Stabilization of Swamp Soil Using Steel Slag, Fly Ash, and Glass Bottle Powder To Determine Unconfined Compressive Strength Test (UCS) Value (Study Case on Kp. Tegal Wangi Street No.62, Rw. Arum, Sub-district Gerogol, Cilegon City, Banten)

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Article Info

Article history:

Accepted March 10, 2024
Approved April 10, 2024
Published April 29, 2024

Keywords:

Steel Slag, Fly Ash, Glass Bottle Powder, Unconfined Compressive Strength Test.

ABSTRACT

Soil is an important part of construction which function as a support for the building above. Swamp soil has a soft texture and high water content, making it difficult for the soil support construction on it. The purpose of this study is to determine the soil classification based on Unified Soil Classification System (USCS) and to determine the soil characteristic by adding supplemental materials at varying percentages: 20% steel slag, 20% fly ash, and 0%, 5%, 10%, and 15% glass bottle powder, with curing periods of 0, 7, 14, and 28 days. The research method conducted is testing of soil grain size, Atterberg limits, compaction, and Unconfined Compressive Strength (UCS) test. The UCS value will be calculated for a period of time of 0 days, 7 days, 14 days, and 28 days, and at different percentages of 20% Steel slag, 20% Fly ash and 0%, 5%, 10%, and 15% glass bottle powder.The research findings indicated that the soil, according to the USCS classification system, falls into the OH soil classification, indicating pure clay, with a plasticity index value of 26.79%. With the addition of steel slag, fly ash, and glass bottle powder, there was a reduction in the plasticity index from 26.79% to 9.22% in variation E (20% steel slag, 20% fly ash, and 15% glass bottle powder) after a curing period of 28 days. The highest qu value was recorded in variation D (20% steel slag, 20% fly ash, and 10% glass bottle powder) after 28 days of curing, measuring 4.587 kg/cm^2.

Available online at http://dx.doi.org/10.36055/fondasi

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1. INTRODUCTION

Soil can consist of two or three components. In dry soil conditions, it comprises only two components: soil particles and air pores. Saturated soil contains two parts: solid particles and pore water. In unsaturated conditions, soil consists of three components: solid particles, air pores, and pore water. Wetlands are scientifically defined as areas continuously or seasonally inundated with water due to obstructed drainage, exhibiting specific physical, chemical, and biological characteristics. Swampy soil possesses a soft texture and high water content, making it challenging for construction support. Types of swampy soil include clay, silt, and peat. To enhance soil bearing capacity, stabilization measures are required. One approach involves adding chemical additives such as steel slag, fly ash, and glass bottle powder [1].

Steel slag is a waste product generated during iron and steel manufacturing, composed of various chemical and mineral components. It consists of solid waste materials discarded from steel plants during the iron and steel smelting process. Initially in liquid form, steel slag comprises a mixture of silica and calcium oxide that solidifies during the cooling process [2]. Its utilization abroad includes road pavement and construction materials in countries like Thailand. PT. Krakatau Steel is one of the sources for the utilized steel slag.

Fly ash from coal combustion is a fine, lightweight powder derived from the residual ash of burning coal in boilers at coal-fired power plants. The components of fly ash vary depending on the source of coal burned, yet all contain silicon dioxide (SiO_2) and calcium oxide (CaO) [3]. Glass, a waste material rich in silica content, can serve as a chemical stabilizer for soil. Silica in glass acts as a binding agent in soil stabilization. Moreover, glass powder, due to its extremely fine size, functions as a filler within soil voids [4].

Several studies related to steel slag include [5] The UCT test yielded a value of 0.92 kg/cm2 for a 0 percent steel slag combination after 0 days of curing, while the maximum significant value was 2.40 kg/cm2 for a 20 percent steel slag combination after 28 days of curing. This study indicates that steel slag is a viable option for subgrade improvement. Research [6] Based on this research, the plasticity index decreased from 53.82% in the original soil to 33.43% in the soil mixed with 20% steel waste. The optimum unconfined compressive strength (qu) was observed with the addition of 20% steel waste to the original soil, resulting in a qu value of 1.79 kg/cm2. Research [7] the addition of fly ash to ordinary landfill can increase the value of the free compressive strength test of the original soil by 4.389 kg / cm2 to 11.600 kg / cm2, curing for 28 days in a 5% fly ash mixture, so the use of fly ash can be used for stabilization on the soil. Researh [8] The UCT test results indicate that the highest qu value was obtained from soil containing a 20% fly ash content, with a curing period of 21 days, resulting in a qu value of 2.55 kg/cm2. This represented an increase of 202.38% from the lowest value, which was 1.26 kg/cm2. Research [9] The results of the optimum water content test on the original soil, which was 21.40%, decreased in the 2% PC + 9% SK mixture variation to 19.30% after a curing time of 14 days. In the UCT (Unconfined Compressive Strength) test, the unconfined compressive strength (qu) of the original soil was found to be 1.36 kg/cm3, whereas for the remolded soil, the obtained unconfined compressive strength (qu) was 0.63 kg/cm3.

2. METHODS

2.1 Research Sites

The soil sampling location was located at Jl. Kp. Tegal Wangi No. 62, Rw. Arum, Kec. Gerogol, Cilegon City, Banten, That would be more precisely located at coordinates 5°58'48.1"S - 106°00'41.2"E. The research location can be shown in figure 1.

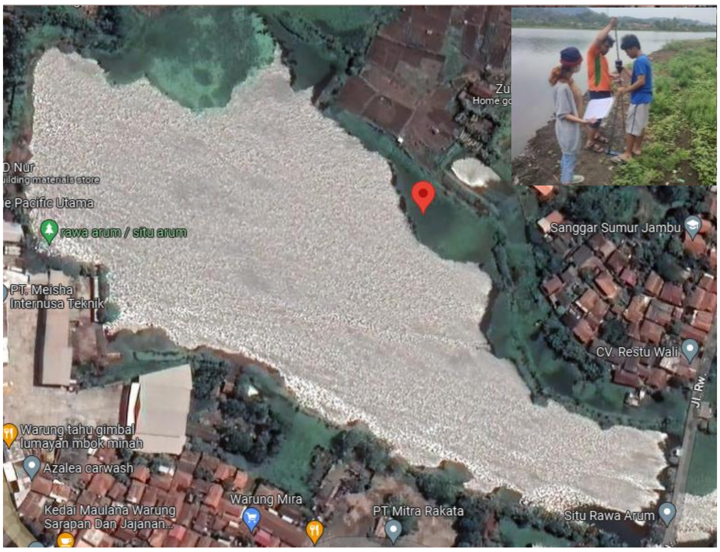
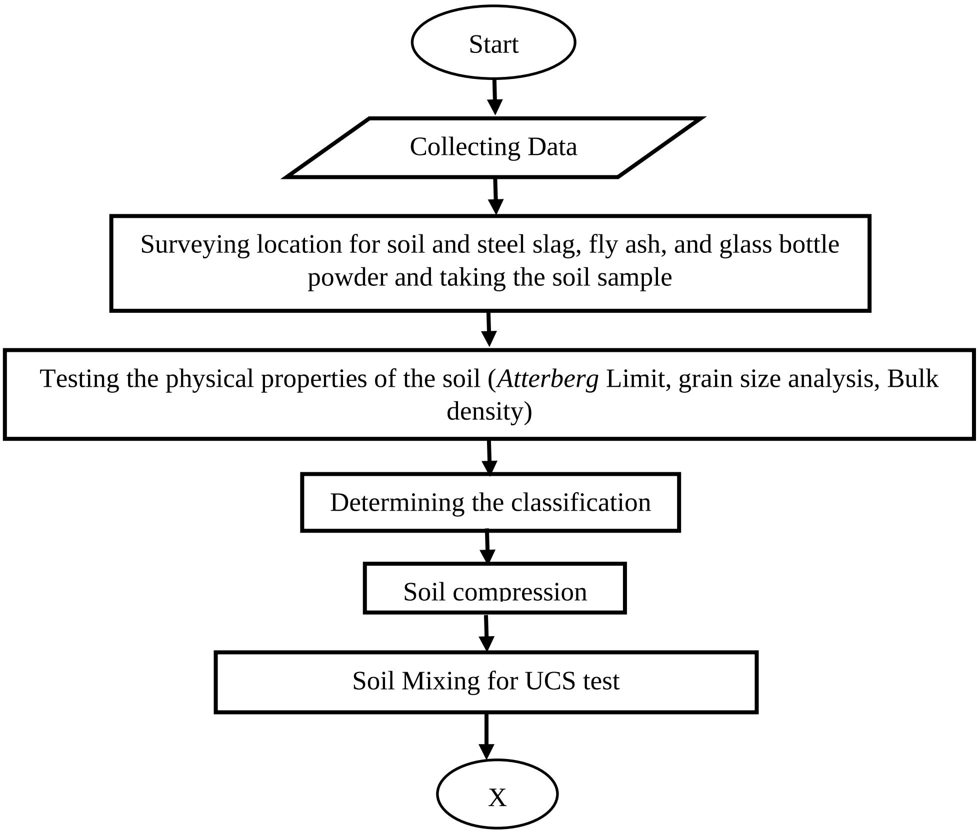


Figure 1. Situ Rawa Arum

2.2 Stage of Research

The soil study commenced by collecting data through extensive literature research, consulting various academic sources such as books and scientific journals. Subsequently, a site survey was conducted to gather soil samples for the research. The soil sampling location was located at Jl. Kp. Tegal Wangi No. 62, Rw. Arum, Kec. Grogol, Kota Cilegon, Banten. Steel slag was acquired from PT. Krakatau Posco, while fly ash was obtained from PLTU Lontar 3. Glass bottles were sourced from TPA Tangerang. The soil samples were mixed with steel slag, fly ash, and glass bottle powder to fill the voids within the soil samples.



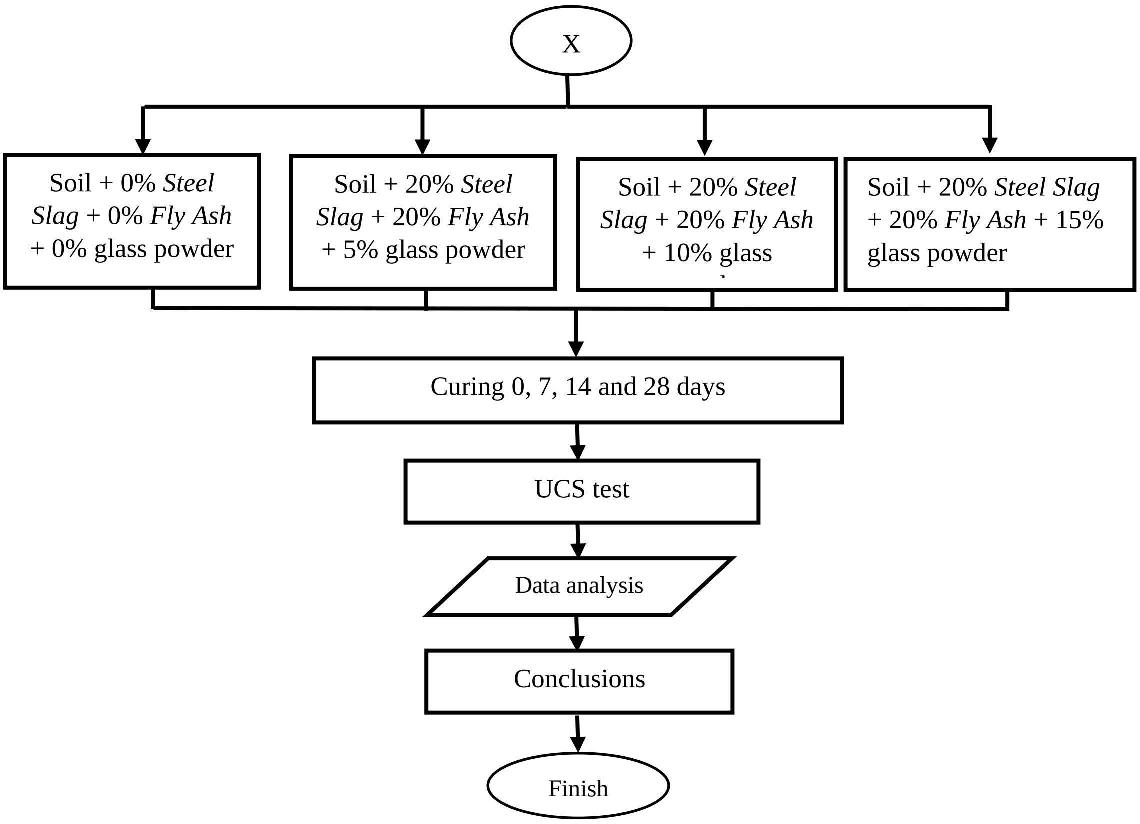


Figure 2. Research Flowchart

2.3 Number of Samples

Many samples were used in this research, totaling 60 samples for the UCT testing. The additional materials used for this study were 20% steel slag, 20% fly ash, and glass bottle powder at 0%, 5%, 10%, and 15% compositions, along with curing periods of 0, 7, 14, and 28 days.

3. RESULTS AND DISCUSSION

3.1 Results The Physical Properties of Soil

Based on the conducted tests, the obtained data for the original soil's physical properties are as follows:

Table 1. Physical Properties of Origin Soil

No	Test	Unit	Result	Specification	Description
1	Water Content	%	76,95	-	-
2	Specific Gravity		2,053	-	organic clay
3	Sieve Analysis (Passing	%	54,7	>50%	fine-grained
4	Sieve no. 200)				soil
5	Liquid Limit	%	59,2	-	
6	Plastic Limit	%	32,41	-	-
	Plasticity Index	%	26,79	>17	high plasticity

3.2 Soil Classification

The Classification System utilized in this research is the Unified Soil Classification System (USCS). To determine the soil classification, testing data for sieve analysis, liquid limit, and plasticity index are necessary [10]. From the conducted tests, the results were a passing percentage of 54.7% for sieve analysis (passing no. 200), a liquid limit of 59.2%, and a plasticity index of 26.79%. Based on the obtained data, the soil falls into the OH classification.

3.3 The Results of Mix Soil

The testing of the mixed soil was conducted based on predetermined variations, which is:
a) Variation A = 100% swamp soil + 0% SL + 0% FA + 0% GBP
b) Variation B = 100% swamp soil + 20% SL + 20% FA + 0% GBP
c) Variation C = 100% swamp soil + 20% SL + 20% FA + 5% GBP
d) Variation D = 100% swamp soil + 20% SL + 20% FA + 10% GBP
e) Variation E = 100% swamp soil + 20% SL + 20% FA + 15% GBP

Keterangan :
SL = Steel Slag
FA = Fly Ash
GBP = glass bottle powder

3.3.1 Specific Gravity

The testing of the mixed soil's specific gravity used dry soil that passed through sieves No. 4 and No. 10, following the predetermined variations [11]. The results of the specific gravity testing can be observed in Table 2.

Table 2. Specific Gravity of The Mixed Soil

Variation	Gravity Specific
Variation A (0% SL + 0% FA + 0% GBP)	2,053
Variation B (20% SL + 20% FA + 0% GBP)	2,286
Variation C (20% SL + 20% FA + 5% GBP)	2,380
Variation D (20% SL + 20% FA + 10% GBP)	2,449
Variation E (20% SL + 20% FA + 15% GBP)	2,498

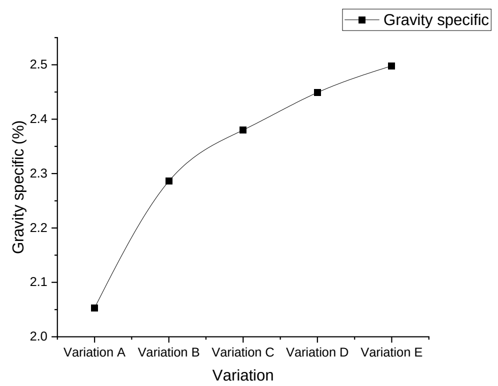


Figure 3. The Specific Gravity of The Mixed Soil

Based on the research findings, it can be concluded that as the amount of glass bottle powder increases, along with 20% steel slag and 20% fly ash, it is capable of increasing the soils specific gravity value. The highest increase in specific gravity occurred in variation E, involving the addition of 15% glass bottle powder, 20% steel slag, and 20% fly ash, which initially was 2.053 and increased to 2.498. The more glass powder he longer the curing time, the specific gravity value increases. [12]

3.3.2 Liquid Limit Test

This test was conducted to determine the effect of adding steel slag, fly ash, and glass bottle powder waste on the liquid limit value. This test uses the Cassagrande [13]. The results of the liquid limit testing can be seen in Figure 3.

Table 3. Liquid limit of mixed soil

Curing (days)	Liquid Limit (%)				
	Variation A (0% SL + 0% FA + 0% GBP)	Variation B (20% SL + 20% FA + 0% GBP)	Variation C (20% SL + 20% FA + 5% GBP)	Variation D (20% SL + 20% FA + 10% GBP)	Variation E (20% SL + 20% FA + 15% GBP)
0	59,2	47	39,2	40	37,5
7	61,8	48	38,8	38,1	37,2
14	50	42,9	39	38,8	38,7
28	49,2	37,8	35,9	35,3	33,38

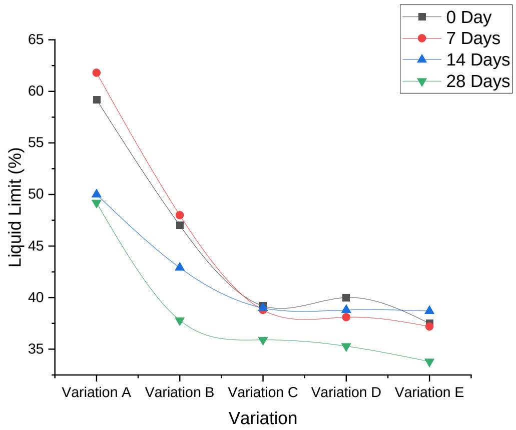


Figure 4. Liquid Limit of Mixed Soil

Based on the graph above, the liquid limit value decreases with the addition of steel slag, fly ash, and glass bottle powder, as well as with increasing curing time. The initial liquid limit value of 59.2% reduced to 33.38% in variation E (20% SL + 20% FA + 15% GBP) with a curing period of 28 days.

3.3.3 Plastic Limit Test

This test was conducted to determine the effect of adding steel slag, fly ash, and glass bottle powder waste on the plastic limit value [14]. The results of the plastic limit testing can be seen in Figure 4.

Table 4. Plastic limit of mixed soil

Curing (days)	Plastic Limit (%)				
	Variation A (0% SL + 0% FA + 0% GBP)	Variation B (20% SL + 20% FA + 0% GBP)	Variation C (20% SL + 20% FA + 5% GBP)	Variation D (20% SL + 20% FA + 10% GBP)	Variation E (20% SL + 20% FA + 15% GBP)
0	32,41	28,10	29,54	26,42	24,49
7	28,07	26,09	26,37	25,74	25,63
14	32,33	27,24	25,95	26,42	26,38
28	31,35	25,42	25,31	24,90	24,58

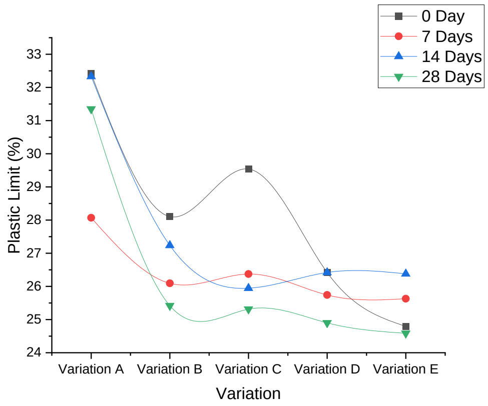


Figure 5. Plastic Limit of Mixed Soil

Based on the graph above, the plastic limit value decreases with the addition of steel slag, fly ash, and glass bottle powder, as well as with increasing curing time. The initial plastic limit value of 32.41% reduced to 24.58% in variation E (20% SL + 20% FA + 15% GBP) with a curing period of 28 days.

3.3.4 Plasticity Index

The plasticity index (PI) is the difference between the liquid limit and the plastic limit. After conducting the liquid limit and plastic limit tests, the plasticity index for each variation of the soil at Rawa Arum, Grogol District, Cilegon City, Banten can be identified in the table below:

Table 5. Plasticity Index of mixed soil

Curing (days)	Plasticity Index (%)				
	Variation A (0% SL + 0% FA + 0% GBP)	Variation B (20% SL + 20% FA + 0% GBP)	Variation C (20% SL + 20% FA + 5% GBP)	Variation D (20% SL + 20% FA + 10% GBP)	Variation E (20% SL + 20% FA + 15% GBP)
0	26,79	18,90	9,66	13,58	13,01
7	33,73	21,91	12,43	12,36	11,57
14	17,67	15,66	13,05	12,38	12,32
28	17,85	12,38	10,59	10,40	9,22

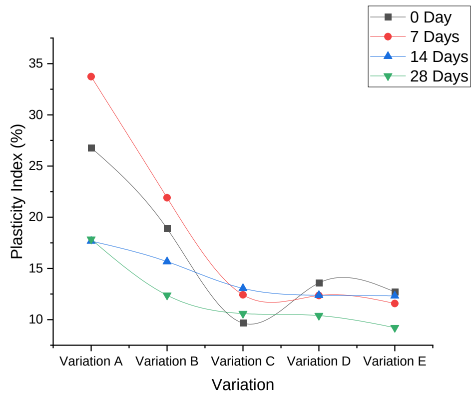


Figure 6. Plasticity Index of Mixed Soil

Based on the graph above, the plasticity index value decreases with the addition of steel slag, fly ash, and glass bottle powder, as well as with increasing curing time. The initial liquid limit value of 26.79% decreased to 9.22% in variation E (20% SL + 20% FA + 15% GBP) with a curing period of 28 days.

3.4 Compaction Test

Unconfined Compressive Strength (UCS) test is a test of soil strength under unconfined conditions. Unconfined Compressive Strength (UCS) is the axial load per unit area at which the specimen fails or when the axial strain reaches 15% [15]. The compaction test is performed to determine the relationship between water content and volume and to assess the soil to meet density requirements. In the compaction test, the experiment is repeated at least 5 times with varying water content. Soil compaction tests aim to establish the optimum water content and maximum dry density [16]. The compaction test is carried out on each mixture variation to identify the maximum dry unit weight and optimum water content in each mixture. Compaction is achieved by rolling and pounding to induce soil compression by expelling air from the pores. Adding a small amount of water to slightly moist soil aids compaction by reducing surface tension. However, it will lead to an optimal water content, which will result in increased pores. [17].

Table 6. Optimum water content and dry maximum

Variation	Optimum Water Content (%)	Maximum Dry Density (g/cm^3)
Variation A (0% SL + 0% FA + 0% GBP)	28,70	1,071
Variation B (20% SL + 20% FA + 0% GBP)	20,98	1,295
Variation C (20% SL + 20% FA + 5% GBP)	22,45	1,303
Variation D (20% SL + 20% FA + 10% GBP)	23,42	1,312
Variation E (20% SL + 20% FA + 15% GBP)	24,03	1,32

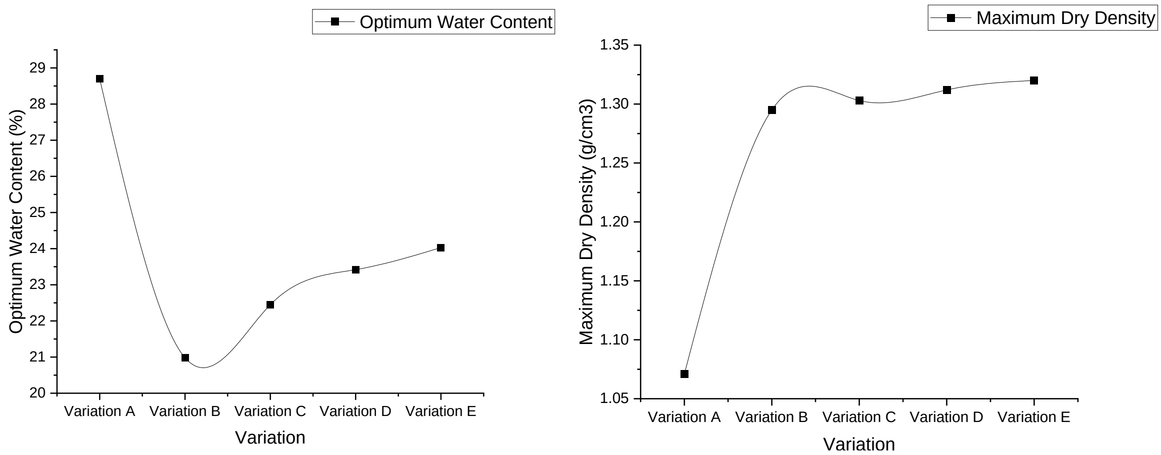


Figure 7. Optimum Water Content and Maximum Dry Density

From the compaction test, data such as optimum water content and maximum dry weight are obtained. The optimum water content will be used to determine the water content in the unconfined compressive test.

3.5 Unconfined Compression Test

Unconfined Compressive Test (qu) is the compressive stress occurring when a specimen fails in an unconfined compression test. It is determined as the maximum load achieved per unit area or the load per unit area at 15% strain [18]. Here is the data obtained from the unconfined compressive test conducted on the mixed soil, which has been calculated and analyzed:

Table 7. Result of unconfined compression test

Curing (days)	Unconfined Compression Test (Kg/cm^2)				
	Variation A (0% SL	Variation B (20% SL +	Variation C (20% SL +	Variation D (20% SL +	Variation E (20% SL +

	+ 0% FA + 0% GBP)	20% FA + 0% GBP)	20% FA + 5% GBP)	20% FA + 10% GBP)	20% FA + 15% GBP)
0	0,613	1,073	0,825	1,592	1,332
7	1,014	2,217	2,240	2,523	1,804
14	1,167	2,736	2,453	2,665	2,052
28	1,179	1,946	3,337	4,587	3,337

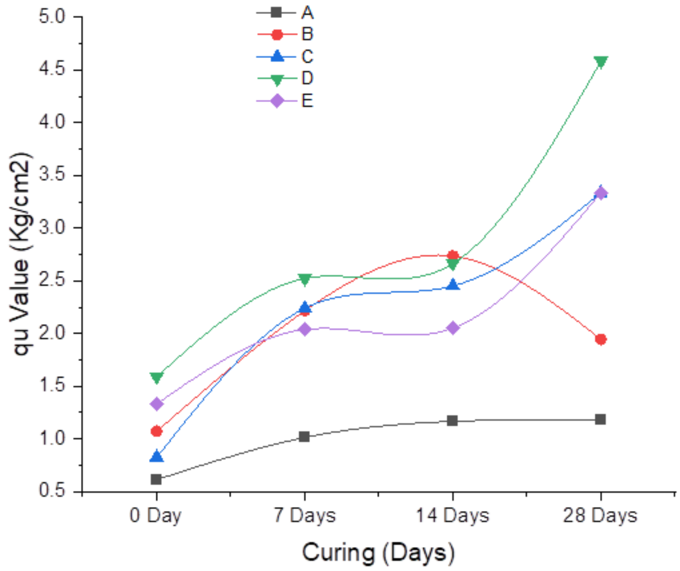


Figure 8. Unconfined Compression Test

From the data in Table 7 and Figure 7, it can be concluded that both the addition of additives and the curing time have an impact on the value of qu (unconfined compressive test). The addition of 10% glass bottle powder in variation D (20% SL + 20% FA + 10% GBP) and a curing time of 28 days resulted in the highest qu value, increasing from the initial 0.612 Kg/cm2 to 4.587 Kg/cm^2.

In Figure 7, Variation B (20% SL + 20% FA + 0% GBP) experienced a decrease with a 28-day curing time. Research [19] it is explained that as the curing time increases, the water content in the soil will decrease. Therefore, with an extremely long curing time, the value of unconfined compressive strength might decrease or become inconsistent. Pozzolanic reactions occur in the presence of water. Without water, the silicates and aluminates present in sugarcane bagasse ash will not have significance, thus hindering the stabilization process from occurring.

According to research [20], the decrease in unconfined compressive strength is attributed to the excess pozzolanic material present in slag and fly ash when mixed with clays. This prevents proper cementation from occurring. Additionally, with a longer curing period, water vaporizes, leading to soil becoming more fragile and a decrease in unconfined compressive strength.

4. CONCLUSION

Based on the research findings and conducted tests, it is concluded that the soil in Rawa Arum, Grogol District, Cilegon City, Banten, falls under the OH soil classification with a plasticity index of 26.79%. The addition of steel slag, fly ash, and glass bottle powder waste effectively decreased the soil's plasticity index from the initial 26.79% to 9.22% in variation E (20% SL + 20% FA + 15% GBP) with a curing time of 28 days. In the unconfined compressive test, it was found that the waste materials - steel slag, fly ash, and glass bottle powder - could enhance the unconfined compressive test. The original soil's unconfined compressive test (qu) was 0.613 Kg/cm2, which increased to 4.587 Kg/cm2 in variation D (20% SL + 20% FA + 10% GBP) with a curing time of 28 days.

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