Improving the physical properties of clay using Sinabung volcanic and rice husk ash with UCT and CBR

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Abstract. Stabilization can be done by adding something to the soil in order to improve its strength and bearing capacity. One of the efforts to stabilize the soil is to add certain chemicals so that the soil will become solid. The additive materials used in this research are Rice Husk Ash (ASP) and Volcanic Ash (AGV) which is obtained from the eruption of Mt. Sinabung. The purpose of this research is to find index properties value as the effect of adding 2%, 4%, 6%, 8% Volcanic Ash and 2%, 4%, 6%, 8%, 10%, 12%, 14%, 16%, 18%, 20% Rice Husk Ash on clay, to find the maximum compressive strength value with UCT (Unconfined Compression Test), to find the CBR (California Bearing Ratio) value as the effect of adding the stabilization agents, and also to find the optimum content of adding Rice Husk Ash. According to the result of this research, the soil has 34.43% water content, 2.65 specific gravity, 47.33% liquid limit, 29.88% plasticity index, and 1.42 kg/cm² compressive strength. Based on the classification system of Unified Soil Classification System (USCS), this soil is included in the group of CL which is inorganic clay with low to medium plasticity. Meanwhile based on the classification system of American Association of State Highway and Transportation Officials (AASHTO), this soil could be classified as type of soil A-7-6. The highest compressive strength value is obtained from the addition of 8% Sinabung ash and 2% Rice Husk Ash which is 3.17 kg/cm² and the optimum CBR value also obtained from the addition of 8% Sinabung ash and 2% Rice Husk Ash which is 8.53%.

1. Introduction
In the geotechnical field, soil is one of the important element that will always be associated with structural work in the field of civil engineering, either as building materials or supporting the foundation of buildings. Soil consisting of a mixture of mineral granules with or without organic matter content can be defined as material consisting of solid minerals that are not cemented (chemically bound) to each other and come from organic materials that have decayed (which has a solid particle) accompanied by liquid and gas which fills the empty spaces between the solid particles [1]. Soil has a considerable influence on planning a construction. Soil is useful as a construction material in various types of Civil Engineering work and as a support for the building foundation. Therefore, research on soil is needed to ensure the stability of the building because the strength of the structure will be directly affected by the ability of the subgrade or local foundation to receive and carry on the workload.

Soil stabilization is an effort to improve the soil bearing capacity (quality) that is not good and increase the bearing capacity (quality) of soil that is already classified as good. The purpose of soil stabilization is to increase the bearing capacity of the soil in holding loads and to improve soil stability.
[2]. This study will discuss about stabilization of clay with the addition of volcanic ash and rice husk ash as stabilizers which are expected to improve physical and mechanical properties of soil samples to obtain clay soil that meets the technical requirements for use in the construction field. Volcanic ash is a natural material released from volcanoes, it can cause damage to the environment, but also has the possibility of other uses that are more profitable. Volcanic ash composition consists of Silica and Quartz. Silica (SiO2) is the main constituent element in cement formation, thus volcanic ash has pozzolanitic properties. Pozzolanitic properties have the behavior of binding to other minerals in the clay so that they become harder in a certain period. Rice husk ash is a by-product of agricultural products, which is considered only as a waste. However, the husk that has been burned has pozzolanic properties that have high silicate elements around 91.72% with 87% of pozzolanic activity index. This pozzolan contains cementation properties when it is mixed with water. Rice husk ash acts as a filler. The function of the filler is as a filler material between the inter aggregate cavities which is expected to increase density and reduce the permeability of the mixture. Besides its size should be relatively smooth, the filler material must have certain properties such as cementation when it meets water and high adhesion with other aggregates [3][4][2].

2. Literature Review

2.1. Study of soil stabilization

In 2016, study about stabilization using Volcanic Ash and Rice Husk Ash has been done. The mixture used in this study was 75% original soil, 2.5% - 25% volcanic ash and 2.5% - 25% rice husk ash with 14 days of curing period. Based on the experiment result, it was found that the soil has the lowest plasticity index which is 5.31% and liquid limit 30.11% on the mixture of 75% original soil, 2.5% volcanic ash, and 22.5% rice husk ash. From CBR laboratory test, obtained that the CBR value on original soil was 12.87%, while the optimal CBR value was obtained from the mixture of 75% original soil + 2.5% rice husk ash + 22.5% volcanic ash with CBR value of 11.28%. From the unconfined compression test, obtained that the compressive strength (qu) of original soil was 1.38 kg/cm², while the compressive strength (qu) of remoulded soil was 0.58 kg/cm². Variations that are too large because the results obtained do not show optimal results so that further research is carried out with the same material but different mixture compositions. The maximum CBR value obtained from the mixture of 4% Sinabung ash + 2%-11% bagasse ash with 14 days curing time was 13.91% [5].

2.2. Clay and the forming minerals

Clay mineral has complex aluminum silicate compounds. This mineral consists of two basic crystal-forming crystals, they are silica tetrahedra and aluminum octahedra. Each tetrahedra unit consists of four oxygen atoms that surround a silicon atom, while the octahedra unit consists of six hydroxyl (OH) ion groups that surround the aluminum atom (Das, 1991). Clay is an original mineral which has plastic properties when it is wet, has a very fine grain size and has a composition in the form of Hydrous Aluminum and Magnesium Silicate in large quantities. Clay minerals mostly have layered structures where the mineral size is very small, ie less than 2 μm (1 μm = 0.000001 m), although there is a classification which states that the upper limit of clay is 0.005 m (ASTM) and is an electrochemically active particle can only be seen with an electron microscope [6][7].

The main source of clay minerals is chemical weathering of rocks containing Orthoclase Feldspar, Plagioclase Feldspar, and Mica (Muskovite). Where all of this can be called as complex aluminum silicates. Clay consists of various constituent minerals, they are clay minerals (Kaolinite, Montmorillonite and Illite) and other minerals that have a size in accordance with the existing constraints (mica group, serpentine group). The basic structural unit of clay minerals consists of silica tetrahedron and aluminum octahedron. These basic units unite to form a sheet structure. The silica tetrahedra units combine to form silica sheets and octahedra units combine to form octahedra sheets (gibbsite sheet). When the silica sheets are stacked on top of octahedra sheets, these oxygen atoms will replace the position of hydroxyl ions in the octahedra to meet the balance of their charge [6].
3. Methodology
In this study, the materials which we used are clay, volcanic ash, and rice husk ash.

- **Clay**
  The soil samples used were taken from Patumbak Deli Serdang. This location was chosen because the soil quarry in this location is often used as a landfill for several construction works in the Medan and surrounding areas.

- **Sinabung Volcanic Ash**
  In general, the composition of volcanic ash consists of Silica and Quartz, so that the volcanic ash is classified into pozzolanic material. Pozzolan material is defined as non-cement which contains silica and alumina. While the classification of pozzolanic material is divided into natural and artificial pozzolan (synthetic). Furthermore, examples of artificial pozzolan are the product of burning clay, rice husk ash, bagasse ash and coal burning (fly ash).
  Volcanic ash has become a very useful material for humans. Volcanic ash contains several types of minerals that are important to increase soil fertility such as zinc, manganese, iron and selenium and are useful for providing building materials, various types of pumice, and others.

- **Rice husk ash**
  Rice husk is the outer part of the rice grain which is the result of the rice milling process. About 20% of the weight of rice is rice husk and approximately 15% of the composition of rice husk is husk ash which is always produced every time the husk is burned (Hara, 1986).
  Rice husk is a hard layer which consists of two leaf form, petal husk and crown husk, where in the rice milling process, the husk will be separated from the grain of rice and becomes waste material or milling waste. Rice mill will produce about 25% of husks, 8% of bran, 2% of rice bran and 65% of rice. The husk is composed of a network of cellulose fibers that contain a lot of silica in the form of very hard fibers.
  Rice husk occupies 7% of the total production of rice which is usually only stockpiled near the rice mills as waste, so that it pollutes the environment, sometimes it is also burned. Rice husk can also be used as fertilizer, supplementary materials for growing vegetables in hydroponic plants.
  The test performed in this study are index properties test (water content, specific gravity, atterberg limit, sieve analysis), compaction test, California bearing ratio (CBR) and Unconfined Compression Test (UCT).

| Table 1. Chemical composition of Sinabung volcanic and rice husk ash |
|---|---|---|
| No | Parameter | Sinabung volcanic | Rice husk ash |
| 1 | Silica oxide (SiO$_2$) | 82.4% | 89.8% |
| 2 | Calcium oxide (CaO) | 5.10% | - |
| 3 | Aluminium oxide (Al$_2$O$_3$) | 4.52% | 2.24% |
| 4 | Water content | 1.89% | 2.14% |

4. Analysis result

4.1. Physical properties of soil

| Table 2. Physical properties |
|---|---|
| No | Parameter | Result |
| 1 | Water content | 34.43% |
| 2 | Specific gravity | 2.65 |
| 3 | Liquid limit | 47.33% |
| 4 | Plastic limit | 17.45% |
| 5 | Plasticity index | 29.88% |
| 6 | Sieve analysis | 48.81% |
Based on the AASHTO soil classification, for the percentage of passing the sieve no. 200 minimum 36%, has a liquid limit of at least 41% and a plasticity index value of at least 11% then the soil samples can be classified in soil type A-7-6.

4.2. Physical properties of Sinabung ash (AGV) and rice husk ash (ASP)
The testing result of physical properties of material used in this study can be seen in Table 3, below:

| No | Test               | Sinabung Ash (AGV) | Rice husk ash (ASP) |
|----|--------------------|---------------------|---------------------|
| 1  | Specific gravity   | 2.62                | 2.55                |
| 2  | Liquid limit       | Non plastic         | Non plastic         |
| 3  | Plastic limit      | Non plastic         | Non plastic         |
| 4  | Plasticity index   | Non plastic         | Non plastic         |
| 5  | Sieve analysis     | 13.80%              | 8.56%               |

4.3. Result of laboratory test

**Figure 1.** shows the liquid limit due to the addition of stabilizers has decreased. The greater the percentage of rice husk ash, the smaller the liquid limit. The Liquid Limit (LL) on original soil reached 47.33%, meanwhile the lowest liquid limit was in the addition of 6% volcanic ash and 2% rice husk ash of 37.57%. This is due to the soil experienced cementation process by the rice husk ash and volcanic ash so that the soil becomes larger grains which makes the attractive force between particles in the soil decreased.

**Figure 1.** Graph of the correlation between the liquid limit on the soil with varying amount of stabilizers
Figure 2. Graph of the correlation between the plastic limit on the soil with varying amount of stabilizers

There is an increase in the plastic limit value due to the addition of stabilization ingredients as shown in Figure 2. For original soil, the plastic limit is 17.45% and it continues to increase until the variation of 2% AGV + 20% ASP plastic limit value reaches 20.22%.

Figure 3. Graph of the correlation between the plasticity Index on the soil with varying amount of stabilizers

Figure 3. shows the decrease in plasticity index from the original soil which initially valued 29.88% then dropped to 21.7% in addition 8% of volcanic ash and 2% of rice husk ash. The decline in value of the plasticity index may reduce the potential of soil to expand and shrink. This process strengthens the bonds between soil particles, which forms harder and more stable granules. The soil pores that have been filled minimize the occurrence of seepage in the mixture of soil and volcanic ash which results in reducing potential for shrinkage. Silica and alumina from rice husk ash mixed with water to form a paste that binds clay particles and cover the soil pores to reduce their plasticity.
Table 4. Data of Original soil compaction test

| No | Test Result             | Value     |
|----|-------------------------|-----------|
| 1  | Optimum water content   | 21.12%    |
| 2  | Maximum dry density     | 1.34 gr/cm$^3$ |

Figure 4. Original soil density curve

Figure 5. Graph of correlation between optimum water content (Wopt) on soil with mixed stabilizer variation
The results of the optimum water content from the experiments performed found that the optimum water content of the original soil was 21.12% and then decreased. Figure 5. shows the optimum moisture content was obtained in the addition of 8% of volcanic ash which is 20.08% and it kept increasing with the addition of rice husk ash. From the testing of soil compaction that has been performed on the original soil obtained the dry content weight is 1.340 gr / cm³. Figure 6. shows that the dry weight value increases when volcanic ash is added to the soil. The maximum soil dry weight was obtained in a mixture of 8% volcanic ash which was 1.67 gr / cm³ and decreased when rice husk ash is added to the mixture.

The result of Unconfined Compression Test on original and remoulded soil can be seen in Figure 7. below:

Figure 6. Graph of correlation between Maximum Dry Weight (γdmaks) on soil with mixed stabilizer variation

Figure 7. Graph of correlation between unconfined compressive strength (q_u) on original and remoulded soil

The unconfined compression value of undisturbed soil obtained from the test is 1.42 kg/cm², and 0.71 kg/cm² for remoulded soil. There is a substantial decrease caused by the treatment received by
remoulded soil which broke the structure of soil. The reduced soil strength due to soil structure damage is called sensitivity. This sensitivity value will determine the classification of soil according to its sensitivity. Thus, the more addition of volcanic ash and rice husk ash will lead to smaller soil compressive strength. This is because adding too much rice husk ash to the soil will reduce the coherency between soil and water grains, so that the soil becomes easily broken when it is given a vertical pressure.

**Figure 8.** Graph of correlation between unsoaked CBR value with the variation of AGC and ASP mixture

**Figure 8.** shows the effect of adding volcanic ash and rice husk ash to the CBR value. It can be seen that the addition of volcanic ash and rice husk ash causes the CBR value to decrease. The addition of 8% volcanic ash is the most effective mixture that can increase the bond between soil grains and volcanic ash, which causes clay soil strength to also increase.

5. Conclusion

Based on the research that has been done, it can be concluded:

1. Based on USCS classification, the soil samples are included in CL (Clay-Low Plasticity) type, which is inorganic clay with low to moderate plasticity.
2. Based on the classification system of American Association of State Highway and Transportation Officials (AASHTO), this soil could be classified as type of soil A-7-6.
3. CBR laboratory test shows that the CBR value of original soil is 6.29%. Here is the largest CBR value obtained from the test:
   - In the mixture of 2% AGV + 2% ASP, the CBR value is 7.54%
   - In the mixture of 4% AGV + 2% ASP, the CBR value is 7.84%
   - In the mixture of 6% AGV + 2% ASP, the CBR value is 8.17%
   - In the mixture of 8% AGV + 2% ASP, the CBR value is 8.53%
4. From the Unconfined compression Test obtained Compressive strength ($q_u$) of undisturbed soil is 1.42 kg/cm², while compressive strength ($q_u$) of remoulded soil is 0.71 kg/cm². Here is the maximum Compressive strength ($q_u$) obtained from the test:
   - In the mixture of 2% AGV + 2% ASP, the Compressive strength ($q_u$) is 2.52 kg/cm²
In the mixture of 4% AGV + 2% ASP, the Compressive strength ($q_u$) is 2.65 kg/cm$^2$.

In the mixture of 6% AGV + 2% ASP, the Compressive strength ($q_u$) is 2.8 kg/cm$^2$.

In the mixture of 8% AGV + 2% ASP, the Compressive strength ($q_u$) is 3.1 kg/cm$^2$.

5. Based on Atterberg limits test on the volcanic ash and rice husk ash, obtained they are non-plastic materials. This also can be seen from all the test result after mixing volcanic ash and rice husk ash into the soil, the physical character and bearing capacity of the soil get improved.

6. After obtained the optimum mixture, then there is a decrease in the value of Compressive Strength. It happened due to excessive amount of stabilizer which has been added to the soil, resulting the cohesion between soil grains and water is getting smaller, so the soil becomes easily broken when it is given vertical pressure.

6. References

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