Makara Journal of Technology

Volume 26 | Issue 1 Article 1

4-30-2022

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Recommended Citation

Nugroho, Soewignjo Agus; Zulnasari, Azra; Fatnanta, Ferry; and Putra, Andius Dasa (2022) "Mechanical Behavior of Clay Soil Stabilized with Fly Ash and Bottom Ash," *Makara Journal of Technology*: Vol. 26: Iss. 1, Article 1.
DOI: 10.7454/mst.v26i1.1444
Available at: https://scholarhub.ui.ac.id/mjt/vol26/iss1/1

Makara J. Technol. 26/1 (2022), 1–7
doi: 10.7454/mst.v26i1.1444

Mechanical Behavior of Clay Soil Stabilized with Fly Ash and Bottom Ash

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Abstract

Soil is one of the most important aspects of an infrastructure given its functions of receiving and holding structural loads. However, not all soils have good physical and mechanical properties. To overcome those conditions, stabilization of the soil is practiced to meet the technical requirements. This study aims to determine the behavior of high plasticity clay stabilized with lime, fly ash, and bottom ash. These additives can be used as a stabilizing agent to increase soil strength. The percentage of additives varied from 5%–25% then mixed with clay and were tested through the (Unconfined Compression Strength (UCS) test. The UCS test was carried out with 6 treatments, including consecutively non-curing and unsoaked, non-curing and soaked, curing for 7 days and unsoaked, cured for 7 days and soaked, cured for 28 days and unsoaked, and cured for 28 days and soaked. Results show that the UCS value increased along with the span of curing time. Meanwhile, the soaking treatment of the sample decreased the UCS value.

Abstrak

Sifat Mekanis Tanah Liat yang Distabilkan dengan Fly Ash dan Bottom Ash. Tanah merupakan salah satu aspek terpenting dari suatu infrastructures karena memiliki fungsi menerima dan menahan beban struktur diatasnya. Tetapi pada penerapannya, tidak semua tanah memiliki sifat-sifat fisik dan mekanik yang baik, untuk mengantisipasi kemungkinan-kemungkinan terjadinya kondisi tersebut maka dilakukan stabilisasi terhadap tanah agar memenuhi syarat-syarat teknis yang diperlukan. Penelitian ini bertujuan untuk mengetahui perilaku tanah lempung plastisitas tinggi yang distabilisasi dengan kapur, *fly ash* dan *bottom ash*. Zat aditif tersebut dapat digunakan sebagai bahan stabilisasi untuk meningkatkan kekuatan tanah. Persentase Zat aditif yang digunakan bervariasi mulai dari 5%-25%, dicampur dengan tanah lempung dan dilakukan pengujian UCS. Uji UCS dilakukan dengan 6 perlakuan yaitu *tanpa pemeraman* dan *tanpa rendaman*; *tanpa pemeraman* dan *rendaman*; *pemeraman 7 hari* dan *tanpa rendaman*; *pemeraman* 7 *hari* dan *rendaman, pemeraman* 28 *hari* dan *tanpa rendaman*; serta *pemeraman* 28 *hari* dan *rendaman*. Hasil penelitian menunjukkan bahwa nilai UCS meningkat seiring dengan lamanya waktu pemeraman. Sedangkan dengan perlakuan perendaman terhadap sampel mengakibatkan nilai UCS menurun.

Keywords: bottom ash, clay, fly ash, soil stabilization, unconfined compression strength

1. Introduction

Soil is one of the most important aspects of an infrastructure given its functions of receiving and holding structural loads [1–3]. However, not all soils have good physical and mechanical properties. Clay soil is a type of soil with a large development (high plasticity); its volume increases in wet conditions and shrinks in dry conditions, which is highly detrimental to infrastructures. To evaluate the possibility of such conditions occurring, stabilization of the soil is carried out to meet the necessary technical requirements.

Soil stabilization can be performed in several ways, including mechanical and chemical soil improvement. Several studies have been conducted to increase the strength of clay soils, such as mixing the soil with added materials (additives). In this study, chemical soil improvement is performed, namely, soil stabilization with lime, fly ash, and bottom ash.

The use of fly ash and bottom ash have the advantage of utilizing waste materials produced by the industry [4]. World production of fly ash in 2000 is estimated at 349 billion tons. Meanwhile, the contributor to fly ash production in Indonesia is the power generation sector. In 2000, the production of fly ash reached 1.66 billion tons and is estimated to reach 2 billion tons in 2006 [5]. Currently the amount of coal waste generated in Indonesia from coal combustion is extremely large, which can contribute to pollution. Thus, using fly ash and bottom ash as additives in soil stabilization can be ideal alternatives.

In addition, fly ash has pozzolanic properties with characteristics of high silica and alumina content. The mixture of pozzolanic material with lime and water causes a reaction and forms a bond. Therefore, fly ash can be used as a stabilizing material for clay soil to increase the carrying capacity of the soil [6]. On the basis of the problems in clay soil, a study was conducted on the characteristics of the clay stabilized with fly ash and bottom ash.

Expansive clay soil. Expansive clay is a term used for soils with a high potential for expansion or shrinkage due to water content changes. With an increase in water content, the expansive soil will expand accompanied by an increase in pore water pressure and the emergence of swelling pressure. The reduction of water content to the limit of shrinkage causes shrinkage, which can cause damage to building structures [7].

Soil is a vital material that is used in civil construction. However, construction on expansive soil will have a tremendous impact, considering its low bearing capacity and its high risk of collapsing, making it is less able to bear the burden of the construction [8]. To evaluate the possibility of these conditions, soil stabilization is carried out to fulfill the required technical requirements.

Soil stabilization. Soil stabilization is used to change or improve the properties of the subgrade to increase the carrying capacity of the subgrade for the construction to be built on it [9].

If a structure is built on expansive soil, damages, such as cracks in road and bridge pavements, lifting of plate structures, damage to pipelines, soil heaving, landslides, and so on, will occur. The usual stabilization efforts on fine-grained soils can be done by adding chemical additives for a reaction to occur, which can increase the bearing capacity. Commonly used materials include cement, fly ash, lime, and a mixture of coal ash and lime [10]. Many studies on soil stabilization have been carried out, including:

Cristanto and Setiawan [11], with the title *The Effect of Fly Ash on the Characteristics of Expansive Soil Development*, revealed that the addition of fly ash into the soil can reduce specific gravity (Gs), increase the plasticity index (PI), increase dry density, reduce swelling potential, and increase soil strength.

Oryn Wijaya [12] and Lembasi [13], with the title *The effect of bottom ash on expansive clay soils in the West Surabaya area on the Swelling Potential value*, unveiled that the levels of bottom ash used include 0%, 12.5%, 25%, 37.5%, 50%, and 62.5%. The results showed that the more the percentage of bottom ash waste is added to the clay soil, the greater the decrease in potential swelling value and the shorter the time required for the development process.

Fergy A.E Sompie [14], with the title *Expansive Soil Stabilization with A Mixture of Coal Ash and Rock Fly Ash With Soil Filling Type Application*, uncovered that the addition of rock fly ash was more effective and efficient than coal in increasing the value of the soil shear strength parameter, but in the application of soil backfill, it would be more effective if coal fly ash and coral are added to obtain a smaller settlement value greater safety factor.

Lime. Lime has properties as a binding material, namely, plastic, easy and quick to harden, good workability, and has good bonding power to stone and brick. The basic ingredient of lime is limestone or dolomite, which contains CaCO3 compounds.

The definition of lime as a stabilizing agent refers to lime minerals in the form of $Ca\ (OH)_2$, CaO, and calcium carbonate $CaCO_3$. Soil stabilization with lime has been widely used in road projects worldwide. For optimum results, lime used must be between 3%–7%. Moreover, lime content between 5%–7% will produce greater strength than the lime content of 3%.

Fly ash. Fly ash is the largest part of coal ash, which has a fine grain size, light weight, gray color, and is non-plastic. Utilization of fly ash in soil stabilization for its pozzolanic properties can also reduce shrinkage and cracking that usually arise when using cement as a soil-stabilizing agent. Generally, fly ash contains chemical elements, such as SiO_2, $A1_2O_3$, Fe_2O_3, and CaO, and additional elements, namely, MgO, TiO_2, Na_2O, K_2O, SO_3, and P_2O_5.

If fly ash is mixed with soil material, a cementation bonding process will occur due to the influence of pozzolans or the natural hardening properties of fly ash owing to the compaction and water conditions. From previous studies, the benefits of using fly ash as a soil-stabilizing agent and concrete material, namely, fly ash, can reduce water requirements, improve cohesion, reduce shrinkage and soil permeability, and increase the strength of high-quality concrete.

Bottom ash. Bottom ash is a waste material produced through the process of burning coal in power plants that is larger and heavier than fly ash. Bottom ash has the physical characteristics of dark gray color, granular, porous, and grain size near to sand and gravel [15].

Clay soil compaction. Compaction of the soil pore space is far processes using the dynamic load that is affected by the movement mechanism of the solid particles. In each standard compaction used value will be the optimum water content (optimum moisture content) that generates the maximum density (maximum dry volume weight). The purposes of soil compaction are as follows: 1) Heightening shear strength; 2) Reducing the vulnerability of compressed (compressibility); 3) Reducing permeability; 4) Reducing the volume changes because of alterations in moisture content and others.

Unconfined compression strength (UCS). Unconfined compressive strength test aims to determine the strength of the soil under axial pressure on the test object until it collapses or reaches an axial strain of 20%. The UCS test is a method used to calculate the shear strength of the soil. This test measures how strongly the soil receives a given compressive strength until the soil is separated from its grains and measures the strain of the soil from the pressure.

This UCS test was carried out on the original soil sample and the non-native soil sample, and then the ability of each sample to the free compressive strength was measured. From the maximum compressive strength value that can be accepted in each sample, the soil sensitivity can be obtained. This sensitivity value measures how the soil behaves during an external disturbance.

2. Methods

Research material. This research study was conducted at Laboratory of Soil and Rock Mechanics, Civil Engineering Department, Faculty of Engineering, University of Riau. The soil samples examined came from the District of Muara Fajar, Pekanbaru City. The lime used was quick lime purchased from the production of PT Brataco, whereas the combustion coal, fly ash, and bottom ash used were obtained from coal ash combustion waste from PLTU Tenayan Raya, Pekanbaru City. In this study, the variation of the test sample used can be seen in Table 1.

Testing procedure. In this study, only the physical and mechanical characteristics of the soil were tested, whereas for mixed materials, such as lime, fly ash, and bottom ash, chemical content tests were not carried out. The physical characteristic test on the soil is Atterberg Limit, whereas the mechanical characteristic test includes the Proctor Standard test and the UCS test. Atterberg limit tests were carried out on native soils and mixed soil variations. The standard proctor test was carried out only on the original soil to obtain the optimum moisture content (OMC) for the manufacture of UCS samples. Meanwhile, the UCS test was only carried out on native soils and mixed soil variations.

Table 1. Number of Variations and Description of Soil Mixture

Sample Variations	Unit	Mixed Description			
		95% MC			Lime
		C	FA	BA	
100% Clay	%	100	-	-	-
Variation I	%	80	10	10	5
Variation II	%	80	15	5	5
Variation III	%	75	10	15	5
Variation IV	%	75	15	10	5
Variation V	%	60	20	20	5
Variation VI	%	60	25	15	5

Notes MC : mix clay; MC a mixture clay with bottom ash and clay ash, which has mixed on percentage each variation
C : clay
FA : fly ash
BA : bottom ash

This study was conducted under conditions of non-cured and unsoaked, non-cured and soaked for 4 days, cured for 7 days and unsoaked, cured for 7 days and soaked for 4 days, cured for 28 days and unsoaked, and cured for 28 days and soaked for 4 days. In the cured condition, the UCS sample was wrapped in 1 kg clear plastic and then put into a cork Styrofoam to maintain the water content of the sample to prevent it from decreasing drastically during the cured period. As for the soaked condition, the UCS sample was wrapped in a plastic with small, punctured holes to allow water entry. The sample was wrapped with plastic wrap to protect it from damage if submerged directly in water.

The test object used in this UCS test is oven-dried clay stabilized with lime, fly ash, and bottom ash. The test object used is the granules that passed the No.4 sieve. The water content used in this test is the optimum water content obtained in the original soil proctor test that has been carried out previously. Mixed soil samples were prepared in this test under different density conditions.
The total weight of the soil mixture used is 1.5 kg. Soil samples and added lime, fly ash, and bottom ash were mixed and stirred in a pan with a weight according to the percentage of each variation then added with water gradually. The evenly mixed sample was divided into 3 layers where each layer was pounded 11 times in a standard UCS tube with a diameter of 60.40 mm and a height of 148.40 mm. Then, the molded were given the conditions of non-cured and unsoaked, non-cured and soaked for 4 days, cured for 7 days and unsoaked, cured for 7 days and soaked for 4 days, cured for 28 days and

unsoaked, and cured for 28 days and soaked for 4 days. The test was carried out 3 times for each variation.

3. Results and Discussion

Atterberg limit test results. In this study, the original soil was tested for consistency limits, which included testing the liquid limit and plastic limit through which the difference between the two can be determined by the plasticity index value. Then the original soil was tested again for its consistency limit against the addition of variations of lime, fly ash, and bottom ash to see the effect of adding material to its consistency. The results of the examination of the limits of consistency on the original soil and the variation of the mixture can be seen in Table 2.

Table 2 presents that the results of the Atterberg Limit test where in the original soil, the liquid limit value is 69.50% and the plastic index value is 38.38%. Then, the value obtained is plotted into a Casagrande plasticity graph. The point from the test results is located above the “A Line” so that based on the USCS classification, the soil classification belongs to the CH group (high plasticity clay). Meanwhile, based on the Atterberg test results for the mixed soil variation limit after being plotted into the Casagrande plasticity graph as shown in Figure 1, mixing clay with added materials, such as lime, fly ash, and bottom ash tends to decrease the liquid limit and increase the limit value, thereby decreasing the plasticity index value.

Figure 1 exhibits that the original soil, which is high plasticity clay or CH, when mixed with lime, fly ash, and bottom ash, causes the mixed soil type to turn into high plasticity silt or MH.

Soil compaction test results. The compaction test carried out in this study was a standard compaction test on the original soil to obtain the OMC and maximum dry density. In this compaction test, five experiments were carried out with varying water content to produce different dry densities. The optimum water content of

Table 2. Results of the Consistency Limit Test for Various Mix Groups

No.	Soil Descriptions	Atterberg Limits		
		LL (%)	PL (%)	PI (%)
1.	100% Clay	69,50	31,12	38,38
2.	Variation I	58,27	39,72	18,55
3.	Variation II	62,74	43,04	19,69
4.	Variation III	58,06	38,93	19,13
5.	Variation IV	56,84	40,02	16,82
6.	Variation V	51,17	37,69	13,48
7.	Variation VI	55,97	39,87	16,10

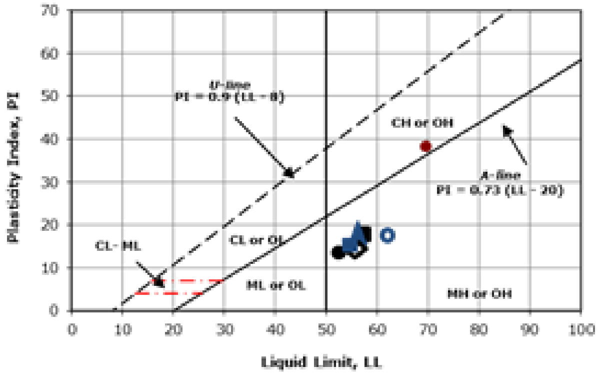

Figure 1. USCS Classification Chart and Results of Soil Consistency Limits of Various Variations

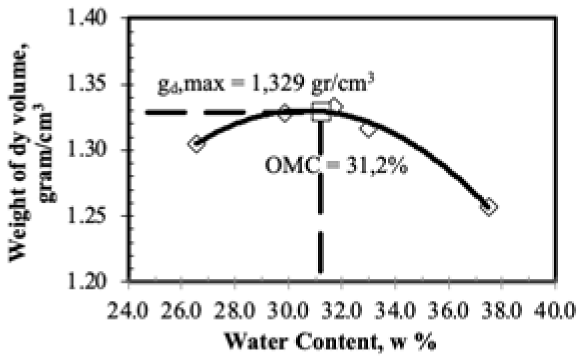

Figure 2. Original Soil Compaction Test Results

the original soil obtained in this compaction test is used as a reference as the water content used in the manufacture of the UCS test specimen mixture. The results of the original soil compaction test can be seen in Figure 2.

In compaction of the original soil, the optimum water content value was 31.2% and the maximum dry density was 1.329 gr/cm^3.

Unconfined compression strength (UCS) test results. The UCS test resulted in the maximum compressive strength or maximum pressure stress (qu) of the soil. In this study, the independent compressive strength test was carried out for three samples per variation, so that three values of qu were obtained. From the three samples, the qu value of the soil was then calculated by the average qu value.

Below are the results of the UCS testing of each variation.

Table 3 shows that the effect of curing and soaking treatment due to the addition of fly ash and bottom ash on the value of unconfining strength (qu). The addition of coal combustion content (bottom ash and fly ash, BAFA) increases the value of the unconfining strength.

The higher the BAFA rate, the higher the qu value [16]. For example, in non-curing and unsoaked conditions, addition of 20% BAFA (Variations I and II), 25% BAFA (Variations II and IV), and 40% BAFA (Variations V and VI), the qu value increased respectively from 258 kPa to 375.81 kPa; 453,749 kPa; and 601.73 kPa. The largest increasing value of qu occurs in the addition of BAFA where the bottom ash (BA) content is lower than the fly ash (FA) content.

Figure 3 demonstrates that the specimen in each variation has the highest value in the cured (curing) condition compared with the uncured condition. The longer the curing time, the higher the value of qu obtained. Based on the graph, the specimens that were cured for 28 days and unsoaked have a higher value than the specimens that were cured for 28 days and unsoaked. However, when the specimens are compared with cured and cured conditions, the specimens that were cured had the highest value. As with the uncured condition, the test object has a high qu value compared with the test object with uncured and soaked conditions. Meanwhile, the specimens that were soaked and uncured had an extremely low UCS value. The reason is because the hydration process between substances has not occurred, thereby affecting the UCS value.

Table 3. UCS Test Results for Various Mixed Variations

No.	Soil Descriptions	qu Value (kPa)					
		Non-cured		Cured for 7 days		Cured for 28 days	
		Soaked 4 days	Unsoaked	Soaked 4 days	Unsoaked	Soaked 4 days	Unsoaked
1	100% Clay	33,243	258,401	-	-	-	-
2	Variation I	210,681	353,977	573,800	636,021	615,616	711,497
3	Variation II	101,626	375,811	425,350	629,216	474,493	900,576
4	Variation III	120,442	380,743	509,425	756,832	423,569	992,232
5	Variation IV	100,335	453,749	590,461	762,231	491,408	1042,008
6	Variation V	311,070	459,059	638,843	794,325	803,952	1120,875
7	Variation VI	222,579	601,730	424,528	838,945	818,075	1506,158

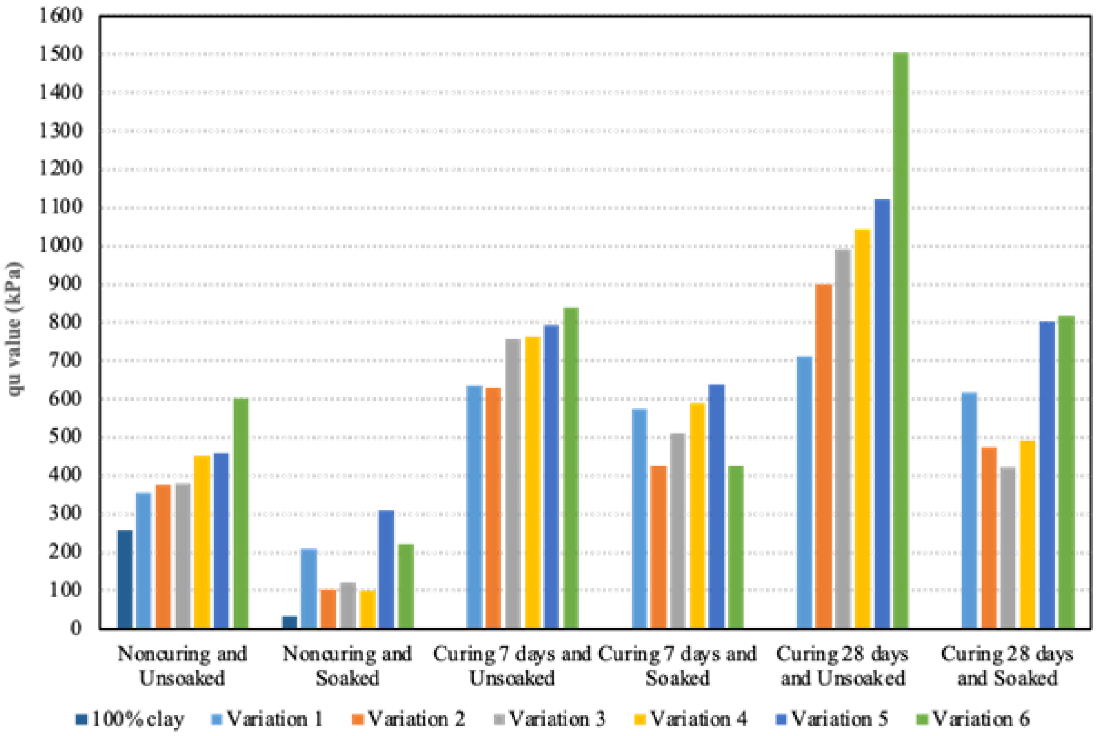

Figure 3. Effect of Curing and Soaked on Various Mix Samples

This hydration process can also be seen in cured specimens with uncured specimens, where specimens treated with cured conditions have a high qu value due to the hydration process of added materials with soil particles. Meanwhile, in the uncured condition and directly tested specimens, no chemical reaction occurred between the soil particles and particles, lime, fly ash, and bottom ash.

When viewed in Variations I and V with cured and soaked treatment, the value of qu tends to be higher compared with other mixed variations. The reason is because the same percentages of fly ash and bottom ash have better gradations and interlock between particles.

Effect of water content on UCS value. In addition to the effect of curing and immersion treatment on the compressive strength of UCS in each variation, the effect of water content on the compressive strength of UCS was also analyzed. The relationship between curing and soaking treatments on the water content can be seen in Graphic 2.

Graphic 2 (Figure 4) reveals that the samples that were not cured have different water content values when the sample was immersed. The samples that were tested directly had a lower water content than the samples that were directly soaked. In direct testing, a loss in water content transpired in each variation compared with the original soil sample because at the time of mixing, all the stability materials and the moisture content used were the OMC for the original soil. Furthermore, the ripened samples also have different water content values if the samples were soaked after curing. The soaked sample, even though it has been ripened, also had a high-water content value. When compared with the water content of the same sample soaked, the value of the water content that was soaked directly was higher than that which was soaked after curing because the cured sample was closer to being impermeable to water due to the particles between the mixtures already binding

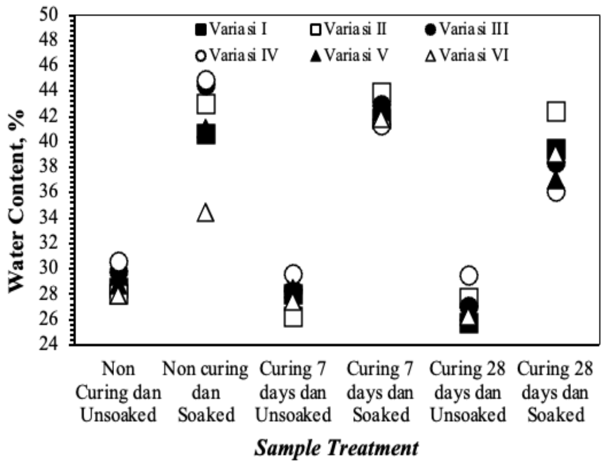

Figure 4. Water Content Value of Each Variation

to each other. Samples that were only cured had water content values that were close to each variation. According to [17] [18], in soaked conditions, the higher the water content in the compacted soil, the lower the soil bearing capacity, and vice versa.

4. Conclusions

Based on ASTM 4318, the clay used is high plasticity clay with a liquid limit of 69.50%, a plastic limit of 31.12%, and a plasticity index of 38.38%.

From the results of the compaction of the proctor on the original soil, the optimum water content was 31.2% and the maximum dry density (MDD) was 1.329 gr/cm^3.

The addition of lime, fly ash, and bottom ash increases the value of UCS. The more additives used in the soil mixture, the higher the value of the free compressive strength of the UCS.

The highest value of free compressive strength occurred in Variation VI with a UCS value of 1506.158 kPa when cured for 28 days and unsoaked.

Cured and soaked conditions affect the value of the free compressive strength of the UCS. The specimens that were cured for 28 days and unsoaked had the highest free compressive strength values in each mixture variation.

The water content affects the UCS value. The higher the water content value, the lower the UCS value obtained.

Ultimately, this study provides suggestions that can be used for further research as follows: 1) Sampling points at locations can be reproduced and more evenly distributed to obtain varied and accurate results. 2) In further research, soil samples can be tested in a laboratory to obtain the water absorption capacity of soil.

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