Durability and strength improvement of clayshale using various stabilized materials

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Abstract. In Indonesia, the study of clayshale has begun to be widely discussed. Clayshale is well known as a degradable material. The process of degradability in clayshale shows the weakening of the shear strength. This clayshale characteristic leads to several failures in the geotechnical design. To avoid degradability, soil stabilization testing was carried out by using cement, lime and rice husk ash. In the soil stabilization study, the use of cement and lime is already common and effective for some type of problematic soil, but the cost of material production is expensive and not environmentally friendly. Rice husk ash as agricultural waste material has the potential as a stabilizing material because it is availability and reaction ability with lime as known pozzolanic reaction. From the test results, each mixture has different response and potency. Cement has better resistance to wetting and drying with a significant increase in unconfined compressive strength. Whereas the lime itself did not significantly increase durability and unconfined compressive strength, but the effect of rice husk ash to the soil-lime mixture increasing durability despite the reduction in unconfined compressive strength.

1. Background

Clayshale is known as a soil material with low durability. In some investigations of soil, clayshale tends to be considered a rock, but when the soil is exposed to the surface and filtered by air and water, very fast decomposition occurs. This physical change process shows the weakening of the shear strength of the soil, which according to Gatrung [1], the shear strength of the clayshale soil will rapidly decrease when it comes in direct contact with the atmosphere or hydrosphere which contains oxygen and hydrogen. As a result of the weakening of the shear strength will cause problem in geotechnical engineering such as landslide, low bearing capacity, and large deformation.

One of the landslide cases due to clayshale problems is the soil failure of Sports Center Facility in Hambalang, Bogor. The soil failure was caused by an exposed clayshale layer due to soil engineering on project and weathered by water and air without any treatment. I.M. Alatas and P.T. Simatupang have studied that the disintegration ratio of Hambalang clayshale soil is completely non-durable material after first immersion [2]. Therefore, soil improvement in clayshale soil requires to maintain integrity and increase of soil strength.

Selection of stabilization method is divided into two categories, mechanical stabilization and chemical stabilization. In clayshale soils, chemical stabilization is a more appropriate method due to...
weathering which requires stabilized materials to enhance or maintain the strength and integrity of the soil. Extensive studies have been carried out using various stabilized materials. Z. Sabzi has reviewed and compiled several stabilization materials which might be done to increase the strength of soil [3]. Cement and limestone are the oldest and most commonly used stabilization materials due to their abundant availability. But on the other hand, this raises problems that are not environmentally friendly in the production process. So that the use of agricultural waste materials can be an environmentally friendly solution. In Indonesia, the availability of agricultural material is obtained from rice husk ash (RHA). The use of RHA has been widely researched which mainly discusses the significance of strength in expansive soils or soft soils. Abdulwasattar has research that the use of 5% RHA and 10% RHA with 6% cement has a considerable increase in shear strength [4]. While research from Muntohar states that the use of 6% lime and 12.5% RHA content has the highest CBR [5]. As a material that can produce cementation by mixing it with lime-based (cement and limestone) material, RHA is expected to increase the problem of low durability in clayshale soils.

In this review, the effectiveness of cement, lime and RHA materials in improving durability and strength of clayshale will be tested. Durability testing refers to ASTM D 559 (Standard Test Method for Wetting and Drying Compacted Soil-Cement Mixtures) whose conditions are recommended by the Portland Cement Association for soil-cement mixture. Meanwhile, strength testing will be carried out using Unconfined Compressive Strength (UCS) to measure undrained strength in each stabilized material.

2. Materials

2.1. Clayshale

The clayshale soil for this research is taken from Sukamakmur District, Bogor Regency, West Java. Based on previous research, the dominant minerals contained in Hambalang clayshale are quartz and kaolinite[6]. Naturally, the index properties of the clayshale soil are as follows:

| Properties               | Result          |
|--------------------------|-----------------|
| Specific gravity         | 2.69            |
| Particle size            | 88.8% Silt      |
| Liquid limit (%)         | 30.52           |
| Plastic limit (%)        | 20.62           |
| Index plasticity (%)     | 9.9             |
| Natural water content (%)| 7.44 – 15.55    |

In the USCS classification, clayshale is classified as low plasticity silt with activity 1.03 which can be categorized as normal activity, whereas based on the AASHTO classification, clayshale is classified as A-4.

The compaction test show optimum moisture content is at 14.05 % with maximum dry density at 1.89 g/cm³

2.2. Cement

Cement material may be considered as primary stabilized agent and it is not dependent on soil minerals. If the cement comes in contact with water, the hydration process will take place. During the
hydration of cement, calcium hydroxide \( \text{Ca(OH)}_2 \) is released. The cement hydration product has high strength, which increases as it ages, while calcium hydroxide contributes to the pozzolanic reaction as in the case of lime stabilization [7]. Type of cement used in this study is Portland cement which will have a reaction like below:

\[
2(3\text{CaO} \cdot \text{SiO}_2) + 6\text{H}_2\text{O} (\text{I}) \rightleftharpoons 3\text{CaO} \cdot \text{SiO}_2 \cdot 3\text{H}_2\text{O} + 3\text{Ca(OH)}_2
\]

In this study, the highest percentage of cement followed the recommendation of the Portland Cement Association for designing paving materials using soil-cement which for clayshale soils in the AASHTO A-4 soil group had a value of 10% cement from dry weight of soil [8]. As for the lowest percentage following several studies that 3% of cement already have the effect of increasing strength [5].

2.3. Lime
The use of lime as a soil stabilization material has long been developed and is one of the oldest stabilization techniques. In many studies lime has been shown to significantly change the properties of clay soils such as reducing plasticity index, increasing shrinkage limit, compressive strength and CBR values so as to overcome the problem of swelling in the expansive clay soil [9].

Generally, the lime material used as stabilization material is hydrated lime and quicklime. Quicklime is the result of burning limestone at a temperature of ± 90 °C with the composition of most Calcium Carbonate \( \text{CaCO}_3 \). Meanwhile, hydrated lime is the result of the extinction of lime with water to form hydrates \( \text{[Ca(OH)}_2\text{]}_n \). When lime is poured with water, the following reaction occurs:

\[
\text{CaO} (\text{s}) + \text{H}_2\text{O} (\text{I}) \rightleftharpoons \text{Ca(OH)}_2 (\text{aq}) (\Delta \text{H}_\text{r} = -63.7 \text{ kJ/mol of CaO})
\]

In this research, the type of lime is used is quicklime which is more likely a pozzolanic reaction occurs. \( \text{CaO} \) products used in this research have the following characteristics:

| Table 2. Quick lime Characteristic |
|-----------------------------------|
| Properties | Result |
| CaO content | > 95 % |
| Molar mass | 56.0074 g/mol |
| Density | 3.34 g/cm^3 |

2.4. Rice Husk Ash
Rice husk ash is a pozzolanic material which is rich in silicates. Generally, Rice husk ash cannot be used alone as a soil stabilizer because of the lack of cementation. RHA will react with lime and produce bonding gel \( \text{[Ca(SiO)}_3\text{]} \) [5].

\[
\text{Ca(OH)}_2 + \text{SiO}_2 \rightarrow \text{C − S − H} (\Delta \text{H}_\text{r} = -63.7 \text{ kJ/mol of CaO})
\]

Several studies investigated the effect of RHA on soil with 2% - 12% RHA. The result showed that by increasing the dose of RHA, the optimum moisture of sample increased, while the dry density of soil decreased. The California bearing ratio (CBR) and unconfined compressive strength (UCS) was also slightly improvement with increase in the RHA content. [10]. Rice husk ash used in this research was the result of burning husks from rice farming in West Java.
3. Methodology

3.1. Sample Preparation
This research was to examine the physical change, durability, unconfined compressive strength against cementation that occurs in each specimen. Specimen variations were made based on differences in cementation with the following variations:

| Table 3. Type and content variations of stabilization materials in clayshale soil specimens |
|---------------------------------------------------------------|
| Sample no. | Cement | Lime | RHA | Remark          |
|------------|--------|------|-----|-----------------|
| 1 (C0)     | -      | -    | -   | Clayshale only  |
| 2 (C3C)    | 3%     | -    | -   | Clayshale + 3% cement |
| 3 (C10C)   | 10%    | -    | -   | Clayshale + 10% cement |
| 4 (C3L)    | -      | 3%   | -   | Clayshale + 3% lime |
| 5 (C6L)    | -      | 6%   | -   | Clayshale + 6% lime |
| 6 (C9L)    | -      | 9%   | -   | Clayshale + 9% lime |
| 7 (C3L6R)  | -      | 3%   | 6%  | Clayshale + 3% lime + 6% RHA |
| 8 (C6L12R) | -      | 6%   | 12% | Clayshale + 6% lime + 9% RHA |

Samples used for durability and unconfined compressive tests were cast through the stages of the process of mixing, molding and curing.

Mixing is done by stirring the stabilized material with clayshale soil, the whole percentage of mixing material presented in this study was the ratio of the soil’s dry weight.

Each specimen had different mixing and molding time, clayshale requires restraining a day before molding so that the moisture content becomes homogeneous. Whereas in cement, mixing and molding was carried out as soon as possible so that the cement did not harden (<1 hour) and limestone requires restraining for 4 hours after the hydration process was complete. Water losses due to evaporation during the mixing process were recorded.

| Table 4. Mixing & molding test specimens |
|-----------------------------------------|
| Moisture Content (%) | Mixing Time (hour) | Density (g/cm³) | Dry Density g/cm³ | Evaporation % |
|----------------------|-------------------|-----------------|-------------------|---------------|
| C0                   | 13.93             | 24              | 2.15              | 1.89          | 0.12          |
| C3C                  | 13.65             | 1               | 2.13              | 1.84          | 0.40          |
| C10C                 | 13.14             | 1               | 2.07              | 1.82          | 0.90          |
| C3L                  | 11.48             | 4               | 1.96              | 1.72          | 2.57          |
| C6L                  | 8.99              | 4               | 1.91              | 1.68          | 5.06          |
| C9L                  | 5.41              | 4               | 1.90              | 1.67          | 8.64          |
| C3L6R                | 14.49             | 4               | 1.79              | 1.57          | -0.44         |
| C6L12R               | 15.50             | 4               | 1.68              | 1.45          | -1.45         |

Table 4 show on stabilized cement, the evaporation that occurs is not significant, whereas in stabilized lime, increasing lime content lead increasing the evaporation, this is to ensure that the hydration process occurs. The release of heat was also an indication of the occurrence of the process.
however, in a mixture of lime and RHA, relative evaporation does not occur, this is possible because lime is not fully hydrated.

Before Molding, mixture on each sample will be added with water according to its evaporation to ensure that the optimum moisture content was matched the optimum moisture content of the original clayshale soil. On the process of molding samples, the guidelines used are based on ASTM D698 (Standard Test Methods for Laboratory Compaction). Samples were molded using a 4 inch mold with standard effort energy according to ASTM D698.

As shown in table 4, the compaction result in each specimen has decreased dry density behavior. The results showed that the addition of RHA could increase the moisture content of the specimen, while the soil dry density decreased.

After the molding process, the sample is prepared for two tests, durability test according to ASTM D 559 and unconfined compressive test. For Durability samples, after molding the soil was extruded to the diameter and height of the sample according to the 4 inch mold. According to ASTM D 1632 (Making and Curing Soil-Cement Compressive and Flexure Test Specimens in the Laboratory) curing on a 4 inch sample was carried out at room temperature, whereas for UCS it will be extruded using a 3.65 cm ring and 7.3 cm height and curing on desiccator.

The curing period is made uniformly for 7 days for all test specimens. It aims to compare the cementation process so that it can determine the best durability and strength of stabilized soil.

Figure 1. Molding for durability test and unconfined compressive test.

3.2. Index Properties
All specimens were tested for Index properties using the Atterberg Limits (ASTM D4318) and Specific gravity (ASTM D854) tests. Index properties are performed to see the physical changes of the mixture. Making sample for mixture does not require special handling. The proportion of stabilized agent is sought based on its dry weight and for the Atterberg limits test the sample will be sieved with a # 40 sieve according to the standard.

3.3. Unconfined Compressive Strength Test
The unconfined compressive strength test was carried out in order to show the behaviour of specimens under compressive loads and particularly important for understand potential stabilization with various additive. The unconfined compressive strength test was conducted according to ASTM D 2166 - D 2166M.
3.4. Durability Test

The durability test is aimed at testing reaction of the stabilized soil to the effect of repeated drying and wetting [11]. The durability testing referring to ASTM D559 (Wetting and Drying Compacted Soil-Cement Mixtures).

After 7 days curing of durability specimen, weight and dimensions were measured each day of treatment period. The sample was submerged in water for 5 hours at room temperature and placed into an oven for 42 hours. Specimen gave two firm stroke on all areas with wire scratch brush with corresponding to approximately 13,3 N force. The procedure above constitute one cycle (48 hours) of wetting and drying. Again submerge the specimen in water and continue the procedure for 12 cycles.

Figure 2. Unconfined compressive strength test.

Figure 3. Wetting and Drying Test.
4. Result and Discussion

4.1. Index Properties
Result from table 5 show specific gravity value of specimen tends to increase with increasing cement or lime concentrations. This is because lime and cement have a specific gravity of value around 3.2 so that the value also goes up with the increase in concentration. While the addition of RHA gives a significant decrease in Specific gravity value due to RHA itself has a low specific gravity value (2.2).

| Specimen | Liquid Limit (%) | Plastic Limit (%) | Plasticity Index (%) | Specific of Gravity |
|----------|------------------|-------------------|----------------------|--------------------|
| C0       | 30.52            | 20.62             | 9.90                 | 2.69               |
| C3C      | 29.85            | 26.87             | 2.98                 | 2.71               |
| C10C     | 39.02            | 33.01             | 6.02                 | 3.10               |
| C3L      | 32.13            | 29.59             | 2.54                 | 2.75               |
| C6L      | 37.35            | 34.50             | 2.85                 | 2.73               |
| C9L      | 41.45            | 34.29             | 7.16                 | 2.73               |
| C3L6R    | 41.15            | 36.38             | 4.77                 | 2.71               |
| C6L12R   | 41.90            | 40.31             | 1.59                 | 2.65               |

Generally, plastic limits and liquid limits in each specimen have a tendency to increase from the original soil. The addition of RHA actually increases both liquid limits and plastic limits significantly. Whereas the plasticity index remains under 10 which shows the low plasticity of the stabilized soil.

4.2. Unconfined Compressive Strength Test
The graph in figure 4 shows the results of unconfined compression strength where the axis is the strain of the sample and the ordinate is the deviator stress. In unconfined compressive testing, the unconfined compressive strength value ($q_u$) of the clayshale itself is already on extremely hard category (8.18 kg/cm$^2$) with strain 2.1%.
Cement provides significantly increased of $q_u$. At 3% cement content, the soil-cement strength increased by 1.1 times from the clayshale soil only (9.02 kg/cm$^2$). Meanwhile, at the 10% cement specimen the $q_u$ was reach 2.3 (18.48 kg/cm$^2$). While the strain was increased but not significantly.

Lime itself did not provide enough strength as a stabilizing material. 3% and 6% lime content respectively having the value $q_u$ below the original soil (6.44 kg/cm$^2$ and 6.34 kg/cm$^2$) whereas in lime content 9% had $q_u= 9.63$ kg/cm$^2$ and there is a significant increase in strain at 9% of lime content.

Another results, from RHA and lime mixture, increasing content led decreasing $q_u$. Higher content (lime 6% and 12% RHA) had value of $q_u= 3.23$ kg/cm$^2$ with strain was reach 6.6% and the lowest content (lime 3% and 6% RHA) has a $q_u= 3.83$ kg/cm$^2$ and strain 5.6%.

4.3. Durability Test

The graph in figure 5 shows the results of durability where the axis is the weight loss of the sample and the ordinate is number of cycle. From the first submerging experiments in cycle no. 1, original clayshale was unable to withstand and almost dissolved in water. So in figure 5 the original Clayshale sample was not able to pass on 12 cycles.
In cement mixture, the 3% content specimen is dissolved in the 2nd cycle. Whereas at 10% content, the specimen can survive at the 12th cycle in which the weight lost due to testing is 20.4%.

Lime also has the same tendency, where at 3% & 6% content specimen is dissolved in the 2nd cycle. Whereas at 9% content, the specimen can survive at the 12th cycle in which the weight lost due to testing is 49.4%.

In the mixture of RHA and lime, specimens have better durability than lime itself, where at 3% lime and 6% RHA is able to survive until the 4th cycle before the soil is dissolved. While at 6% lime and 12% RHA has better durability than lime itself with 9% content but not greater than 10% cement. Specimen is able to survive the last cycle with 36.2% weight reduction.

5. Conclusion
It can be concluded from this study that soil stabilizer that some stabilizing soils have some special characteristics. Originally, clayshale soil is a soil that does not have a low strength issue, unconfined compressive strength can reach 8.18 kg/cm² which means extremely hard if it is not exposed to water and air. From durability test show the original clayshale soil did not pass 1 cycle which means that the durability is very low.

The use of cement mixture, has good value from various aspects, both in terms of unconfined compressive strength and durability. But this can be achieved at a fairly high content (10%) according to recommendations from the PCA. The use of 3% and 10% cement reduces the plasticity index from 9.90% until reaching 2.98% and 6.02%, respectively. Unconfined compressive strength in both specimens increased from 8.18 kg/cm² to 9.02 kg/cm² and 18.48 kg/cm², respectively. Durability in both specimens also increased from 1 cycle to 2 cycle and 12 cycle with 20.4% of weight loss.

The use of lime mixture only, has the same tendency as cement but is lower. The use of 3%, 6% and 9% lime content was a reduction in the plasticity index which had values respectively 2.54%,

\[ \text{Figure 5. Durability test results for each specimens} \]
2.85\% and 7.16\%. While the unconfined compressive strength at 3\% and 6\% is lower than the original clayshale soil (6.44 kg/cm$^2$ and 6.34 kg/cm$^2$). Whereas at 9\% lime content is higher than the original clayshale soil (9.63 kg/cm$^2$). Durability at 3\% and 6\% lime content is only capable of 2 cycles while 9\% can reach 12 cycle but with 49.4\% of weight loss.

While the mixture of lime and RHA provides better durability but lower unconfined compressive strength. The use of 3\% lime + 6 \% RHA and 6\% lime + 12\% RHA reduces the plasticity index which had values respectively 4.77\% and 1.59\%. The unconfined compressive strength on both specimen tends to reduces from original clayshale soil which had $q_u$ 3.23 kg/cm$^2$ and 3.83 kg/cm$^2$ with long strain. Durability at 3\% lime + 6 \% RHA content able to reach 4 cycle while the 6\% lime + 12\% RHA content can reach 12 cycles with 36.2\% weight reduction.

The use of RHA will be very effective in increasing the durability of clayshale soils. The use of 6\% lime + 12\% RHA is recommended due to has a higher durability and unconfined compressive strength compared to 3\% lime + 6 \% RHA. Abundant availability and environmentally friendly material become more value in using RHA as a stabilizer.

For further research, unconfined compressive strength testing needs to be done after immersion to see the effect of reducing strength due to water infiltration.

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Acknowledgments

The experimental laboratory research is conducted by Universitas Indonesia through Soil Mechanics Laboratory of Universitas Indonesia. This research also funded by the Donation of International Indexed Publication for Universitas Indonesia’s Student Final Project (PITTA) No. NKB-0799/UN2.R3.1/HKP.05.00/2019.