated, the size of the strips, the plastic content, and the kind of soil employed in the research.

Kassa [8] performed a direct shear test to measure soil shear strength. The test was performed by deforming a specimen at a regulated strain rate on a single shear plane established by the apparatus's setup. Three models were evaluated to exhibit the influence of surcharge and structural load on shear resistance and displacement, each under a different normal load. Kassa [8] also emphasised a significant and marginal decline in optimum moisture content (OMC) and maximum dry density (MDD) values through the standard proctor compaction test. As the reinforcement ratios and sizes increased, the internal friction and cohesion intercept angle improved dramatically.

Soltani-Jigheh [9] investigated the utilisation of plastic waste materials for the strengthening of clayey soils. An experiment was accomplished to examine the undrained shear behaviour of clayey soil combined with plastic waste. Clayey soil was mixed with various amounts of plastic waste; 0%, 0.5%, 1%, 1.5% and 3% in dry weight, and the consolidated undrained triaxial test was one of the experimental investigations performed on the mixes to explore the impacts of plastic waste on clayey soil behaviour.

At 1.0% plastic content, the inclusion of plastic waste varied the undrained behaviour of samples from contractive to dilative. The plastic waste substance ahead of 1.0% boosted the soil shear strength. Overall, the inclusion of more than 1.0% plastic waste enhanced the clayey soil shear strength, which was dependent on confining pressure values. The improved strength was caused by higher cohesiveness owing to plastic waste's confinement effect and tensile stress. Coat friction between soil and plastic particles may occur in clay mixtures with stiff plastic waste.

Research Methodology

A. Sample Collection

1) Soil sample

The soil sample was assessed on residual soil collected near Damansara River by digging at a convincing depth in Subang Perdana, Shah Alam, Selangor, Malaysia (3°09'00.5" N 101°32'28.8" E) and stored in plastic containers or plastic bags. Later, the disturbed soil was transported to the laboratory for laboratory testing.

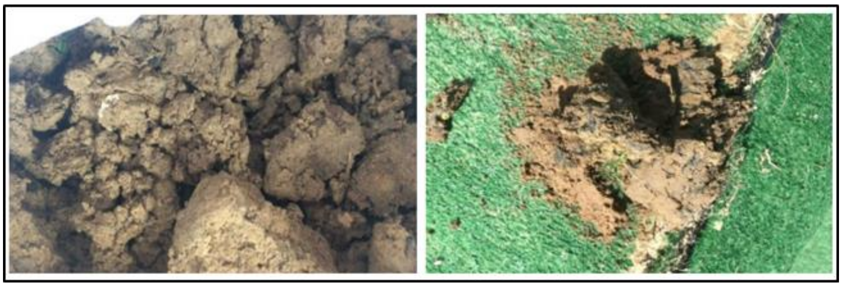

Figure 1. Soil samples collected near Damansara River in Subang Perdana

2) Plastic waste

The polyethene terephthalate (PET) plastic bottle was used and shredded using a shredder machine in this investigation to achieve the consistent size of the plastic shreds. Plastic bottles served as reinforcement in the varied proportions of 0%, 1%, and 2%, which symbolise the plastic waste's mass to the soil sample's mass.

Figure 2. Preparation of plastic sample

B. Experimental Procedure

The conducted tests in this study were separated into two categories, namely Category 1 and Category 2. Category 1 was a process for assessing index properties, while Category 2 reviewed previous research on engineering properties in terms of shear strength. Wet and dry sieving, density bottle, hydrometer, oven-drying, Atterberg limit, and compaction tests were all part of Category 1. Throughout the study, Category 1 was conducted entirely without the use of plastic bottle shreds as reinforcement. Meanwhile, the direct shear test was used for engineering testing in Category 2. There were two stages of Category 2, stage 1 without plastic bottle shreds; 0% of plastic bottle shreds as reinforcement, while in stage 2, the same set of Category 2 was conducted with the proportion of plastic bottle shreds of 1% and 2%. The direct shear tests were all performed on optimal moisture content (OMC) produced at 13.5%. This phase aimed to assess the effectiveness of plastic wastes in treated and untreated soils. However, for this research study, laboratory test results on soil for the direct shear test were reviewed and studied by comparing prior research study results.

C. Test Procedure

1) Index properties

Test conducted according to the following British Standard as in Table II to determine the index properties of residual soil collected.

Table 1. Laboratory Tests to Assess Index Properties

Experimentation list	Code list BS 1377:1975	Parameter determined
Grain size determination	Test (A) Wet sieving	*D*
	Test 7 (B) Dry sieving	
	Test 7 (D) Hydrometer test	
Moisture content	Test 1(A) Oven-drying method	*w*

Experimentation list	Code list BS 1377:1975	Parameter determined
Specific gravity	Test 6 (B) Density bottle method	*Gs*
Atterberg limits	Test 2(A) Cone penetrometer method	PL, LL, and PI
	Test (3) Plastic limit	
Compaction properties	Test (12) Compaction test	*ρ, w,* and *ρd*

2) Engineering properties

Laboratory test results on soil for the direct shear test were reviewed and studied by comparing prior research study results. Previous researchers' test procedures were detailed in this section. Ilieş [7] conducted a comparative study on soil stabilisation with polyethene waste materials and binders. Three soil samples were produced for a shear test with the same shear plane but varied vertical pressures of 100, 200, and 300 kPa. Soil-polyethene admixture samples were prepared at an optimum moisture content of 19% to conduct direct shear tests. Later, by plotting the shear test results into a coordinate system, three points on the chart were distinguished, through which the Coulomb line was drawn, to get the values for cohesiveness and friction angle.

Peddaiah [5] used a calibrated proving ring of 2.5 kN capacity with dial gauge precision of 0.002 and 0.01mm dial gauge for horizontal displacement. The rate of strain rate was set at 1 mm/min. The friction angle and cohesiveness were verified by applying normal stresses of 42, 70 and 97 kN/m^2 to the test. The rate of strain utilised in the study by Peddaiah [5] was assembled with a direct shear testing machine. However, the change in the rate of strain and normal stresses did not affect the final shear strength parameters of the soil, and only the time is taken for shear failure of the soil sample changed. A sufficient amount of soil was extracted and mixed with plastic strips until uniformity and homogeneity were attained. All test specimens were compacted in a shear box of 60 x 60 mm^2 at their respective maximum dry density, 16.75 kN/m^3, and optimum moisture content was at 16.8%, corresponding to values obtained from standard proctor tests. Selected normal stresses were applied to the test specimens, followed by horizontal displacement and shear load reading after the shear failure of the soil sample was noted.

Similar to Kassa [8], a direct shear test was utilised to measure the response of consolidated and drained soil samples to direct shear and soil shear strength. The test was performed by deforming a specimen at a controlled strain rate on a single shear plane established by the apparatus's setup. Three specimens were evaluated to demonstrate the influence of surcharge and structural load on shear resistance and displacement, each under a different normal load. The shear findings at three normal loads were plotted later on a graph and linearly fitted to yield cohesiveness. Meanwhile, the friction angle was derived from the line slope used to fit the shear strength data.

Results and Discussions

A. Index properties of residual soil

As per British Standard (BS) soil classification system, from Fig. 3 and Table 2, the results showed that the soil was classified as silty SAND and had some per cent of clay. The specific gravity of the soil sample utilised in this investigation was 2.17 Mg/m^3, and the moisture content of the soil was 21.24% using the oven-drying method. The cone penetration curve was plotted as shown in Fig. 4. As the liquid limit in this study was 31% and the plasticity index at 10%, the classification of fine soil was categorised as CLAY of low plasticity. According to Fig. 5, the optimum moisture content was 13.5%, while the maximum dry density was 1.82 Mg/m^3.

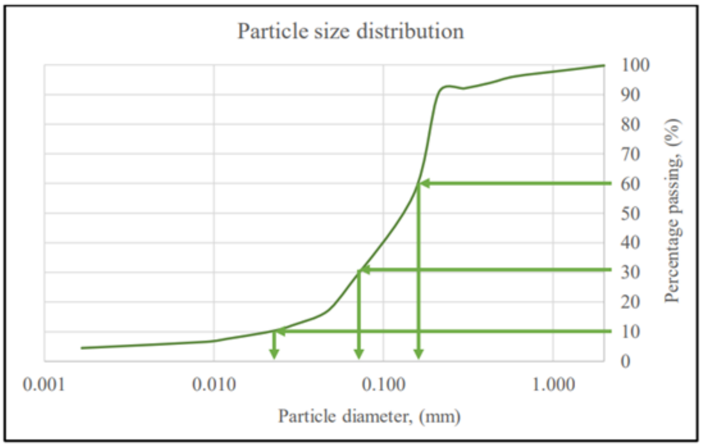

Figure 3. Particle size distribution of residual soil

Table 2. Index Properties of The Soil Sample

Soil properties		Value
Particle size distribution	Gravel (60 mm - 2 mm)	%
	Sand (2 mm – 0.06 mm)	74.0%
	Silt (0.06 mm – 0.002 mm)	10.1%
	Clay (< 0.002 mm)	4.48%
Specific gravity		2.17 Mg/m^3
Moisture content		21.24%
Atterberg limits	Liquid Limit (L.L.)	31%
	Plastic Limit (P.L.)	21%
	Plasticity Index (P.I.)	10%
Compaction properties	Maximum dry density (MDD)	1.82 Mg/m^3
	Optimum moisture content (OMC)	13.5%

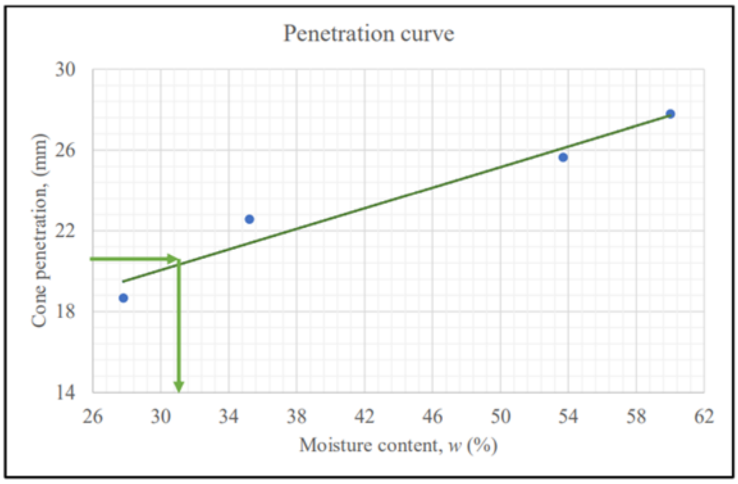

Figure 4. Penetration curve

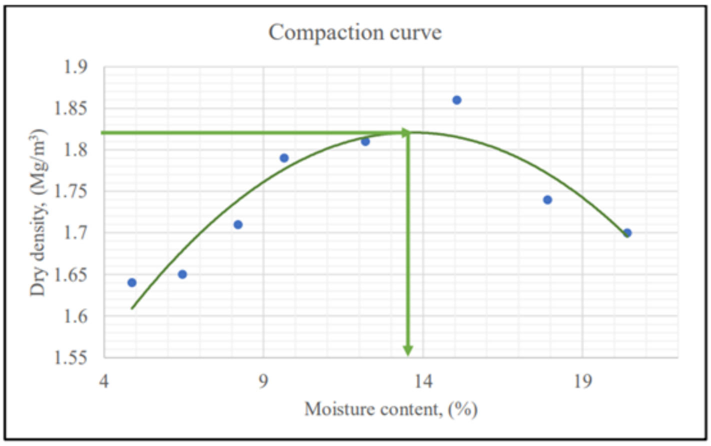

Figure 5. Compaction curve

B. Engineering properties of soil in terms of shear strength

According to Nouri [6], it was worth noting that reinforcement enhanced the shear strength characteristics of the soil, and this perfection increased with the amount of reinforcement. Five layers of reinforced soil had a friction angle that was 48.3% better than unreinforced soil.

It was noted that even one layer of reinforcement in the soil produced a larger friction angle, 26.7°, than unreinforced soil, 22.8°. Thus, for five layers of plastic materials, the value increased soil friction angle and cohesion by 48.3% and 86.7%, respectively.

Each reinforced or treated case has higher adhesion, followed by internal friction angle and feature angle values, than the unreinforced or untreated case. When reinforced soil was tested, the friction angle was enhanced by roughly 49% on average. Meanwhile, unreinforced soil had a cohesiveness of 12 kPa, but reinforced soil had a cohesion of 15 at 35 kPa. Additionally, the feature angles rose from 11 to 74%.

Because reinforcement enhanced the mechanical properties of soil, the presence of plastic elements raised the deviatoric stress. In addition, reinforced samples were less stiff than unreinforced samples. As the number of plastic layers increased, the mechanical properties also improved. Nouri [6] concluded that its shear strength improved when sand was reinforced with five or more plastic layers.

According to Ilieş [7], introducing polyethylene waste materials positively influenced the shear strength parameter, as both cohesion and internal friction angle values were enhanced. The first test was performed on reinforced soil containing 2% plastic material. The resulting cohesion and friction angle values were c at 19.60 kPa and $\varphi = 24.47°$, respectively. As a result, even though introducing a tiny amount of waste material may increase the friction angle compared to the value achieved for the soil in untreated soil. For the second test, the polyethene percentage was advanced to 4%, and the findings revealed cohesion and friction angle values of c at 31.41 kPa and $\varphi = 21.53°$, respectively. Increasing the percentage of plastic grains caused an increase in friction angle due to more polyethene pieces encountered on the shearing plane, resulting in greater shearing stress values.

In the third test, the cohesion and friction angles were c at 5.97 kPa and $\varphi = 27.79°$, respectively, as the polyethene percentage grew to 6%. As a result, it appears to affect both the cohesiveness and the internal friction angle parameter. The final shearing test was performed on samples containing 8% plastic components to assess the impact on the sustained shear strength parameter. The resulting cohesion and friction angle values were c at 10.57 kPa and $\varphi = 28.26°$, respectively. Despite a minor enhancement in cohesiveness values compared to the previous batch of samples with 6% polyethene, the findings were assumed mediocre to those obtained with a 4% plastic-soil combination.

Fig. 6 depicts the Coulomb lines for all soil samples stabilised with polyethene waste subjected to direct shear tests. The 4% polyethene admixture seems to have the highest cohesion values, while adding 8% plastic waste enlarged the internal friction angle higher than any other soil-plastic combination tested.

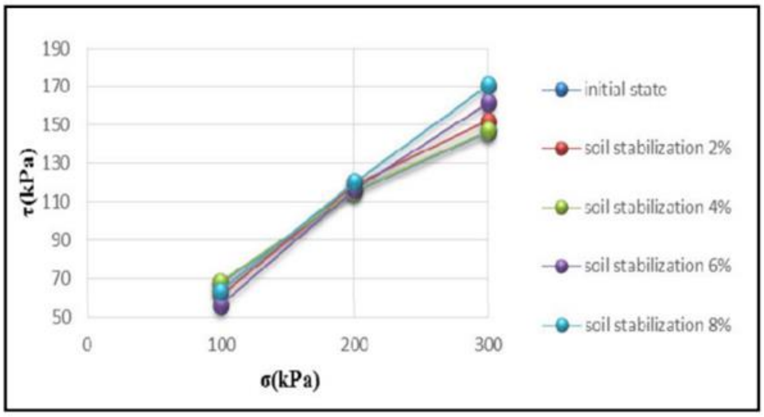

Figure 6. Coulomb lines were drawn for all soil samples stabilised with polyethene subjected to direct shear tests [7].

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An experiment was carried out to investigate the influence of Polyethylene Terephthalate (PET) strips on soil enhancement through a direct shear test with varying proportions of plastic strips; 0.2%, 0.4%, 0.6%, and 0.8%, respectively, and with altered lengths of strips; 15 mm, 25 mm and 35 mm as cited in the literature review. It was revealed that the cohesion and friction angle value for the untreated soil was 19 kN/m^2 and 23.2°, respectively.

Direct shear tests were performed for each percentage of plastic strips and strip size of 15 mm x 25 mm, and the results were reported in Table 3. According to the table, shear strength characteristics were enhanced through direct shear tests at 0.4% plastic substances in soil with a 15 mm x 25 mm strip size. Shear stress rose owing to plastic parts' distribution in different directions along the shear surface between the two halves of direct shear boxes. Fig. 7 illustrates that for 0.4% plastic substances in soil, Mohr envelops lines with cohesiveness and friction angle were increased to 34 kN/m^2 and 32.8°, respectively. It was discovered that as the number of plastic compounds increased, the cohesion and friction angle trend increased. Direct shear test results with plastic contents for 15 mm x 25 mm strip size.

Table 3: Shear strength parameters

The proportion of plastic content	Shear strength parameters	
	Cohesion, c (kPa)	*Friction angle, φ (°)*
0%	19	23.2
0.2%	28	28.7
0.4%	34	32.8
0.6%	18	27
0.8%	13	25

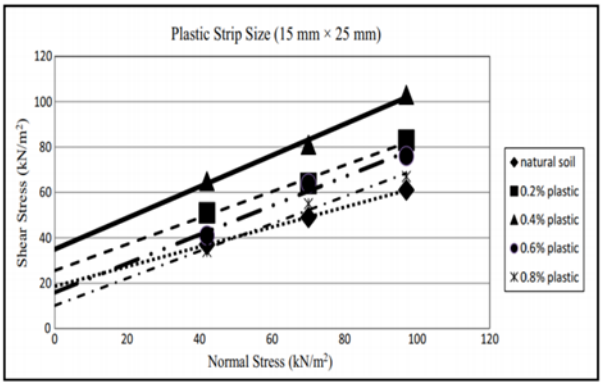

Figure 7. Mohr envelop lines for different percentages of plastic compounds [5]

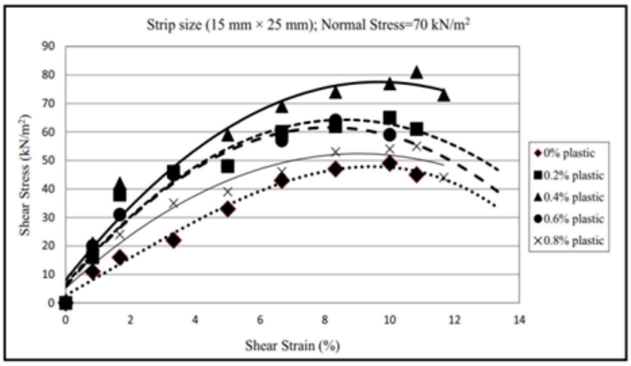

Figure 8. Shear stress-strain behaviour of a plastic reinforced soil [5]

The shear stress-strain behaviour of soil with plastic strips was depicted in Fig. 8 for selective normal stress of 70 kN/m^2. Peddaiah [5] emphasised that this observable fact was attributed to combining soil and plastic mass properties, which may differ from the behaviour depicted exclusively by soil material during shearing. The increase in the friction angle must be because of an increase in the interlocking capacity between the particles. It was also affected by the type of plastic used in the soil. Plastic strips' corrugated and undulated surface resulted in increased cohesion and friction angle. When the shear strength parameters were compared to the properties of natural soils, the shear strength parameters increased significantly. The shear strength parameter values showed a decreasing trend as the plastic content of the soil increased. The increase in the frictional surface between soil particles and plastic parts enhanced shear strength parameters. It was discovered that plastic strips' corrugated or undulated surface plays a vital role in achieving higher cohesion and friction angle. It would be challenging to increase both cohesion and friction angle if the smooth surface of the plastic strip was used.

Peddaiah [5] extended the research by altering the size of the plastic strips while keeping the 0.4% of plastic strips constant. An identical set of tests was performed for each size of plastic strip, and the results were reported in Table 4. Fig. 9 on the other hand, depicted the Mohr envelops for plastic reinforced soil with varying plastic strip lengths of 15, 25, and 35 mm. It was revealed that the shear strength parameters show an increasing pattern for the 15 mm x 15 mm strip size compared to the 15 mm x 35 mm strip size. According to Peddaiah [5], increasing the length of plastic strips reduces shear strength parameters.

Table 4. Direct Shear Test Results With The Varied Size of Plastic Strips For 0.4% Plastic Content

Plastic strip size for 0.4% plastic content	Shear strength parameters	
	Cohesion, c (kPa)	*Friction angle, φ (°)*
15 mm x 15 mm	42	36.5
15 mm x 25 mm	34	32.8
15 mm x 35 mm	23	25.4

Overall, the findings of the direct shear test done by Peddaiah [5] demonstrate that cohesiveness and friction angle rose to 0.4% of natural soil's plastic content by mass. Shear strength parameters decreased as the percentage of plastic substances increased. Smaller strip sizes, like 15 mm x 15 mm, showed a tremendous enhancement in shear strength parameters at 0.4% plastic content.

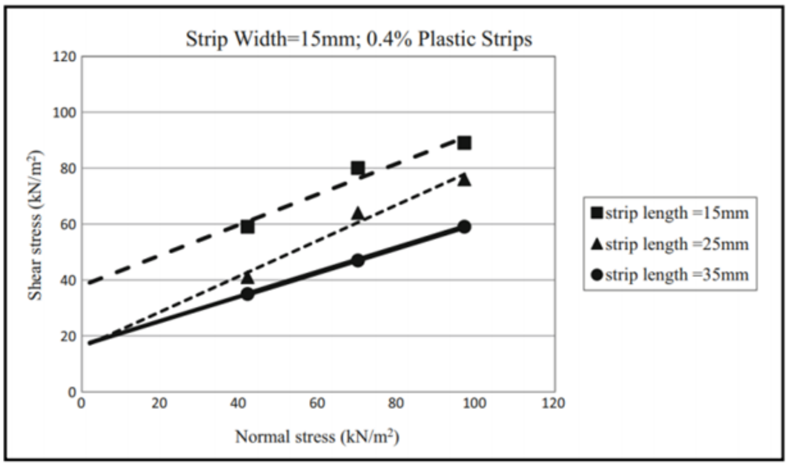

Figure 9. Mohr envelops for soil with varying strip lengths [5]

The nature of the plastic surfaces was vital in improving the strength characteristics of the soil plastic mass. Peddaiah [5] claimed that plastic strips with undulated surfaces have higher cohesiveness and friction angle. Besides, for the outstanding engineering properties of soil reinforced with plastic strips, it was suggested to utilise 0.4% plastic content with 15 mm x 15 mm dimension of plastic strip with natural soil.

Kassa [8], like Ilieş [7] and Peddaiah [5], utilised a direct shear test to assess soil shear strength. Based on the test findings, it was feasible to determine that the placement of the plastic strips in the soil impacts the shear capacity of the reinforced soil. If the strip's surface were parallel to the shear plane, shearing would be enhanced, and the capacity will fail. However, any other configuration will advance the soil's shear capacity. Then again, the larger strip sizes were difficult to arrange on the direct shear machine because their surface area was close to the shear box.

According to Kassa [8], the friction angle and cohesion intercept for untreated soil was 5.71° and 49.83 kPa, respectively. The soil's cohesion was ascribed to the low friction angle value. The treated soil's highest cohesiveness and friction angle values were 8.98° and 62.67 kPa, representing a 57% and 26% advancement, respectively. These results were attained at 0.5% for a 15 x 20 mm strip size. The cohesion and friction data for each treatment level and strip sizes are shown in Table 5.

Table 5. Direct Shear Test Results

Strip size (mm)	Treatment level (%)	Shear strength parameters	
		Cohesion, c (kPa)	*Friction angle, φ (°)*
None	0	49.83	5.71

Strip size (mm)	Treatment level (%)	Shear strength parameters	
		Cohesion, c (kPa)	*Friction angle, φ (°)*
5 x 7.5	0.5	51.64	6.66
	1	54.43	7.15
	2	56.88	7.64
10 x 15	0.5	60.84	7.31
	1	61.17	7.76
	2	61.87	8.36
15 x 20	0.5	62.67	8.98
	1	62.50	8.75
	2	62.00	8.28

Escalating the plastic substance for the equivalent plastic strip size enhanced the friction angle and cohesion for 5 x 7.5 mm and 10 x 15 mm strips but declined the friction angle and cohesion for 15 x 20 mm strips. Increasing the plastic size for the same content, on the other hand, increased the friction angle and cohesiveness. As noted in the literature review, when reinforcement percentages and sizes were enhanced, the friction angle and cohesion intercept increased dramatically. In a nutshell, the author summarised that the ideal aspect ratio of plastic size and plastic substance that causes the best outcomes could be chosen depending on the consequence of the various parameters for a particular engineering relevance.

According to Soltani-Jigheh [9], the shear strength of the clay-plastic waste admixture was greater than the comparable values of untreated clay. Briefly, plastic waste enhanced the clay shear strength. Fig. 10 depicts the impact of flexible plastic waste on effective friction angle and cohesiveness values. Fig. 10 indicates that all admixture samples have a lower friction angle than untreated soil, with the sample having 0.5% plastic waste having the least friction angle. The friction angle value rose as the plastic waste content value increased beyond 0.5% plastic waste. Specifically, when the plastic waste content increased, they became more in contact with one another, resulting in greater friction.

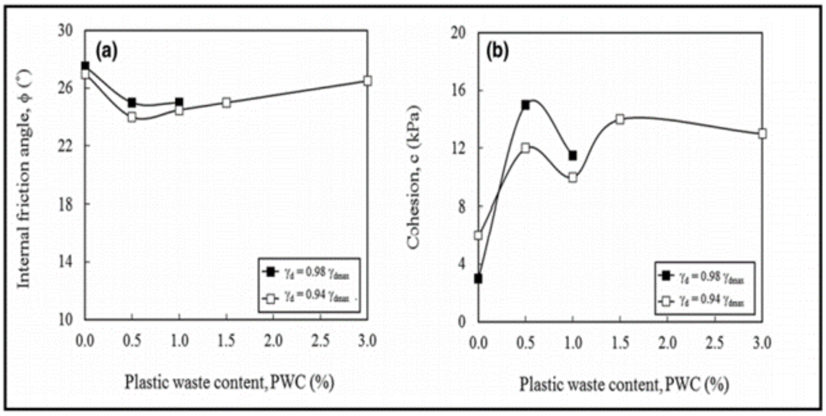

Figure 10. The effect of plastic waste on friction angle and cohesion [9].

Besides, it also revealed that modifying the cohesiveness parameter with plastic waste content strongly contrasts with the friction angle patterns in correlated mixtures. The cohesiveness values were greater than the corresponding values of untreated soil, and they were maximum in mixed samples with a plastic waste concentration of 0.5%. After that, adding plastic waste to the clay lowered the cohesiveness value. More plastic waste may be deduced, increasing the space between soil particles and lowering cohesion parameter values. In contrast to untreated soil, greater cohesiveness of mixtures suggested confinement due to plastic debris.

Ultimately, Soltani-Jigheh [9] observed that the inclusion of more than 1% plastic waste enhanced the clayey soil shear strength, dependent on confining pressure values, initial density, and plastic flexibility, as described in the literature. The improved strength was caused by higher cohesiveness, owing to plastic waste's confinement effect and tensile stress. In clay mixtures, including rigid plastic waste, friction between soil and plastic particles may happen. Finally, the findings signify that treated soil containing 1.5% and 3.0% plastic waste was more physically powerful than untreated soil.

Friction angle is a physical representation of particle interlocking—the greater the particle interlocking, the greater the friction angle. Particle crushing under high normal stress might be one of the causes of a low friction angle. All soil types in the previous study revealed that the friction angle values became higher as the plastic content was added into the soil. This explained how the presence of plastic material in the soil contributed to increasing grain-to-grain content or, to be more specific, led to better packing and, consequently, enhanced frictional resistance.

This current study is a continuation of the experiment conducted by Peddaiah [5]. Peddaiah [5] advocated preparing the Polyethylene Terephthalate (PET) plastic bottle waste by utilising the shredding machine in future research. Plus, this paper followed a methodology developed by Peddaiah [5]; Kassa [8]; and Ilieş [7] to investigate the influence of plastic waste as a soil stabiliser, specifically Polyethylene Terephthalate (PET) plastic bottles, on soil stabilisation.

Taking into consideration together all the evidence from the past research study, it is possible to hypothesise that the significant remarks for the ideal proportion of plastic to be utilised in soil for engineering application and the enhancement in shear strength parameters may differ for other soils, type of plastic utilised and engineering test carried out as well as the method conducted for the dimension of the plastic waste.

Hence, it could conceivably be hypothesised that Polyethylene Terephthalate (PET) plastic bottle shreds utilised in this study could maximise silty sand's shear strength. An implication of this can be achieved through the direct shear test. Significant marks were attained by mixing the soil sample with 2% plastic waste compared to the controlled sample and 1% plastic waste in the soil.

Conclusion

This research article aimed to evaluate the impact of utilising plastic waste as an additive in the soil stabilisation process. The following hypotheses were developed based on the findings and reviews. The most imperative findings of this study were that the ideal treatment level of plastic waste in soil that fulfils the study's goals and objectives was 2% where the amount of plastic waste was anticipated to strengthen the soil strength.

When taken together, these observations highlight plastic waste's function in generating soil stabilisers that are favourable to the environment. In brief, stabilising residual soil with plastic bottle shreds was a harmless remedy because it combated the indecisiveness concerns of the weak soil. The shreds worked as reinforcements may also help to compensate for volume fluctuations induced by variations in water content. Incorporating plastic bottle waste into the construction industry was also an essential step in addressing the predicament of improper plastic waste disposal.

In addition, this research suggests that the relevance of the direct shear test, it is possible to improve the mechanical properties of stabilised soil. Furthermore, the findings lead to a hypothesis that admixture of soil with Polyethylene Terephthalate (PET) plastic bottle shreds enhanced the soil strength. Intriguingly, a large quantity of PET waste from plastic bottle shreds resulted in more favourable outcomes than smaller ones. This current study is one of the first attempts to study an extensive investigation into the efficacy of plastic waste as a soil stabiliser in residual soil through a direct shear test with plastics in shreds forms to analyse the soil sample's shear strength.

However, it was unfortunate that the study did not perform engineering testing on the soil. Besides, other types of plastics should be included in the comparison to make it more conclusive on which plastics would be good to utilise in engineering projects. This was because other plastics, such as Low-Density Polyethylene (LDPE), High-Density Polyethylene (HDPE), and many more, would probably affect quantum changes in soil properties. Furthermore, due to the small sampling size, it was impossible to determine plastic waste's genuine behaviour when used as a reinforcing soil enhancement material. It is currently unknown what happens when plastic waste is used as a soil stabiliser to large sample size. Hence, it is vital to carry out extensive scale testing before applying plastic waste as a soil stabiliser for practical applications. Lastly, this study was constrained by the absence of various other tests such as the compressive test, free swell index test, and permeability test. This present study also recommends conducting other triaxial tests in the future, such as the consolidated drained (CD) test, for long-term analysis.

Therefore, further investigation and experimentation are strongly recommended. The ultimate action of other soil with plastic bottle shreds must be delved into and expanded. Several experiments should be conducted to study the impact of plastic waste as a soil stabiliser.

Despite the relatively limited study, this work offers valuable insights into enhancing the properties of residual soil by using plastic shreds. Further research might explore the potential of plastic waste as a soil stabiliser in soil, including various plastic waste categories with plastic waste shreds and none shreds plastic waste. Further work should be undertaken to explore how this reflects the mechanical and engineering properties of the soil.

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