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Characterization of Soil Stabilized with Various Contents of PET Sheets

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ABSTRACT

The extensive generation of Polyethylene Terephthalate (PET) waste, exceeding 50 million tons annually, presents both an environmental challenge and an opportunity for sustainable geotechnical applications, particularly in soil stabilization. While various forms of PET materials, including shredded materials, fibers, sheets, and strips, have shown promise in soil reinforcement, there are inconsistent findings regarding their effectiveness across different soil types and PET configurations, necessitating further investigation into the optimal use of PET sheets for soil stabilization. The purpose of this study is to determine the physical properties of polyethylene terephthalate (PET) stabilized soil. Amount of 0.3%, 0.6% and 0.9% of PET from the dry weight of soil with dimension of 20mm length and 10mm width were mixed with soil. The compaction test results show that the optimum moisture content (OMC) of the soil sample increased to 15.3% at 0.3% and 0.6% PET content, but decreased to 14.3% at 0.9% PET content. A similar trend was observed for the maximum dry density (MDD) of the soil, which increased to 1.79 Mg/cm³ at 0.3 and 0.6% PET content but declined to 1.75 Mg/cm³ at 0.9% PET content. From the permeability test, 0.9% PET content was found to be optimal for reducing the water flow rate within the soil sample, yielding a hydraulic conductivity of 1.033 cm/s. Meanwhile, 0.3% PET content proved optimal for increasing the CBR value of the soil sample to 21.81%. These findings indicate that PET waste exhibits considerable potential as a soil stabilizer, wherein the optimum content is governed by the desired enhancement in specific engineering characteristics.

Keywords: Geotechnical properties; soil stabilization; polyethylene terephthalate sheet

INTRODUCTION

The growing global emphasis on sustainable construction practices has led to increased interest in innovative soil improvement techniques that incorporate recycled materials. The plastic waste materials are one of the biggest contributors to the garbage disposal system in Malaysia. Based on Chen et al. (2021), there are over 1300 plastic manufacturing factories, making Malaysia one of the largest plastic producers globally. In Malaysia, more than 0.98 million tons of untreated plastic waste was produced annually (Chen et al. 2021). Polyethylene terephthalate (PET), primarily sourced from discarded plastic bottles and packaging materials, represents one of the most abundant plastic wastes worldwide, with annual production exceeding 50 million tons (Dissanayake & Jayakody 2021). The potential repurposing of PET materials in geotechnical applications offers a promising solution to both waste management challenges and soil stabilization needs.

Soil reinforcement using PET materials has been widely studied and implemented in geotechnical engineering practice. The mechanical properties of PET sheets, including high tensile strength, durability, and chemical resistance, make them particularly suitable for soil reinforcement applications. When strategically placed within soil layers, the PET sheet can create a composite material system that redistributes applied stresses and improves the overall engineering behavior of the soil mass. Furthermore, the use of PET sheets in soil modification represents a cost-effective alternative to traditional reinforcement materials, while contributing to sustainable construction practices.

Review by Iravanian and Haider (2020) shows that waste plastic bottles can effectively be used as a reinforcing material and it is an eco-friendly solution. There are various shape of recycled PET used in soil stabilization, for example shraded and fiber (Haider et al. 2023; Hasanzadeh & Shooshpasha), and also sheets and strips (Kassa et al. 2020; Boobalan et al. 2023). However, different size of PET react with different type of soil for sure will give different results. For example, Gowtham & Sumathi (2017) reported that when 0.5%, 1.0%, 1.5%, and 2.0% of 10mm fiber was added to Black cotton soil, increasing the percentage of fibers increased the maximum dry density (MDD). However, a study by Mohammed et al. (2018) showed that when 5 to 10 mm fiber of PET was mixed with clay soil, the MDD value decreased with the increase in PET percentage. Next, Urian et al. (2023) used shredded PET at 2%, 4%, and 6% to improve clayey soil. The irregular shapes with sizes ranging from 3 mm to 12 mm showed an improvement in the mechanical characteristics of the clay. Then, Haider et al. (2023) mixed the shredded PET with low cement content and found an increase in soil strength upon mixing. Saeed & Arshid (2023) used plastic strips with varying lengths of 10 mm, 20mm, and 30 mm, and different proportions of PET strips at 0.2%, 0.5%, and 0.8%. The authors found that the PET strips are effective for soil stabilization and improving the engineering properties of soil. The application of PET strips is mostly for clayey soil types, which improves the friction between soil particles. This improvement in soil friction occurs through the mechanical interlocking between PET strips and clay particles, creating a more stable soil matrix. The flexibility and durability of PET strips make them particularly suitable for clay soils, which typically exhibit poor engineering properties. When PET strips are introduced into clayey soils, they form a randomly distributed reinforcement network that increases shear strength, reduces settlement potential, and improves the overall bearing capacity. This reinforcement mechanism is especially effective in areas prone to soil deformation and where conventional stabilization methods may be cost-prohibitive.

Therefore, to further investigate the suitability of PET in various soils, the PET size focused on in this study is the sheet type. The PET sheet is added into local soil, namely laterite. The aim of this study is to determine the physical properties of PET-stabilized soil at percentages of 0.3, 0.6, and 0.9%. The study's focus on determining optimal PET percentages for soil stabilization could lead to more sustainable and cost-effective construction practices. Understanding these properties is crucial for engineering applications, particularly in regions where laterite soil is abundant. Additionally, the use of sheet-type PET provides insights into alternative waste plastic applications, potentially contributing to both environmental conservation and geotechnical engineering advancement.

METHODOLOGY

SOIL SAMPLES

The soil sample used in this study is a laterite soil which contains iron oxide and aluminum hydroxide resulting from the decay of rock. This soil is usually an oldest, residual soil and abundantly found in tropical country such as Malaysia. Thus, it is often used as construction materials (Geremew & Mamuye 2019). The soil sample was taken at the Administration Building of the Faculty of Engineering & Built Environment, Universiti Kebangsaan Malaysia, Bangi at depth of 1.0 to 1.5 meters as shown in Figure 1. This area became a study site to stabilize the soil because Ramli et al. (2023) explained that the areas of Ampang, Cheras, Kajang, Dengkil, Labu and Sepang are areas prone to landslides due to weak soil.

FIGURE 1. Location of the soil sample

PREPARATION OF PET SHEETS

The PET material used in this study was sourced from plastic bottles. The PET sheets were cut manually to a length of 20 mm and a width of 1 mm. PET was added to the soil samples at concentrations of 0.3%, 0.6%, and 0.9% by dry weight of the soil. These sizes and plastic contents were selected based on findings that the properties of PET-reinforced soil change with varying sizes. Figure 2 shows the PET material used in this study.

RESULT AND DISCUSSION

PHYSICAL PROPERTIES OF SOIL

The physical properties of the soil sample are summarized in Table 1. According to Unified Soil Classification System (USCS), the soil sample is a sandy lean clay (CL).

FIGURE 2. PET with 20mm x 10mm size mixed with laterite soil

PARTICLE SIZE DISTRIBUTION

The particle size distribution (PSD) was done according to the American Society for Testing and Materials (ASTM D422, 2001) - Standard Test Method for Soil Particle Size Analysis. The sizes used in the sieve analysis were sieve number 4, 10, 16, 30, 40, 50, 100 and 200. One kilogram of soil sample was vibrated on a sieve shaker for 5 minutes. In the hydrometer analysis, 20g of sodium hexametaphosphate solution was used and mixed into the soil sample with 500 ml of distilled water. The solution sample will be placed in a water immersion that has an average temperature of 31°. Hydrometer reading was measured for 24 hours of the set intervals.

SPECIFIC GRAVITY

A specific gravity test was done to identify the ratio of soil density to water density. Amount of 10 g of soil sample passing sieve number 40 were utilize in this study. The sample will be put in a bottle before being dried in a desiccator cage for 30 minutes to remove air as stated in British Standard - BS 1377: Part 2 (BS1377, 1990a).

ATTERBERG LIMIT

The liquid limit and plastic limit of a soil sample can be determined by following the procedure outlined in ASTM D4318 (2010). The liquid limit of the soil is measured using the Casagrande method. In this test, the soil paste is placed in the Casagrande cup, and a groove is made at the centre of it. The cup is then continuously rotated by its handle, lifting it to a height of 1 cm and allowing it to drop freely on the plate's base, until the soil samples touch each other by 12.5 mm. A soil sample that has been sieved and passed through a No. 40 sieve is used to determine the plastic limit of the soil. The sample is then mixed with water and rolled into a thread with a diameter of 3.2 mm. The moisture content of the sample is then recorded.

COMPACTION

A standard compaction test was conducted to measure the optimum moisture content (OMC) and maximum dry density (MDD) of the soil sample. The PET was added according to the percentages. A 2.5 kg rammer was applied to the soil sample with 25 times for each of the three layers as stated in BS 1377: Part 4 (BS1377, 1990b). The moisture content will be calculated by measuring the wet weight and dry weight of the soil at the top, middle and bottom layers of the sample.

PERMEABILITY

Since the soil sample used in the study was a disturbed sample, thus, it was compacted beforehand according to standard compaction. The length of the sample used is 16.5 mm with an area of 132.2 mm^2. The soil sample will then be soaked until it is completely saturated before the permeability test is carried out. The permeability of the soil sample was determined by measuring the time taken for water to flow from the initial to the final height in the standpipe. The results of this test can be used to identify the properties of fluid flow as well as the workability of the soil.

CALIFORNIA BEARING RATIO

The study covers a non-submerged California Bearing Ratio (CBR) test and was done according to BS1377: Part 4 (BS1377, 1990). The soil samples were compacted on CBR molds before being tested using a CBR machine. Gauge readings on the CBR machine are taken at each puncture starting from 0.00 mm up to 7.50 mm using calibration.

TABLE 1. Physical properties of soil sample

Test	Item	Results
PSD	Gravel	1.48%
	Sand	19.7%
	Fines	78.82%
G_s		2.61
Atterberg limit test	Liquid limit (LL)	48.60%
	Plastic limit (PL)	25.25%
	Plastic Index (PI)	23.35%
Soil Classification	USCS	CL

EFFECT OF PET SHEETS ON COMPACTION

The MDD of the control sample is 1.78 Mg/cm^3, while OMC is 15.4%. For a soil sample with a PET content of 0.3%, the MDD and OMC values were 1.79 Mg/cm^3 and 15.3% respectively. The MDD value showed an increase from the control sample while no change was recorded in the OMC value. The soil sample with 0.6% PET content showed a similar trend of MDD value and OMC value, when compare to 0.3% PET content. At 0.9% of PET, the MDD value continued to decrease, reaching 1.75 Mg/m^3, while the OMC value decreased to 14.3%. A summary of the compaction test results can be seen in Figure 3. The soil sample showed an increased in MDD values at 0.3%, but decreased at 0.6% and 0.9% of PET content. This result can be compared with the study done by Peddaiah et al. (2018) who found that MDD values increased at 0.2% and 0.4% PET content, while decreased at 0.6% and 0.8%. Biradar & Moniuddin (2015) reported that the MDD kept increasing up to 1% of PET and reduced at 1.5%.

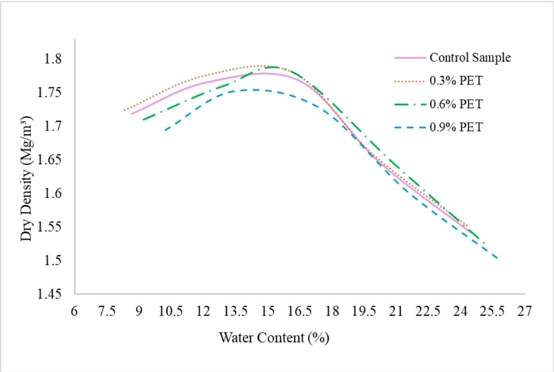

FIGURE 3. Compaction curves for various PET sheet percentages

Amena (2021) also conducted a compaction experiment on PET containing 0.25%, 0.5% and 0.75% brick powder waste. The author found that the MDD value increased from 0% to 0.25% PET content, then decreased at 0.5% and 0.75% PET. Peddaiah et al. (2018) discovered that improvement in engineering properties of silty sand is achieved at 0.4% plastic content with strip size of 15 mm x 15 mm. In this study, the optimal PET content to improve the properties of soil sample is 0.3%. These variations in optimal PET content across different studies suggest that soil composition and characteristics play a crucial role in determining the effectiveness of PET reinforcement. The differences may be attributed to varying particle size distributions, soil plasticity indices, and the physical properties of the PET materials used.

EFFECT OF PET SHEETS ON PERMEABILITY

The average k value for the control sample is 1.60 cm/s. When 0.3% PET was added, the average value of k increased to 2.35 cm/s, as given in Table 2. The average value of k also increased in samples with a PET content of 0.6%, which is 4.12 cm/s. According to Solanki & Bhattarai (2018), more PET content would produce more voids and this would result in decreased permeability. This phenomenon occurs because excessive PET particles create discontinuous void spaces, disrupting the natural flow paths within the soil matrix. However, the value of k decreased in the soil sample with a PET content of 0.9%, which is 1.03 cm/s. This shows that, after a certain percentage, the PET-stabilized soil decreases the value of k. This may be due to the interstices being filled with more content of PET, as well as the random arrangement of PET making it more difficult for water to penetrate the soil sample. The reduced permeability coefficient indicates that excessive PET content creates a barrier effect, potentially affecting soil permeability characteristics.

TABLE 2. Results of pemeability test

Sample	Trial	Time $(t_2 - t_1)$ (s)	h_1 / h_2	k (cm/s)
0% PET	1	92	1.833	1.5504
	2	92	1.833	1.5504
	3	84	1.833	1.6980
0.3% PET	1	61	1.833	2.3382
	2	58	1.833	2.4592
	3	63	1.833	2.2640
0.6% PET	1	42	1.833	3.3960
	2	34	1.833	4.1951
	3	30	1.833	4.7544
0.9% PET	1	120	1.833	1.1886
	2	140	1.833	1.0188
	3	160	1.833	0.8915

EFFECT OF PET SHEETS ON CALIFORNIA BEARING RATIO

Figure 4 shows soil samples with 0.3% and 0.9% PET sheet after CBR penetration. At the penetration of 2.5 mm and 5 mm, the CBR value of the control sample soil are 23.54% and 19.49% respectively. For the soil sample with 0.3% PET content, the CBR value at 2.5 mm penetration is 21.81% and 5mm penetration is 19.08%. On a soil sample with 0.6% PET, the CBR value is 5.23% and 6.08% at 2.5 mm and 5 mm respectively. Lastly, for a soil sample with a PET content of 0.9%, the CBR value obtained at 2.5 mm penetration is 7.66% and 8.23% at 5mm penetration. In Malaysia, a good subgrade material for road construction should achieve CBR value of 12% and above, ensuring stable and sustainable road infrastructure (Jabatan Kerja Raya, 2013).

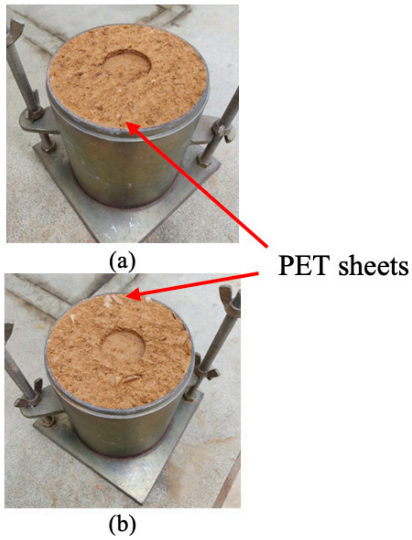

FIGURE 4. (a) 0.3% (b) 0.9% PET sheet

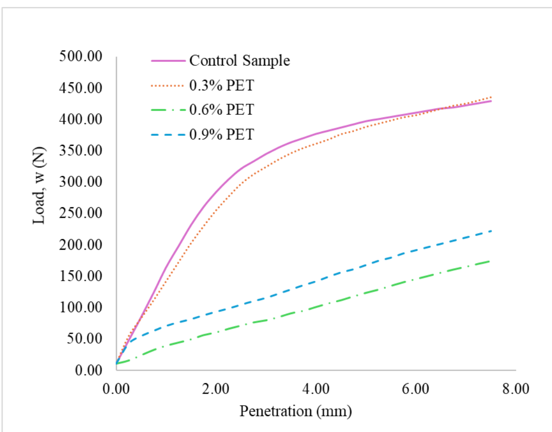

FIGURE 5. Summary of CBR at 2.5mm and 5mm penetration

From Figure 5, the control sample showed the highest CBR value, followed by 0.3% of PET. This is supported by a study conducted by Peddaiah et al. (2018) who showed an increase in CBR values on soil samples with 0.2% and 0.4% PET, and a decrease at 0.6% and 0.8% PET content. Although no increase was obtained in the CBR value in this study, this is because the size of the plastic bottle pieces used in this study is 20 mm x 10 mm, which is smaller compared to the sample used by Peddaiah et al. (2018) which is 15 mm x 25 mm.

However, it is different from the results conducted by Amena (2021) which shows an increase in the CBR value at PET content of 0.25%, 0.5% and 0.75%. The incresing of the CBR value in the study is due to addition of the brick powder. In this study, the comparison of the CBR value for the control sample with 0.3% PET shows only a slight difference. Therefore, a PET content of 0.3% was selected as the optimal content for increasing soil strength through CBR testing.

VARIATION OF MDD, OMC AND CBR WITH INCREASING PET

Comparisons with previous works were conducted to obtain a clear picture of the effects of PET addition. As shown in Figure 6, the current study demonstrates that the density increased from 1.78 to 1.79 Mg/m³ when 0.3% and 0.6% PET were added, but decreased to 1.55 Mg/m³ with 0.9% PET addition. This trend is similar to that reported by Peddaiah et al. (2018), who observed an increase to 1.84 Mg/m³ at 0.4% PET followed by a decrease to 1.73 Mg/m³ at 0.8% PET for silty sand. In contrast, Chakravarthy et al. (2020) reported a decrease in MDD with each 5% PET addition, reaching the highest value of 1.81 Mg/m³ at 20%. They used clay soil with a PI value greater than 7, indicating that the soil material was highly plastic. Amena (2021), however, mixed PET with brick powder, and the results showed almost constant readings after adding the materials.

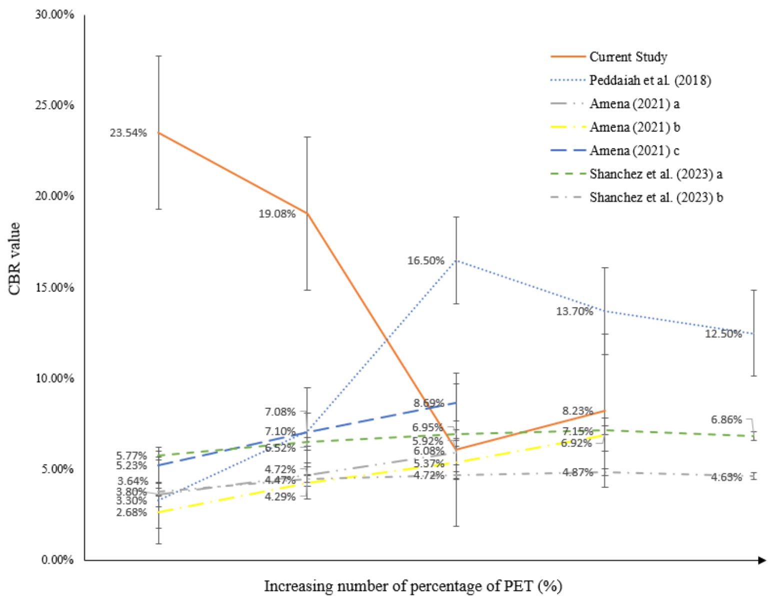

FIGURE 6. Variation of MDD with increasing PET

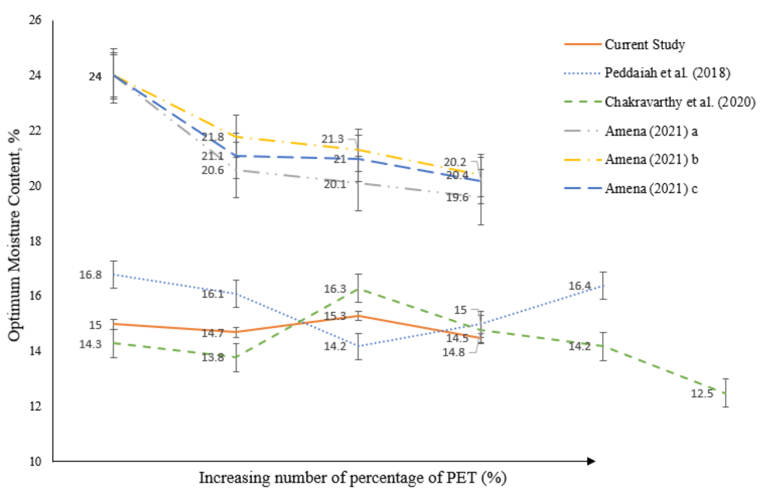

FIGURE 7. Variation of OMC with increasing PET

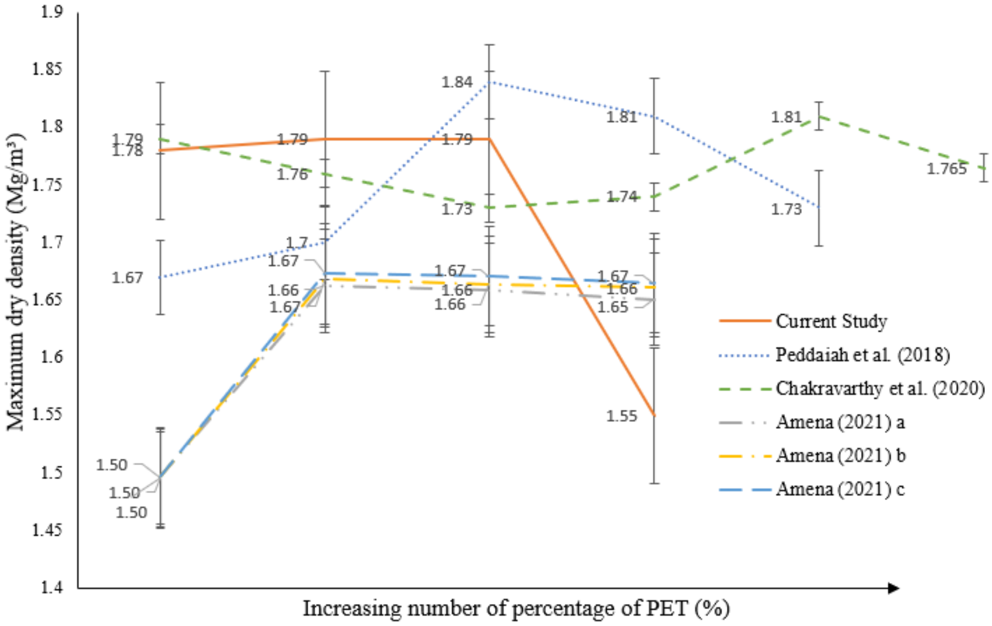

FIGURE 8. Variation of CBR value with increasing PET

Figure 7 illustrates the relationship between PET percentage and OMC. The observed trend in the current study aligns with Chakravarthy et al. (2020) but contrasts with the findings of Peddaiah et al. (2018). In this study, the maximum OMC was achieved at 0.6% PET addition, while Chakravarthy et al. (2020) reported the highest OMC at 10% PET content. Peddaiah et al. (2018), however, observed peak OMC at 0.8% PET addition. These results indicate that pure clay soil requires a higher percentage of PET compared to soil containing a mixture of clay and coarse materials.

Figure 8 presents the relationship between CBR and PET percentage. The results indicate that increasing PET content beyond a certain threshold does not enhance the CBR value. The findings align with Peddaiah et al. (2018), who reported a peak CBR value of 16.50% at 0.4% PET content, comparable to the current study's maximum CBR value of 19.08% achieved at 0.3% PET. Understanding the variations in geotechnical parameters with PET percentage is crucial for optimizing soil stabilization and improvement techniques. Furthermore, this knowledge facilitates more accurate predictions of PET-reinforced soil performance under diverse soil conditions.

CONCLUSION

The findings reveal significant relationships between PET content and soil engineering properties. The optimal PET content varies depending on the desired soil characteristic. At 0.3% and 0.6% PET content, both OMC and MDD reached their peak values with 15.3% and 1.79 Mg/cm³ respectively, indicating enhanced soil compaction properties. However, for permeability control, 0.9% PET content proved most effective in reducing water flow through the soil matrix. The lowest PET content tested at 0.3% PET yielded the highest CBR value of 21.81%, suggesting that even small amounts of PET can significantly improve soil bearing capacity. These results demonstrate that PET waste can be effectively utilized for soil improvement, with the optimal content varying based on the specific engineering property targeted for enhancement. Future recommendations include conducting Scanning Electron Microscope (SEM) studies to understand the behavior of PET sheet-stabilized soil. Also, careful consideration must be given to selecting the appropriate PET content based on the primary soil property requiring improvement.

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DECLARATION OF COMPETING INTEREST

None.

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