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# Stabilizing Peat Soil with Plastic Waste

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## Abstract

This study explores the differences in properties between natural peat soil and peat soil with added increments of polyethylene terephthalate (PET) plastic waste. The objective is to compare the shear strength of untreated peat soil with that of peat soil treated with varying amounts of plastic strips. Four soil samples were used in this study i.e. natural peat soil without any plastic strips, peat soil with 0.4%, 0.5%, and 0.6% plastic strips (by mass). The plastic strips, used as stabilizers, were cut to a size of 15mm x 15mm. The peat samples were collected from Mardi Pontian, Johor. The index properties of the peat soil were determined using the Atterberg limit, sieve analysis, and loss on ignition test. The Standard Proctor compaction test results align with the research objective of determining the optimum values for maximum dry density (MDD) and optimum moisture content (OMC) for both the untreated and treated peat soils. The strength of both untreated and treated samples was assessed using unconfined compressive strength (UCS) tests conducted at 0 and 28 days of curing. Laboratory tests revealed that the natural peat soil has a moisture content of 250% and an organic content of 77%. The specific gravity ranged from 1.48 to 1.8. The liquid limit was 230, while the plastic limit was not considered applicable due to the nature of peat soil. The addition of plastic strips increased the MDD and decreased the OMC. Notably, the shear strength of the peat soil improved with the addition of 0.6% plastic strips. Based on this study, the optimum MDD and OMC were achieved with 0.4% plastic strip content, while the highest shear strength was observed with 0.6% plastic strip content.

**Keywords:** Soil, Stabilization, Peat Soil, Plastic Waste

## Introduction

Peat soil poses significant challenges for construction and foundation purposes due to its inherent properties. It is characterized by high permeability, compressibility, and consolidation settlement, but it also has low shear strength, bearing capacity, and bulk density. These factors make peat unsuitable for foundation construction as it can lead to excessive settlement when subjected to compressive stress.

Peat forms when organic matter accumulates faster than it decays, often in wetland areas with high water tables where dead vegetation is preserved beneath a layer of soil [1]. In countries like Malaysia, large areas of peat land are present. Peat soil consists of more than 75% organic materials and is known for its low shear strength and high compressibility. It contains humic substances, including humin, humic acids, fulvic acids, and other organic acids [2,3]. According to Huat [4], peat is unsuitable for engineering and construction because accessing the water table is challenging, often being at or above the ground surface in wetland areas. Mohamad Idris and Yusof [5], advised against major building development on peat soil due to the high cost and associated risks.

To improve peat soil for construction, it needs to be treated to enhance its properties. Soil stabilization refers to methods that alter the natural soil's characteristics physically, chemically, mechanically, biologically, or through a combination of these methods to meet engineering requirements [6]. One area of interest in soil stabilization is the use of waste materials, such as plastics, which although are a significant creation by humans, their disposal poses environmental threats. By stabilizing peat soil, its strength and stability can be increased, making it more suitable for construction purposes.

One approach to soil stabilization is the incorporation of waste materials, such as plastics. While plastics are a notable human invention, their management and disposal pose significant environmental challenges. By using plastics in soil stabilization, it may be possible to improve the engineering properties of peat soil while addressing some issues related to plastic waste. Overall, while peat soil's natural properties make it unsuitable for construction, appropriate stabilization techniques can enhance its properties, making it a viable option for construction purposes.

When plastic waste is disposed of carelessly in landfills, greenhouse gases such as methane and ethylene are released into the atmosphere when the plastics are exposed to sunlight for extended periods [7]. This research explores the potential of using plastic waste as a soil stabilizer. Previous studies have shown that plastic waste can enhance the strength of weak soils. Choudhary et al. [8] investigated the addition of plastic strips to flexible pavements, finding a noticeable increase in the California Bearing Ratio (CBR) value. The incorporation of plastic bottle strips into silty sand resulted in improved maximum dry unit weight, shear strength parameters, and CBR value. Specifically, 0.4% plastic content improved the soil's engineering properties [6]. Kassa et al. [9] studied the use of waste plastic materials for strengthening and stabilizing clayey soils. Plastic waste was broken into smaller strips and mixed into the soil at rates of 0.5%, 1%, and 2% by weight of dry soil. The study revealed a significant increase in the soil's shear strength (SS) values.

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The research aims to investigate the effect of different percentages of plastic bottle strips added to peat soil. Using plastic waste as a stabilizer is an eco-friendly method for soil stabilization. Various tests are conducted on soil samples to determine soil properties, maximum dry density, optimum moisture content, and shear strength. These tests include the Atterberg limit, standard Proctor test, and unconfined compressive strength of peat soil and peat soil with stabilizers, all carried out as per British Standard (BS 1377-2:2022). Utilizing plastic waste in soil stabilization not only enhances the engineering properties of weak soils like peat but also offers a sustainable solution to managing plastic waste. The integration of plastic waste into soil stabilization practices can contribute to improved soil strength and environmental sustainability.

## *Literature Review*

Johor hosts the largest range of coastal estuary biological systems in Peninsular Malaysia, encompassing various wetland types such as seagrass beds, mangrove swamps, coral reefs, riparian borders, and peat swamp forests. The peat soils in Johor have developed on different substrates: marine soils, marine clays, and acidic sulfate soils. Specifically, the peat on Johor's west coast overlies acidic sulfate soil, while the east coast peat rests on sand and clay. Peat has traditionally been used as an alternative to firewood for cooking and heating in temperate and northern regions of Europe. However, with the increasing use of gas and oil for these purposes during the 20th century, the domestic use of peat declined. Despite this, the high demand for electricity has led to the development of large power plants fueled by peat. More recently, peat has been used for power generation in small units ranging from 20 to 1,000 kW. The carbon and hydrogen content of peat make it a viable fuel source [10]. In agriculture, peat is mixed with mineral soil to enhance the moisture-holding capacity of sandy soils and improve the water infiltration rate of clayey soils.

Engineers have noted that peat is a particularly hazardous soil, best avoided when possible. Peat or organic soil is very soft and prone to instability, such as localized sinking and slip failures. It also undergoes significant primary, secondary, and even tertiary settlement under moderate load increases. These characteristics make peat an unreliable foundation material, leading to substantial challenges in construction and engineering projects. While peat serves useful purposes in agriculture and as a fuel source, its properties pose significant challenges for engineering and construction. The unstable nature of peat soils necessitates careful consideration and often avoidance in construction projects, particularly in regions like Johor where extensive peatlands exist.

Peat soils, like other organic soils, can undergo significant chemical and biological changes over time. These changes can further modify the soil's mechanical properties, such as compressibility, shear strength, and hydraulic conductivity. Lowering the groundwater table can cause the peat to shrink and oxidize, leading to increased humification, permeability, and compressibility. A comprehensive review of the literature indicates that significant work has

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been done globally to determine the engineering behavior of peat soil. Thirteen research articles on the stabilization of peat soil and other soil types using plastic waste and other stabilizers were referenced for this study (Table 1). These studies demonstrate that using various stabilizers can significantly enhance the properties and strength of peat soil.

According to a study Almsedeen et al. [11], unconfined compressive strength (UCS) test results show that stabilizing peat soil with MgO improves its strength significantly. Research on peat soil with shredded tire chips indicated significant improvement in geotechnical properties. The highest unconfined compressive strength was observed at 10% stabilizer content [12]. Numerous studies have used plastic bottle strips as stabilizers for various soil types, including silt soil. These studies have shown that adding plastic strips can increase soil strength. For instance, Peddaiah et al. [13] investigated the effect of plastic bottle strips on silty sand, conducting tests like compaction, direct shear, and California bearing ratio (CBR) with various amounts of plastic strips and different aspect ratios in terms of length. The stabilization of peat soil using various stabilizers, including plastic waste, has shown promising results in improving soil properties and strength. This approach not only enhances the engineering characteristics of weak soils but also offers an environmentally friendly solution for managing plastic waste. By leveraging these stabilization techniques, the challenges associated with peat soil in construction and engineering can be effectively addressed.

The laboratory tests have shown that plastic can effectively be used as a stabilizer to address both waste disposal problems and to stabilize weak soils (Table 1). Significant improvements were observed in maximum dry unit weight, shear strength parameters, and California Bearing Ratio (CBR) values when plastic reinforcement was used in soil. The extent of improvement in soil properties depends on the type of soil, the amount of plastic content, and the length of the plastic strips used. Research has shown that a 0.4% plastic content with strips can effectively alter the engineering properties of silty sand. Previous studies have varied the percentage of plastic strip added from 0.2% to 2% by weight of the soil sample. While there have been no specific studies on peat stabilized with plastic bottle strips, past research on other soils suggests that similar improvements in soil strength can be expected. For this research, the percentage of plastic bottle strips used was 0.4%, 0.5%, and 0.6% by weight of the soil sample. This range is chosen based on previous findings and aims to determine the optimal plastic content for stabilizing peat soil.

## Problem Statement

Peat soil is a significant soil type in Malaysia, covering approximately 3.0 million hectares or 8% of the country's total land area. Peat soil is challenging in construction due to its low strength and high water content, which can lead to instability and significant settlement over time. This poses risks and challenges for engineering projects. Peat deposits can vary in depth, with shallow deposits typically less than 3m thick and deep deposits exceeding 5m in Malaysia. The

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sample of peat for this research was retrieved from MARDI, Pontian, Johor, not exceeding a depth of 0.5m due to the high water table. Traditional stabilizers and methods for peat soil, such as steel and other admixtures, are costly. As an alternative, non-traditional stabilizers, particularly plastic waste, have gained attention due to their ease of application, short curing period, and potential for reducing environmental pollution. Using plastic waste as a stabilizer reduces pollution and finds an economical use for plastic waste that would otherwise persist in the environment for a long time. Understanding how plastic waste can improve the properties of peat soil could lead to more sustainable and cost-effective construction practices, particularly in regions with extensive peat deposits like Johor, Malaysia. This study aims to contribute to the understanding and application of plastic waste as a stabilizer for peat soil, providing practical insights into its effectiveness and optimal usage. By addressing the objectives outlined, the research will provide valuable data for engineering projects dealing with peat soil stabilization and contribute to sustainable development practices.

**Table 1.** Properties of different soil and stabilizer

| Author | Type of Soil | Stabilizer | SG | LL (%) | PL (%) | IP (%) | OMC | MDD (kg/ m³) | UCS (kPa) |
|---|---|---|---|---|---|---|---|---|---|
| Samsuddin, [14] | Peat | Em | 1.45 | 70 | 48 | 22 | - | - | 20.93 |
| Razali et al. [15] | Peat | - | 1.38-1.70 | 220 | - | - | 80 | 7.5-10.2 | - |
| Gangwar and Tiwari, [6] | Silt | Plastic bottle strip | - | 53 | 35 | 18 | 14 | 1.5 | - |
| Bhattarai et al. [16] | Silt | Plastic strip | 2.38 | 73 | 47 | 30 | 17.10 | 1.6 | - |
| Yacob and Som, [3] | Peat | Magnesium oxide | 0.6 | - | - | - | 0.89 | - | 35 |
| Rahgozar and Saberian,[12] | Peat | Shredded tyre chip | - | 335 | - | - | 0.88 | 0.16-0.21 | 40.5 |
| Kolay et al. [17] | Peat | Class F pond ash | 1.21 | 202 | - | Np | - | - | - |
| Peddaiah et al. [13] | Natural soil | Plastic bottle strip | 2.68 | 34 | 25 | 9 | 16.8 | 16.75 | 19 |
| Mali et al. [18] | Black cotton soil | Plastic waste | 2.12 | - | - | - | 23.77 | 16.40 | - |
| Mallikarjuna and Bindu Mani, [19] | Cotton soil | Plastic waste strip | 2.62 | 68.5 | 33.3 | 35.2 | 17.4 | 16.50 | - |
| Bhuvaneshwari et al. [20] | Expansive soil | Flyash | - | 30 | 21 | 9 | 14 | 16.00 | 11.76 |
| Gardete et al. [21] | Clayed soil | Plastic waste, tyre fibre | - | 20.6 | 31.5 | 10.9 | 12.8 | 19.20 | - |

## *METHODOLOGY*

This study focuses on the utilization of plastic bottle strips as a stabilizer for peat soils, retrieved from MARDI, Pontian Johor. The research aims to improve the compressive strength of peat soil, which is characterized by low shear strength, high compressibility, and high permeability, making it unsuitable for construction purposes. Plastic bottle strips are chosen as the stabilizer in this research. They are shredded into small sizes, approximately 15mm x 15mm, and added in varying percentages (0.4%, 0.5%, and 0.6% by weight of soil) to assess their effectiveness.

### *Testing Methods:*

- Sieve Analysis: conducted to determine the particle size distribution of the peat soil sample.
- Atterberg Limits: used to determine the liquid limit, plastic limit, and plasticity index of the peat soil.
- Loss on Ignition: performed to estimate the organic content in the peat soil sample.
- Standard Proctor Test: carried out to establish the optimum moisture content and maximum dry density of both untreated peat soil and peat soil stabilized with plastic bottle strips.
- Unconfined Compressive Strength (UCS) Test: conducted to measure the shear strength of the soil samples. Tests are performed at 0 and 28 days of curing to assess both immediate and long-term effects of stabilization.

### *Materials Preparation*

The soil samples were tested to determine their properties using Atterberg limits test, loss on Ignition, and sieve analysis according to the standards outlined in BS 1377-2:2022. Engineering tests were conducted to establish the optimum moisture content and maximum dry density for both peat soil and peat soil with varying percentages of plastic strip content. The samples were then subjected to an Unconfined Compression Test (Proving ring type) to determine their shear strength. The peat soil samples were tested immediately after preparation and after 28 days of air curing. The results of all physical and engineering tests are tabulated in Table 2 and Table 3. Pontian, located in the state of Johor, is known for its problematic peatlands. The study area was situated at the Museum Nanas, MARDI station, Pontian, Johor. Plastic waste bottles were collected and cut into small sizes approximately 15 mm x 15 mm, then mixed with the peat soil in increments of 0.4%, 0.5%, and 0.6% by weight of the soil. Various tests were conducted on the soil samples to determine their properties and shear strength, alongside the optimum values of moisture content and dry density. Figure 1 and 2 shows a sample of a plastic bottle strip and depicts the locations of sample collection.

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**Figure 1.** Plastic bottle strip 15mm × 15mm

**Figure 2.** Collection of soil sample

## Results And Discussion

The physical and engineering properties of natural peat and stabilized peat soil were investigated in the Geotechnical and Rock Mechanics Laboratory at the Universiti Teknologi Malaysia, Johor. Initially, half of the samples were dried in an oven at 80°C for 24 hours, while approximately 30g of soil was kept in a container and oven-dried to determine the soil's natural moisture content. Table 2 presents the basic properties of untreated peat.

**Table 2.** Basic properties of peat soil

| Soil Property | Average Value |
|---|---|
| Natural Moisture Content | 250% |
| Organic Content | 77% |
| Specific Gravity | 1.48-2.80 |
| Liquid Limit | 230 |
| Plastic Limit | NP |
| Plasticity Index | - |
| Bulk Density | 1.05 g/cm$^3$ |
| Dry Density | 0.52 g/cm$^3$ |

The natural moisture content of peat is 250%, indicating that the water content in the soil is about 250% of the total mass of peat soil. Huat et al. [22] emphasized that peat soil has high natural water holding capacity due to its structure, which contains organic coarse particles. The loose and hollow structure of these coarse particles allows peat to retain a significant amount of water.

The specific gravity of peat soil ranges from 1.48 to 2.8 $Mg/m^3$, indicating that peat soil is denser than water. According to Rahgozar and Saberian [12], substances with a specific gravity greater than 1 are denser than water and will sink in it, disregarding surface tension effects. The organic content of the soil is 77%, which qualifies it as peat. Peat is distinguished from other organic soil materials by having organic matter of more than 75% and ash content of less than 25% by dry weight [1].

The liquid limit value is high at 230%, due to the high water content in the soil. However, Atterberg limits are not appropriate for peat and highly organic soils. More suitable index tests for assessing peat's geotechnical behavior include natural water content, organic content, and degree of humification [23]. The bulk density of peat is observed to be 1.05 $g/m^3$, while the dry density is 0.52 $g/m^3$. According to the Guideline for Construction on Peat and Organic Soils in Malaysia, peat has a low bulk density ranging from 0.95 to 1.15 $g/m^3$.

### *Particle Size Distribution Analysis*

Sieve analysis was conducted to determine the soil size distribution, ranging from a 2mm sieve size down to the pan. Based on the particle size distribution in Figure 3, the soil is classified as fines fraction, which refers to the portion of soil composed of particles passing through a 63 µm test sieve (<2 mm). Fine fraction generally includes particles smaller than 2 mm that pass through a 2 mm sieve.

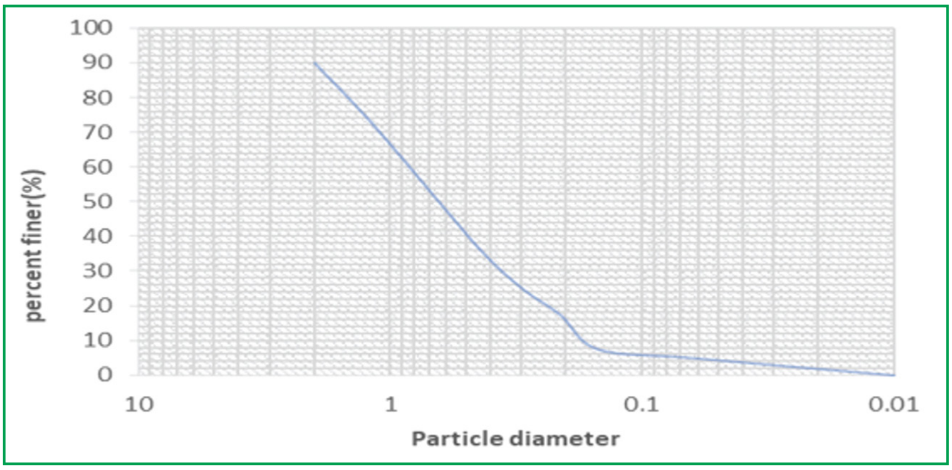


**Figure 3.** Particle distribution of peat soil

### *Standard Proctor Compaction*

Figure 4 shows the compaction curves for different percentages of plastic strips, and the results are tabulated in Table 3. The diagonal line represents the optimum values of dry density and moisture content. Based on the results obtained, the maximum dry density (MDD) for natural soil is 0.65 $kg/m^3$. This value increases to 1.5 and 1.85 $kg/m^3$ at 0.4% and 0.5% plastic strip content,

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respectively, but decreases when 0.6% plastic strip content is used. The decrease in MDD is attributed to the insufficient bonding between the solid fraction of soil and the plastic strips as the plastic content increases. This leads to segregation, where the fine soil particles are replaced by the coarser plastic strips during compaction.

The optimum moisture content for peat with plastic content decreases from 25% to 22% and it was found that at 0.5% plastic content, the soil particles and plastic strips bind well and achieve closer packing during compaction. According to O'Kelly [23], the plastic strips break into smaller sizes under compaction efforts, effectively integrating with the soil and promoting further soil compaction. This process eliminates voids in the soil, resulting in higher maximum dry density and lower optimum moisture content. Therefore, the optimal plastic content for the soil is considered to be 0.5%.

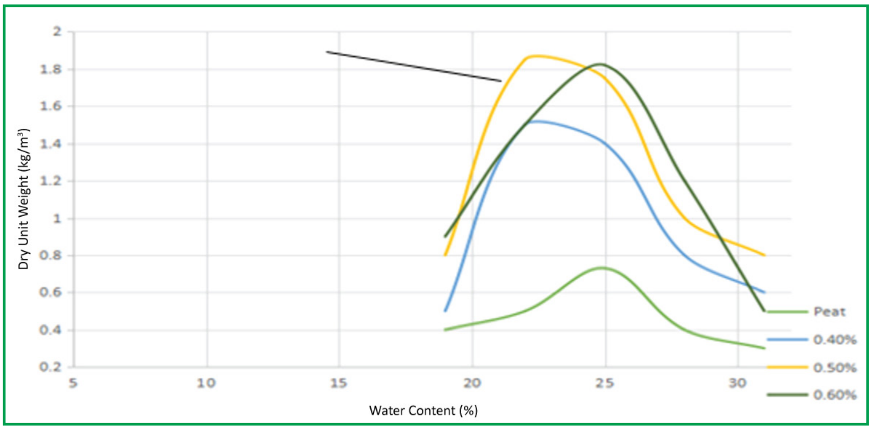



**Figure 4.** Compaction curve

### *Unconfined Compression Strength (Proving Ring Type)*

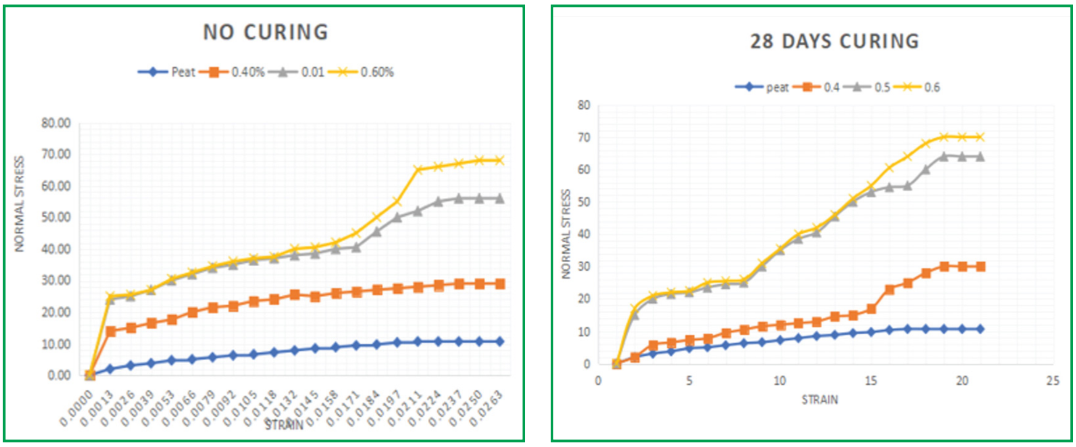
This test is one of the important parameters for observing the shear strength of peat or other soils before and after improvement. Peat soil, with and without reinforcement, underwent Unconfined Compressive Strength (UCS) testing following the guidelines of BS1377:1990, and the results are compared in Figure 5. A calibrated proving ring with a capacity of 2.5 kN and dial gauge accuracy of 0.002 mm, along with a 0.01 mm dial gauge, was used for this test. The soil samples had a diameter and height of 38.6 mm and 76 mm, respectively. It was observed that the peat soil exhibited lower normal stress when reinforced with plastic strips. The samples were then cured for 28 days to observe any changes in shear strength. From the graph, there was a slight difference in normal stress between 0 days and 28 days of curing. Table 3 presents the results of shear strength for peat soil and peat soil with different plastic contents. Peat soil showed lower strength both at 0 days and after 28 days of curing.

The lower shear strength observed in peat soil can be attributed to its natural water content being maintained without the addition of plastic for reinforcement. In contrast, peat soil with 0.6% plastic content exhibited higher shear strength due to the increased presence of plastic strips. The shear stress increased because the plastic pieces were distributed in different directions within the soil samples, thereby increasing the frictional surface between the soil particles and plastic strips. This effect is enhanced by the corrugated surface of the plastic, which contributes to increased cohesion and angle of internal friction.

The increase in the angle of internal friction can be attributed to the higher interlocking capacity between the particles, which depends on the type of plastic added to the soil [24]. Based on these results, it can be concluded that the increment in shear strength is achieved due to the natural surface characteristics of the plastic strips, which enhance both cohesion and angle of internal friction.

**Table 3.** Test results of peat soil with plastic content (15mm x 15mm)

| Sample No. | Percent of Plastic Content | Compaction Parameters | | Shear Strength (kN/m²) | |
|---|---|---|---|---|---|
| | | OMC | MDD | 0 days | 28 days |
| 1 | Peat | 25 | 0.73 | 5.53 | 5.53 |
| 2 | 0.4% | 23 | 1.40 | 14.50 | 15.00 |
| 3 | 0.5% | 22 | 1.75 | 28.00 | 32.00 |
| 4 | 0.6% | 23 | 1.82 | 34.00 | 35.00 |




**(a)** **(b)**

**Figure 5.** Normal stress vs Strain, (a) no curing, (b) 28 days curing

## *Conclusion*

From the experimental laboratory tests carried out, several conclusions can be drawn for peat soil stabilized by plastic strips. In the Standard Proctor test, the maximum dry density was observed to peak at 0.5% plastic content by mass of peat soil and decreased at 0.6%. Similarly, the optimum moisture content was achieved at the same percent of plastic content. The study successfully achieved its second objective to determine the optimal values for moisture content and maximum dry density.

In the Unconfined Compressive Strength test (Proving ring type), the soil with the highest plastic content, 0.6% by mass of soil, exhibited the highest shear strength among the peat soil samples. The increase in cohesion and angle

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of internal friction with 0.6% plastic content resulted in a shear strength of 35 kN/m² after 28 days of curing. The main objective of comparing the shear strength of peat soil with and without stabilizer was achieved.

It can be concluded that the surface characteristics of the plastic strips, whether smooth or corrugated, and the size of the strips significantly affect the strength of peat soil. Using plastic strips derived from waste plastic bottles not only improves the strength of the soil but also helps in addressing the problem of plastic waste disposal. Moreover, this method is economical compared to other admixtures used in previous research.

For optimal results, PET (Polyethylene Terephthalate) plastic bottles should be shredded rather than cut with scissors to obtain strips of more consistent size. Furthermore, to further improve the strength of the soil, it is suggested to use binding agents that enhance the bonding between soil particles and plastic content. These binding agents could also induce chemical reactions with the soil and stabilizer, thereby increasing the soil's strength.

However, there are limitations to this study. The tests were conducted with a small range of plastic content percentages, and the differences in strength observed were relatively small. Further research is recommended with higher percentages of plastic content and the addition of binding agents. Additionally, while PET was used in this study, other types of plastics may offer better performance as soil stabilizers for peat soil.

In conclusion, this research investigated the basic properties and two engineering tests of the soil. For future research, it is suggested to perform additional laboratory experiments such as consolidation and settlement tests, permeability tests, and others to obtain a more accurate characterization of peat soil and its strength improvements. This study demonstrates a significant approach to using plastic waste as a soil stabilizer to enhance soil properties and promote sustainability by reducing plastic waste disposal in landfills.

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## Conflicts of Interest

The authors declare no conflict of interest.

## Author Contributions

**Nurul Syahira Izaty Abu Hassan:** writing, original draft preparation. **Dayang Zulaika Abang Hasbollah:** writing, reviewing, editing. **Nordiana Mohd Muztaza:** supervision, methodology. **Yuliana Yuliana:** visualization, validation.

## Data Availability Statement

The data used to support the findings of this study are included within the article.

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