Soil Stabilization using Polypropylene Clamshell Food Containers

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Abstract. Soil stabilization is the method of improving the physical properties of soil, such as shear strength and bearing capacity of the soil, by using controlled compaction or the addition of admixtures to produce an improved soil material that has all the desired engineering properties. The new technique of soil stabilization uses plastic waste as an alternative material is of outmost crucial since plastic wastes are non-biodegradable and remain intact after being buried in soil for many years. The present study is focused on investigating the effectiveness of utilizing polypropylene clamshell food containers as soil stabilizers. The physical properties of the untreated clayey soil are determined by conducting moisture content, specific gravity, particle size distribution, and the Atterberg limit test. Also, the Standard Proctor compaction test, as well as the unconfined compressive strength test, are carried out to determine the compaction and strength parameters of the soil sample before and after reinforcing with different percentages of polypropylene clamshell food container strips such as 0.4%, 0.8%, and 1.2%. Findings from this study indicate that the addition of polypropylene clamshell food container strips in the clayey soil is capable of becoming a soil stabilizer agent as the optimum compressive strength of the soil was achieved with replacement of 0.8% of plastic strips, along with increasing the Optimum Moisture Content (OMC) while decreasing the Maximum Dry Density (MDD). Successful implementation of polypropylene plastic in soil stabilization can help minimize the volume of plastic waste in the environment, which then leads to developing a sustainable future by utilizing recyclable material as alternative sources in the geotechnical field.

1. Introduction
Soils substantially have low shear and tensile strength, where their characteristics highly depend on the surrounding area. Consequently, soil requires adequate reinforcement to enhance the basic properties in order for construction to be built over the soil structure. Soft clay soil, also known as saturated clay soils, has low shear strength values but high values for compression and secondary compression and creep behaviour. Clay soils are considered problematic soil due to the high compressibility properties of clay soils, which eventually resulted in settlement under loading, with swelling or compression when in contact with water [1].

Stabilization can improve the shear strength and overall bearing capacity of soil with the addition of stabilizing agents. Once stabilized, the permeability of soil decreases, which in turn reduces the shrink/swell potential of soil where the soil volume change depending on temperature and moisture content. Results of the California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) test deduced that the bearing capacity and compression strength of soil is improved with the addition of 1.0% and 0.50% combination of plastic waste and plastic granules, respectively [2].
The soil stabilization process involves determining proper additives and admixtures rates to be applied to attain the desired engineering properties as a result of improving the parameters such as shear strength, compressibility, and density. All these years, many road engineers have applied traditional admixtures such as lime, cement, and fly ash to increase the properties of the soil. Thereby laboratory and field performance testing had proved that the inclusion of such stabilizer agents could improve the strength and stability of the soils. Nevertheless, the application of these additives may result in a costly method, as stated by [3], where the cost of soil stabilization is minimized if the plastic strips prepared from waste plastic bottles are used for soil stabilization instead of those expensive admixtures such as cement and lime, etc. As construction on weak soil is a great challenge in the field of geotechnical engineering, the need to improve the quality of soil using soil stabilization is becoming more crucial. As a result, new methods are continuously being explored to improve the strength properties and decrease the swell behaviour of soil. Reusing plastic waste as an admixture for soil stabilization is not only an eco-friendly method for improving the subgrade soil of pavement besides reducing the amount of plastic waste efficiently but also a cost-effective and energy-saving method. Several studies have proved that the application of plastic waste in soil will contribute to the development of soil's strength characteristics.

Nowadays, people would prefer to use clamshell containers as an ideal packaging material for food since such packaging is not only lightweight and durable enough to keep the food inside safe but also comes with secure protection where the containers are more easily opened and can be resealed [4]. The rise in food delivery services in the present moment during Covid-19 lockdowns worldwide will further drive the usage of plastic food containers [5]. Due to that, people usually use them only once before being thrown away into bins or littering along the streets, which contributes to the exponential increase in the use of single-use plastic [6]. Therefore, an attempt is made in this paper to investigate the effectiveness of utilizing polypropylene clamshell food containers as soil stabilizer.

2. Methodology

2.1. Sample collection

2.1.1. Clayey soil. About 30 kg of clayey soil samples were collected by using a hoe and shovel from Kampung Parit Satu Barat, Sungai Besar, Selangor and brought to the soil mechanics laboratory for testing. The soil sample was placed in polyethylene bags and was tied tightly to prevent the loss of moisture content. A soil index test was conducted to determine the physical properties of soil such as moisture content, particle size distribution, specific gravity, plasticity, compaction, and strength characteristics.

2.1.2. Polypropylene clamshell food containers. The clamshell plastic food containers used in this study were made of polypropylene which is categorised among the types of plastic with resin number 5. The strips were prepared from polypropylene clamshell food containers bought from a convenience store, 99 Speedmart in Taman Seroja, Bandar Baru Salak Tinggi, Sepang, Selangor. The food containers were cut manually into strips with a dimension of 2 mm x 20 mm using a scissor. The strips that pass through the 10mm sieve test are used as a stabilizer to reinforce the clayey soil with different proportions of 0.4%, 0.8%, and 1.2% by weight of the soil, respectively.

2.2. Sample preparation

The soil sample was prepared for compaction and strength test by mixing with various percentages of polypropylene clamshell food container strips, i.e., 0.4%, 0.8%, and 1.2%. Table 1 shows the proportions of polypropylene clamshell food container strips that were added into clayey soil as an additive for sample preparation. The percentages of plastic strips used in this study are based on a previous study carried out on discarded plastic waste [7].
2.3. Soil index test

2.3.1. Moisture content. Moisture content is determined as the ratio of the water mass contained in the soil to the mass of the dry soil. The soil sample was oven-dried for 24 hours at the temperature of 110°C±5°C to obtain the percentage of water contained in the soil sample in accordance with BS 1377: Part 2:1990:3.2. The moisture content of the soil sample is determined by obtaining the average reading of three samples.

2.3.2. Particle size distribution & hydrometer test. Sieve analysis test is carried out to measure the distribution of particle size in the soil sample. 2kg of subsample is used in the wet sieve method based on BS 1377: Part 2:1990:9.2 to separate coarse-grained particles from fine-grained particles that passed through 63 μm mesh sieve. In the dry sieve method, the retained fractions were oven-dried then passed again into a nest of sieves; 5mm, 4.75mm, 3.35mm, 2mm, 1.18mm, 0.6mm, 0.425mm, 0.3mm, 0.212mm, 0.15mm, and 0.063mm in accordance with BS 1377: Part 2:1990:9.3. Hydrometer test is conducted in accordance with BS 1377: Part 2:1990:9.5 for the particle size smaller than 0.063 mm where 50g of soil sample were used.

2.3.3. Specific gravity. Specific gravity is determined as the ratio of the weight of a given volume of soil to the weight of water displaced by soil. The pycnometer method is used to determine the particle density of soil sample in accordance with BS 1377: Part 2:1990:8.3. This test was performed using three density bottles, each filled with 20 g of oven-dried soil sample and de-aired distilled water. The density bottles were placed in a desiccator for one hour to remove entrapped air. The specific gravity of the soil sample is obtained by calculating the average specific gravity of the three samples tested.

2.3.4. Atterberg limit. Cone penetration test based on BS 1377: Part 2:1990:4.3 is carried out to determine the liquid limit of the fine-grained soil sample meanwhile, the plastic limit is measured as the gravimetric moisture content in accordance with BS 1377: Part 2:1990:5.3, at which soil sample was rolled until the diameter of the thread reaches 3.2 mm without splitting. The difference in values of liquid limit and plastic limit is determined as plasticity index, as a means of classifying the soil plasticity.

2.4. Standard Proctor compaction test
In accordance with BS 1377: Part 4:1990:3.3, A Standard Proctor compaction test is conducted to determine the compaction parameters, i.e., Optimum Moisture Content (OMC) and Maximum Dry Density (MDD). A 2.5kg rammer falling through a height of 300mm is used to compact the soil
sample mixed with 100mL of water in three layers with 25 evenly distributed blows on each layer into a compaction mould, as shown in figure 1. This test was conducted repeatedly for untreated clayey soil sample and treated clayey soil sample with varying proportions of 0.4%, 0.8%, and 1.2% of polypropylene clamshell food container strips, as shown in figure 2.

2.5. Unconfined compressive strength test (UCT)

The unconfined compressive strength of soil is measured as the maximum value of compressive force per unit area that the soil sample can sustain. The unconfined compressive strength test in accordance with BS 1337: Part 7:1990: 7 was carried out on four cylindrical specimens with each dimension of 100 mm in length and 50 mm in diameter that was extruded directly from compaction specimens as shown in figure 3 then they were tested immediately. This test was conducted using a load frame apparatus, as shown in figure 4, to determine the maximum compressive strength of untreated clayey soil sample and treated clayey soil sample with varying proportions of 0.4%, 0.8%, and 1.2% of polypropylene clamshell food container strips. The readings of the force measuring device and the axial deformation gauges were recorded simultaneously at regular intervals of compression. Several sets of readings were obtained in order to define the stress-strain curve.
3. Results and discussion

3.1. Physical properties of soil sample
The physical properties of untreated clayey soil are determined by conducting moisture content, specific gravity, particle size distribution, and the Atterberg limit test. Based on the physical properties test conducted, the soil sample is classified as clayey SILT of Intermediate Plasticity (CI) according to British Soil Classification System (BSCS). Details of the soil index properties are shown in table 2.

Table 2. Physical properties of soil sample.

| Soil Properties        | Test Values |
|------------------------|-------------|
| Colour                 | Dark brown  |
| Moisture content       | %           |
| Specific gravity       | 2.26        |
| Particle size distribution |          |
| (a) Gravel             | %           |
| (b) Sand               | %           |
| (c) Silt               | %           |
| (d) Clay               | %           |
| Liquid Limit, LL       | %           |
| Plastic Limit, PL      | %           |
| Plasticity Index, IP   | %           |
| Soil Classification    | CI          |

3.2. Standard Proctor compaction test
The plot of compaction curves where dry density against moisture content of soil sample reinforced with varying proportions of 0.4%, 0.8%, and 1.2% of polypropylene clamshell food container strips as shown in figure 5.

Figure 5. Compaction curves of soil samples.

It is proven based on a series of conducted compaction test that by mixing plastic strips with clay soil at different replacement of 0.4%, 0.8%, and 1.2% by weight of soil respectively, the Maximum
Dry Density (MDD) decrease concurrently with the increase of Optimum Moisture Content (OMC) in comparison to untreated soil due to the presence of plastic strips that filled up the voids in between soil particles thereby reducing the soil permeability. Table 3 shows the Maximum Dry Density (MDD) significantly fell from 1.171Mg/m³ to 1.102Mg/m³ with an increase in the proportion of plastic strips from 0% to 1.2% by weight of the soil. Conversely, the Optimum Moisture Content (OMC) gradually increased from 42.83% for untreated soil to 48.04% for soil stabilised with 1.2% plastic strips replacement. It may be disclosed based on the findings that the compacted soil samples become denser as a result of the volume of air in the soil sample slowly depleted, which also contributed by the reduction in soil content with respect to the increment of the plastic percentage by 0.4%, thereby caused reduction in dry density of soil.

Table 3. Optimum moisture content and maximum dry density of soil samples.

| Sample                                      | Optimum Moisture Content (OMC) (%) | Maximum Dry Density (MDD) (Mg/m³) |
|---------------------------------------------|-----------------------------------|----------------------------------|
| Clayey soil (100%)                          | 42.83                             | 1.171                            |
| Clayey soil + 0.4% Polypropylene clamshell food container strips | 44.45                             | 1.135                            |
| Clayey soil + 0.8% Polypropylene clamshell food container strips | 46.25                             | 1.117                            |
| Clayey soil + 1.2% Polypropylene clamshell food container strips | 48.04                             | 1.102                            |

Figure 6 and figure 7 reveal the results of compaction tests on untreated and treated soils with plastic waste. Both figures also indicate the comparison results of this study with previous research results of soil mixed with different plastic waste. Previous studies conducted by [2], [8] and [9] revealed that the Maximum Dry Density (MDD) increased at 0.5% of plastic waste replacement by weight of the soil meanwhile, [7] proved that with the addition of 0.4% of discarded plastic waste but further increasing the percentage of plastic will result in the reduction of Maximum Dry Density (MDD). However, the current study shows a declining trend in Maximum Dry Density (MDD) values from 0% to 1.2% of polypropylene clamshell food container strips by weight of the soil.

Figure 6. Maximum dry density comparison between study and previous research.
The studies done by [2] and [7] revealed that the Optimum Moisture Content (OMC) values initially decrease with 0.5% and 0.4% plastic waste replacement, respectively. However, beyond those percentages of plastic replacement, the Optimum Moisture Content (OMC) was observed to increase gradually. Meanwhile, [8] and [9] gained the highest Optimum Moisture Content (OMC) when reinforced with 2% of plastic waste. However, this study found that the Optimum Moisture Content (OMC) values gradually increased from low to high percentage of polypropylene clamshell food container strips.

![Optimum Moisture Content](image)

**Figure 7.** Optimum moisture content comparison between study and previous research.

### 3.3. Unconfined compressive strength test

The stress-strain curves are plotted as shown in figure 8 for soil sample reinforced with varying proportions of 0.4%, 0.8%, and 1.2% of polypropylene clamshell food container strips. The stress at first increases quickly while the strain increases slowly, but as the soil yields, the strain increases dramatically while the stress levels are off.

![Stress vs Axial Strain %](image)

**Figure 8.** Stress against strain curves of soil samples.
It is proven based on a series of unconfined compressive strength tests that by mixing polypropylene clamshell food container strips with clayey soil at different replacements of 0.4%, 0.8%, and 1.2% by weight of soil, respectively, the unconfined compressive strength values keep increasing then decreasing after 1.2% of plastic strips was added to the soil. The unconfined compressive strength value of untreated clayey soil was found to be 18.2kN/m$^2$. With the addition of 0.4% of polypropylene clamshell food container strips, the unconfined compressive strength value slightly increased to 18.8kN/m$^2$. After that, the unconfined compressive strength value significantly rose to 44.9kN/m$^2$ with the addition of 0.8% of plastic strips. Further increase in the plastic replacement at 1.2% of plastic strips by weight of the soil showed a decrease in the unconfined compressive strength value, which was determined to be 37.8kN/m$^2$. This is because clay content replacement by polypropylene clamshell food container strips caused a reduction of cohesive force in the soil sample. Compaction reduces the gaps between the soil particles when the water trapped inside the soil matrixes expels from soil pore holes caused a reduction in the dry density of soil and enhanced the bond between the particles, thereby increasing the compressive strength of the soil.

Figure 9 indicates the comparison results of unconfined compression tests of this study with previous research results on untreated and treated soils with different plastic waste. Previous studies conducted by [2] and [8] revealed that the unconfined compressive strength values increased at 0.5% of plastic waste replacement by weight of the soil. Meanwhile, [9] proved that the strength values increased with an addition of 1% discarded waste plastic covers, such as milk and curd packets but afterward, it decreases in unconfined compressive strength values with further addition of plastic waste. However, this study found that the unconfined compressive strength values significantly increased at the insertion of 0.8% of polypropylene clamshell food container strips by weight of the soil.

![Unconfined Compressive Strength](image)

**Figure 9.** Unconfined compressive strength comparison between study and previous research.
Table 4 reveals the findings on strength parameters of soil samples for unconfined compressive strength and shear strength.

| Sample                        | Unconfined Compressive Strength $q_u$ (kN/m²) | Shear Strength $S_u$ (kN/m²) |
|-------------------------------|-----------------------------------------------|-------------------------------|
| Clayey soil (100%)            | 18.2                                          | 9.10                          |
| Clayey soil + 0.4% Polypropylene clamshell food container strips | 18.8                                          | 9.40                          |
| Clayey soil + 0.8% Polypropylene clamshell food container strips | 44.9                                          | 22.45                         |
| Clayey soil + 1.2% Polypropylene clamshell food container strips | 37.8                                          | 18.90                         |

This study proved that the unconfined compressive strength was clearly affected by a further increment of polypropylene clamshell food container strips. There is an increase in soil cohesion with the addition of plastic strips in the soil sample, which leads to an increase in unconfined compressive strength. However, further increase in plastic content led to a decrease in cohesion and thereby decrease in soil strength. In addition, the shear strength of soil, which is directly related to cohesion, shows a similar pattern such that a maximum value of 22.45 kN/m² is obtained at 0.8% plastic replacement, but thereafter, the value decreases. It may be inferred from the results of the study that the strength of the treated soil up to the addition of 0.8% of plastic strips had increased, however thereafter, it decreased eventually at 1.2% of plastic replacement. Hence, the optimum percentage of polypropylene clamshell food container strips to be added as a stabilizer is found at 0.8% by weight of dry soil.

4. Conclusion
The engineering properties of the soil sample collected from the study area are classified as clayey SILT of Intermediate Plasticity (C1). The effect of adding the polypropylene clamshell food container strips with soil samples at different replacement of 0.4%, 0.8%, and 1.2% by weight of soil, respectively, has caused the Maximum Dry Density (MDD) to decreased. At the same time, the Optimum Moisture Content (OMC) increased. Meanwhile, the unconfined compressive strength of soil was found to have increased for soil treated up until the addition of 0.8% of plastic strips. Still, afterward, it eventually decreased at 1.2% of plastic replacement. Based on the observations on strength characteristics, it is noted that the optimum proportions of polypropylene clamshell food container strips to stabilize the clayey soil is found at 0.8% by weight of dry soil. Overall, it can be deduced that the polypropylene clamshell food container strips are suitable as a soil stabilizer in improving the strength characteristics of the soil. Successful implementation of polypropylene plastic in soil stabilization can help to minimize the volume of plastic waste in the environment, leading to a sustainable future by utilizing recyclable material as alternative sources in the geotechnical field.

5. References
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