MULTIDISCIPLINARY APPLIED RESEARCH AND INNOVATION
e-ISSN: 2773-4773

MARI

Vol. 6 No. 4 (2025) 127-135
https://publisher.uthm.edu.my/periodicals/index.php/mari

Unconfined Compressive Strength (UCS) of Soft Clay Stabilize with Coffee Ground for Batu Pahat Soft Clay

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DOI: https://doi.org/10.30880/mari.2025.06.04.019

Article Info

Received: 01 September 2025
Accepted: 15 October 2025
Available online: 01 December 2025

Keywords

Coffee Ground, Clay Soil, Soil Strength, Soil Stabilizer, Unconfined Compressive Strength (UCS)

Abstract

Soil stabilisation using food waste compost has been used for the improvement of soft soil, in improving the shear strength and limiting the deformation behaviours. In this research, composition treatment has been found to be very helpful in the process of improving soft soil characteristics. The aim of this study is to determine the successfullness potential of coffee grounds and the posibility has been tested through Unconfined Compressive Strength (UCS) test. The overall result that were obtained showed the improvements in soil's physical properties, strength and stability and it was resulted in the change of category from very soft soil to soft soil. The comparison between of 20% coffee ground 28 days curing UCS test result, 25 kPa and 0% of coffee ground UCS test result, 10.9 kPa proved a positive progress between stabilized and unstabilized soil. This indicates that the more percent of additives is added, the more stabilized the soil will be. As this research shows that 20% of coffee ground with 28 days of curing has proven to be the best percentage to stabilize the soil.

1. Introduction

Soft clay is a common soil type encountered in various civil engineering applications. However, its inherent properties, such as high-water content and low strength, often pose challenges for construction projects. It includes instability, excessive settlement, and difficulty in bearing loads. So that, engineers must have the ability to make sure of a diverse form of soil for use as production purpose [1]. To overcome these problems, soil stabilization techniques are employed to enhance the mechanical properties of soft clay. Recently, research has focused on utilizing more sustainable and eco-friendly alternatives for soil stabilization such as by using coffee grounds. In most cases, an environmental benefit is combined with the technical and economic advantages of using these additives, since an industrial by-product is reused [2].

Back in the early days, engineers would avoid sites and construction materials that were unsuitable whenever the requirements conditions for the construction weren't fulfilled. An approach known as "soil stabilization" was developed with the main objective of making the soil suitable for the requirements of specific engineering projects. Numerous studies have been conducted on the stabilization of soft soils with different additions, like cement [3].

This study aims to determine the potential of coffee ground as a stabilizer for soft clay. In order to achieve the aim of the study, there are three objectives that must be fulfilled which are determining the physical

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characteristics of soft clay at the study area, evaluating the unconfined compressive strength of coffee ground mixed with soft clay and determining the effectiveness of coffee grounds as soil stabilizer for soft soil.

2. Methodology

This study involves the mechanical and physical test specifically strength and compaction test. To assess the strength of the stabilized samples, samples of the mixes underwent the unconfined compressive strength (UCS) test. Finding the cohesive (fine-grained) soils' shear strength characteristics in their undisturbed or remolded states is the significance of this UCS. Additionally, other tests such as moisture content, particle size distribution and Atterberg limit were also conducted for this research.

2.1 Moisture Content

Moisture content (MC) is an important parameter to consider when dealing with clay soil. The procedure for determining the moisture content of clay soil is relatively simple and involves the following steps. Weighing the blank aluminum tray and recording the results are the initial stages in determining the soil moisture content. From the recorded data, the moisture content of the soil can be calculated using the following formula:

% mc = [(weight of wet soil - weight of dry soil) / weight of dry soil] X 100 (1)

Specimens with the lowest W/C ratio had the highest UCS. The specimen with the highest W/C ratio has the lowest UCS. It is evident that as the W/C ratio increased, the unconfined compressive strength, or UCS, rejected it [4].

2.2 Sieve Analysis

Sieve analysis is a widely used method for determining the particle size distribution of soil. Understanding the geotechnical characteristics of the foundation soil is essential for designing the foundations of various structures, including bridges, buildings, dams, and so on. Thus, geotechnical qualities of soil are investigated using 25 laboratory tests [5]. The sieve sizes for silt soil are 4.75mm, 2.36mm, 1.18mm, 0.6mm, 0.3mm, 0.15mm, 0.075mm, and pan. The calculation percentage of soil sample is following to this formula:

$$C_u = \frac{D_{60}}{D_{10}} \quad (2)$$

Where;
Cu =uniformity coefficient
D60 = Opening diameter 0.25mm
D10 = Opening diameter 2mm

When Cu is greater than 4, the soil is classified as well graded, whereas when Cu is less than 4 the soil is classified as poorly graded/uniformly graded [5].

2.3 Atterberg Limit

2.3.1 Liquid Limit

The liquid limit test is a standard laboratory test used to determine the water content at which a soil changes from a plastic state to a liquid state. The liquid limit test is a simple and reliable way to determine the soil's behavior under varying moisture content conditions, making it an essential tool for soil engineers and geotechnical professionals [6]. This test is commonly used in soil mechanics and engineering to determine the soil's consistency and behavior under different moisture conditions. The value of water content of liquid limit and its proportion in the soil will be the only factors influencing the soil's liquid limit if the clay fraction governs the characteristics.

$$W_{LL} = C/100 \, w_{CLL} \quad (3)$$

Where C is the percentage of clay.

2.3.2 Plastic Limit

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According to Atterberg, a soil's plasticity is determined by its capacity to roll out into threads, or its "ausrollgrenze" in German. He also detailed a rolling-out test that determined the water content at which the threads collapsed, which was the plastic limit [7]. It is used with the liquid limit to calculate the plasticity index (PI), which allows cohesive soils to be categorized on a plasticity chart by plotting the PI against the liquid limit. The difference between the liquid and plastic limits is known as the plasticity index. The range of moisture contents in which soil is pliable is called its plasticity index; the higher the plasticity index, the finer the soil.

2.3.3 Plasticity Index

The basic index of a soil is its plasticity index, which is utilised to categorise fine grained soils using a plasticity chart. The plasticity chart is important because it shows that plasticity is a two-dimensional attribute. The plasticity chart is a commonly utilised tool for distinguishing clays from silts and further classifying them based on the level of their compressibility.

The plasticity index formula is:

$$PI = LL - PL \quad (4)$$

Where:
PI = Plasticity Index
LL = Liquid Limit
PL = Plastic Limit

When soil is evaluated using established protocols, such as the Casagrande technique, the moisture level at which the soil changes from a plastic to a liquid form is known as the liquid limit. The moisture level at which soil can no longer be shaped without breaking is known as the plastic limit. The difference between the two water contents is the plasticity index [8].

2.4 Hydrometer

With the hydrometer method, density of the soil suspension is determined using a Bouyoucos hydrometer at specific times depending on the particle size being measured [9]. With the pipette method, clay particles are removed with a pipette at a specific time, sand particles are separated with a 270 mesh (53.3 μM) screen, and both the clay and sand particles are quantified with gravimetric measurement [9]. The method described here is for particle size analysis using the hydrometer method.

2.5 Unconfined Compressive Strength

The unconfined compressive strength test is a common lab test used to measure the strength of a soil sample. The test applies compressive stress to an unconfined cylindrical soil specimen at a constant strain rate until it fails. This test determines the soil's shear strength, which is crucial for various engineering purposes. To get accurate and consistent results, it is essential to follow a standardized testing procedure. This involves using specific equipment, applying a precise strain rate, and properly preparing and handling the sample. It is also important to conduct multiple tests on different soil samples to ensure the results are representative. In this study, the unconfined compressive strength tests were performed according to ASTM D 2166. The samples were placed in the loading device and subjected to uniaxial compression at a constant strain rate of 1 mm/min [4].

3. Results and Discussion

The study incorporated varying percentage of Coffee Ground and Cements into the soil. The weight of Coffee Ground for soil stabilizer percentage for sample A are 0%, 5%, 10% and 20%. Meanwhile, sample B is incorporated with 5% and 10% of cement. It must be ensured that the organic materials are distributed evenly. The results have been discussed in terms of physical properties, soil mechanics with stabilizer (coffee grounds) and engineering properties (Unconfined Compression Strength Test).

3.1 Physical Properties of Soft Soil

The soft clay sample was collected from a site in Batu Pahat, Johor, Malaysia at a depth of 3 meter. Based on the AASHTO soil classification system, the minimum percentage to pass the sieve no.200 is 36%, has a liquid limit of at least 41%, and has a plasticity index of at least 11% so that the soil samples can be classified in the soil type A-7-6 [11].

For original soil, particle size distribution analysis shows that the value of D_{50} was 0.0044. The percentage of soil passing through the sieve no. 200 was 31.8% with the liquid limit of 63.70%. Meanwhile, the plastic limit has the value of 45.36% and the plasticity index has the value of 18.34%. From the data collected, it is proven that from the result that the sample of soft soil tested has a very high plasticity with the value of plastic limit was 45.36%, liquid limit of 63.70% and plasticity index of 18.34%.

3.2 Atterberg Limit

3.2.1 Liquid Limit

Fig.1 shows the relationship between average penetration and moisture content and the graph is a typical liquid limit plot showing how average penetration varies with different moisture contents. The data points show a clear trend that penetration increases with moisture content, indicating that the soil transitions from a semi-solid to a more liquid state. From the graph, the lowest moisture content observed was 62.79% and the highest moisture content was 64.44%. The graph clearly shows that as moisture content increases, average penetration also increases, which indicates that the soil transitions from a semi-solid to a more liquid state.

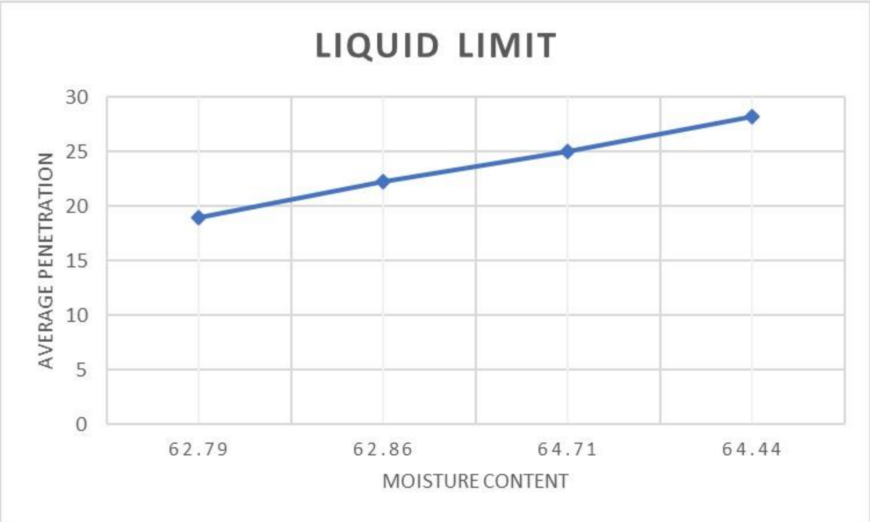

Fig.1 *Graph of the Liquid Limit test*

3.2.2 Plastic Limit

The plastic limit test was conducted concurrently with water content in four separate test four tests and compares it with the plastic limit of the soil. The recorded water content was 46.15%, 48%, 42.86% and 44.44%, whereas the plastic limit of the soil remains consistent at 45.36%. The consistent plastic limit value and varying water content values provide insights into the soil's plasticity and behavior under different moisture conditions. The consistency of plastic limit indicates a stable characteristic of the soil's plasticity, which is a critical parameter in assessing soil behavior under varying moisture conditions.

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3.2.3 Plasticity Index

The provided data describes key parameters used in soil mechanics to understand the behavior and classification of a soil sample. The Plastic Limit of 45.36% represents the water content at which the soil transitions from a plastic to a semi-solid state. The Liquid Limit of 63.70% is the water content at which the soil changes from a plastic to a liquid state. The Plasticity Index, calculated as the difference between the liquid limit and the plastic limit, is 18.34%. This index (PI = 63.70% - 45.36% = 18.34%) quantifies the range of water content over which the soil remains plastic and is an indicator of the soil's plasticity.

Plastic Limit = 45.36%
Liquid Limit = 63.70%
Plasticity Index = Liquid Limit – Plastic Limit = 18.34%

3.3 Dry Sieve Analysis

Table 1 shows the results of dry sieve analysis obtained tested on the soil sample. The clay soil that was tested passed the smallest sieve at 0.075mm which was 105.00g and the cumulative percentage passing that was obtained was 31.795%.

Table 1 *Result of Dry Sieve Analysis*

Sieve no. Size (mm)	Mass Retained (g)	Mass Passing (g)	Cumulative Percentage Passing (%)
14.00 mm	0	200	100.000
5.00 mm	0.00	200.000	100.000
2.36 mm	0.15	199.850	99.925
1.18 mm	0.33	199.520	99.760
0.600 mm	0.36	199.160	99.580
0.425 mm	0.47	198.690	99.345
0.300 mm	3.70	194.990	97.495
0.212 mm	5.20	189.790	94.895
0.180 mm	9.10	180.690	90.345
0.075 mm	12.10	168.590	84.295
Pan Total	105.00	63.590	31.795

3.4 Hydrometer

Table 2 shows the results that we obtained during hydrometer test. The test was carried out in 24 hours. Based on the elapsed time, that are each of the time that we noted down the data in the hydrometer bath. The hydrometer reading that we obtained lessen the more the soil was left in the bath. This is because of the deposits that went down the cylinder in the hydrometer bath making the reading went from high to low. It shows that the hydrometer sink down as the deposits of the soil tested sink down as well.

Table 2 *Data of hydrometer test*

Date/Time	Elapsed time, t (min)	Hydrometer reading, R_h'	True reading, R_h	Effective depth, H_R (mm)	Modified reading, R_d	Particle diameter (µm)	Percentage Finer than D, K (%)
9:45	0	26.0	26.50	97.57	26.50	59.420	85.317
9:45	0.5	25.50	26.00	99.57	26.00	59.420	83.707
9:46	1	25.00	25.50	101.57	25.50	40.656	82.098
9:48	3	24.50	25.00	103.57	25.00	23.703	80.488
9:49	4	24.00	24.50	105.57	24.50	20.724	78.878
9:53	8	23.00	23.50	109.57	23.50	14.929	75.659

Table 2 *Continued*

10:00	15	21.50	22.00	115.57	22.00	11.197	70.829
10:15	30	19.50	20.00	123.57	20.00	8.187	64.390
10:45	60	17.00	17.50	133.57	17.50	6.019	56.341
11:45	120	15.00	15.50	141.57	15.50	4.382	49.902
1:45	240	13.00	13.50	149.57	13.50	3.185	43.463
9:45	1440	8.50	9.00	167.57	9.00	1.376	28.976

Fig. 2 shows a graph of the relationship between cumulative percentage passing and sieve size. Moreover, this graph provides a visual representation of the particle size distribution in the sample. It shows that the material contains a broad range of particle sizes, from larger particles that are retained on the first few sieves to finer particles that pass through the smaller sieves. A well-graded soil, which includes a variety of particle sizes, typically exhibits better compaction and strength characteristics compared to uniformly graded soils.

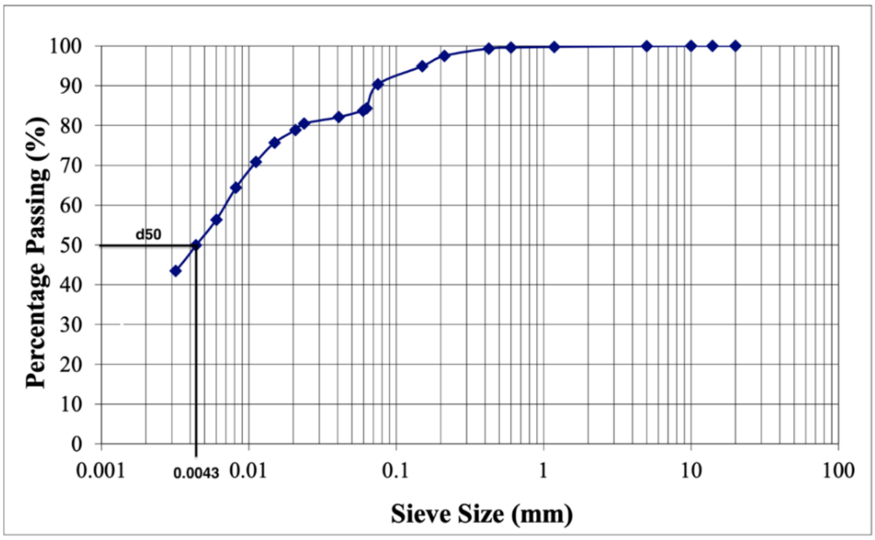

Fig. 2 *The hydrometer & dry sieve analysis test*

3.5 Unconfined Compression Strength Test (UCS)

The test demonstrates the correlation between unconfined compressive strength of soil and additives stabilizer with various percentage composition. Table 3 shows the Unconfined Compression Strength Test data for both 7 and 28 days.

Table 3 *Unconfined Compression Strength Test Data*

% Additives	Unconfined Compressive Strength, q_u in 7 days (kPa)	Unconfined Compressive strength, q_u in 28 days (kPa)
0%	8.35	10.9
5% CG	11.20	11.7
10% CG	13.35	15.7
20% CG	24.0	25.0
5% Cement	1.94	6.20
10% Cement	8.10	12.2

Fig. 3 (a) and (b) shows the relationship between unconfined compressive strength (kPa) with percentage of coffee ground (%) and cement (%) for curing period of 7 and 28 days, respectively. In particular, Fig. 3 (a) illustrates the graph of unconfined compressive strength (kPa) with different percentage of coffee ground as the stabilizer with the duration of the soil curing for 7 and 28 days. The initial graph starts without any stabilizer which refers to the zero percentage of Coffee Ground. Typically, soil gains some inherent strength due to the natural drying and consolidation processes during the curing period. However, without the addition of stabilizing agents, these strength gains are usually minimal and primarily due to moisture loss and particle rearrangement. The strength of soil mixed with 5% coffee grounds in 28 days increased 4.46% from the strength of the sample in

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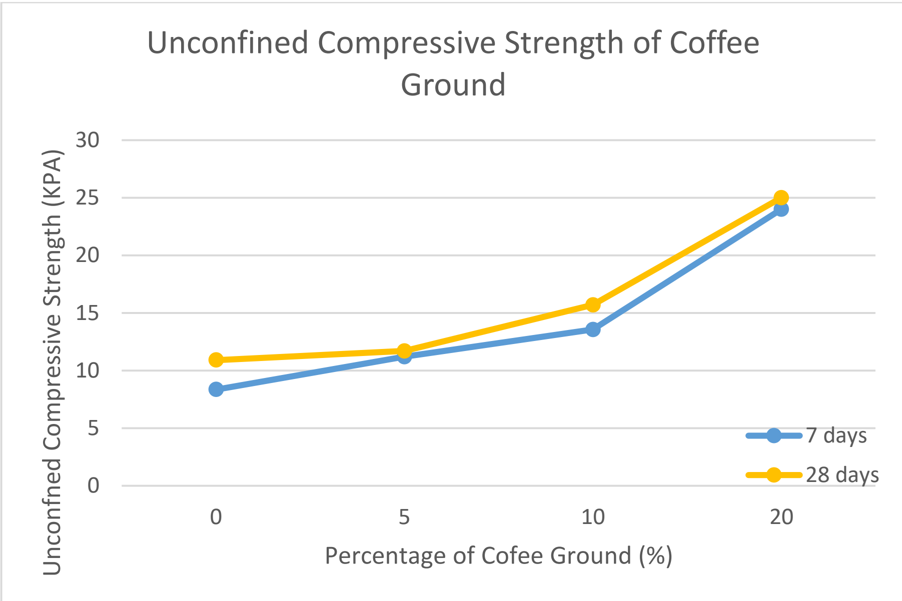
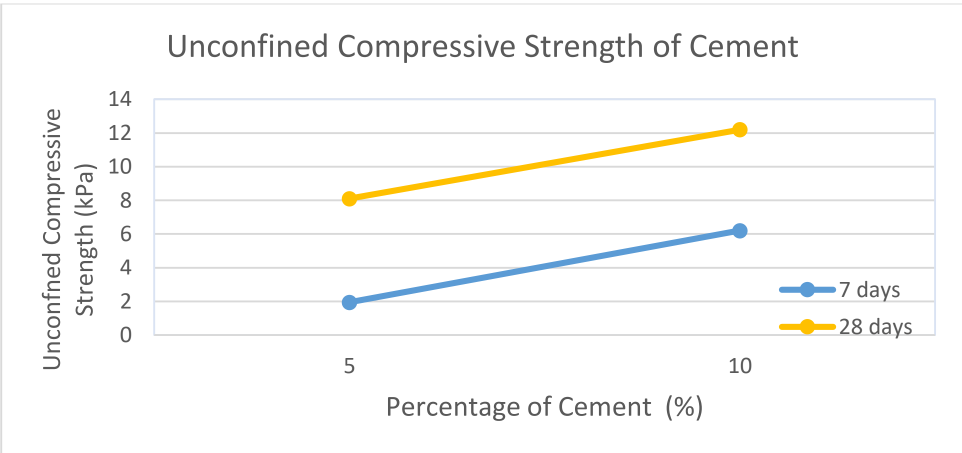
7 days. Initially, the fibrous nature of the coffee grounds helps to improve particle binding and increase cohesion within the soil matrix. Over the 28-day curing period, the organic matter in the coffee grounds undergoes slow decomposition, which aids in further integrating the grounds with the soil particles.

For the highest percentage of stabilizer, which is 20% of coffee ground, the graph indicates that the coffee ground reacted to strengthen the soil during curing process. The strength of soil mixed with 20% coffee grounds in 28 days increased 4.17% from the strength of the sample in 7 days. As the soil cures over 28 days, the organic matter within the coffee grounds likely continues to decompose and integrate more thoroughly with the soil particles. This ongoing process can lead to a slight densification and improvement in the soil's structural integrity, reflected in the 4.17% increase in strength.



(a)

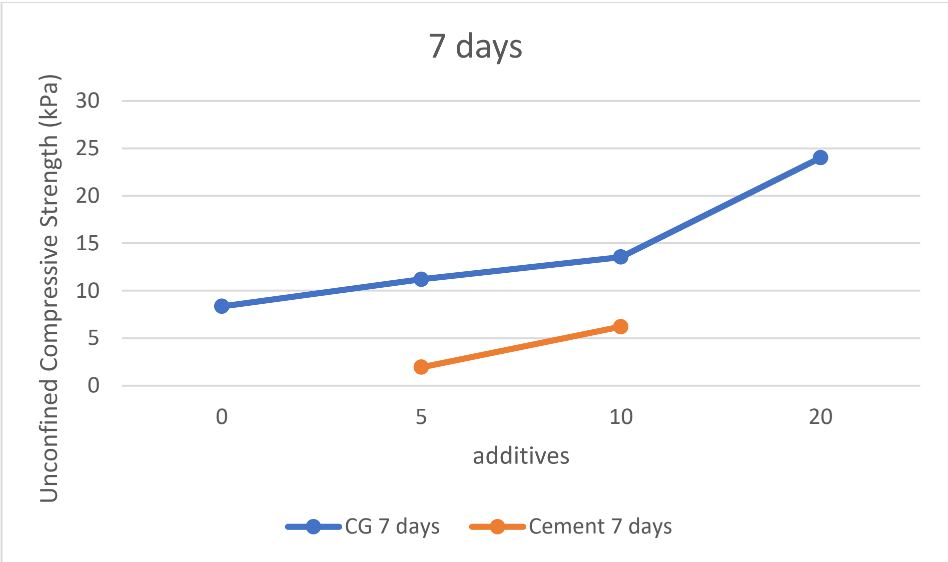


(b)

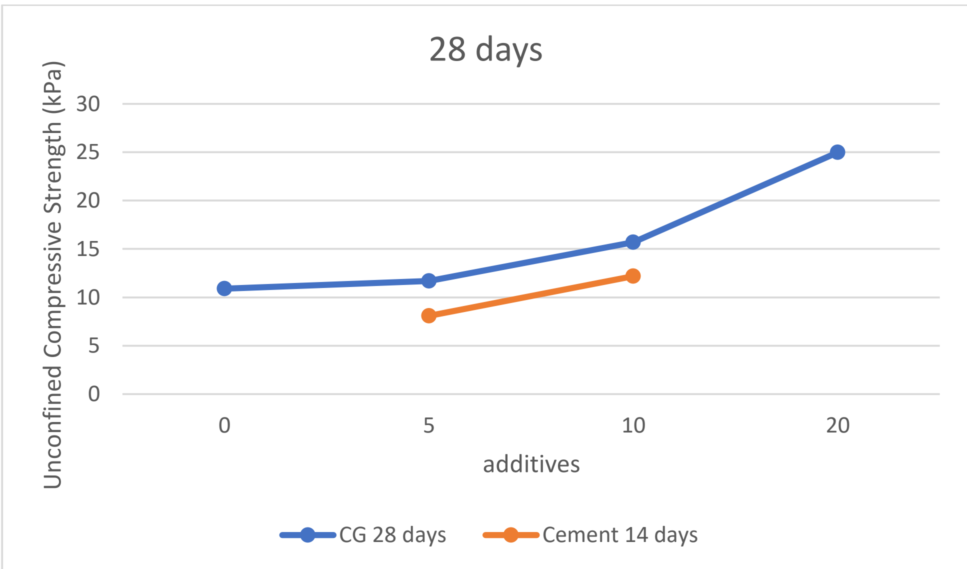
Fig. 3 *Graph of relationship between unconfined compressive strength (kPa) with (a) percentage of coffee ground (%) and (b) percentage of cements (%)*

Fig. 3 (b) represents the relationship of unconfined compressive strength (kPa) with different percentage of cements with the duration of the soil curing for 7 and 28 days. The graph showed the cement reacted to strengthen the soil while the sample was curing. The strength of soil mixed with 5% cement in 28 days increased 219.6% from the strength of the sample in 7 days whereas the strength of soil mixed with 10% cement in 28 days increased 50.6% from the strength of the sample in 7 days. The strength gain of soil mixed with 10% cement over 28 days indicates the effectiveness of cement stabilization, where ongoing hydration reactions contribute significantly to the soil's structural integrity and durability.

Fig. 4 (a) and Fig. 4 (b) shows the relationship between unconfined compressive strength (kPa) on soil with mixed stabilizer variations percentages in 7 days and 28 days curing. The graph showed the soil mixed with coffee grounds had more strength than the soil mixed with cement. The results of the unconfined compression strength test shows that higher strengths were achieved for the sample's additives with 10% coffee grounds is 13.35 kPa compared with the sample soil mixed with 10% cement obtained 8.1 kPa. According to Hastuty et al. [10], Fig. 4 (a) and Fig.4 (b) shows the 20% coffee grounds achieved to improve the category of soil from very soft (<0.25 kg/cm^2) to soft (0.25-0.50 kg/cm^2) based on the classification of soil to the unconfined compression test. The unconfined compressive strength of soil mixed with 20% coffee ground curing 28 days is obtained 0.25 kg/cm^2. From Fig. 4 (a) the strength of soil with 20% coffee grounds increases 187.4% from the strength of soil without any admixture whereas for Fig. 4 (b) the strength increases 129.4% after 28 days the sample cured. In summary, the addition of coffee grounds not only provides an immediate boost to soil strength but also contributes to further gains over time, making it a viable and sustainable option for soil stabilization projects.



(a)



(b)

Fig. 4 *Graph (a) Unconfined Compressive Strength with soil additives in 7 days; (b) Unconfined Compressive Strength with soil additives in 28 days*

4. Conclusion

Based on the result of the test that were carried out, it shows that the soft soil tested changed category from 10.9 kPa, very soft to 25 kPa, soft. The additives of cement were made to compare to the additives of coffee ground as cement works better as soil stabilizer. From this testing, it is known that coffee ground is a good stabilizer. In order to achieve a better result, it is advised that coffee ground must be added more than 20% to improve soil strength. The aim of this project is proven to succeed as the physical characteristics of soft clay at the study area was determined, the unconfined compressive strength of coffee ground mixed with soft clay was evaluated and the effectiveness of coffee grounds as soil stabilizer for soft soil was determined.

Acknowledgement

This research was funded by Universiti Tun Hussein Onn Malaysia through MDR (Vot Q 696) and GPPS (Vot Q304).

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design, data collection, analysis and interpretation of result, draft manuscript preparation:*** *Adlin Nur Liyana Shamsul, Nur Ellysha Zulkifli, Siti Hazzirah Ramli, Mardiha Mokhtar. All authors reviewed the results and approved the final version of the manuscript.*

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