The comparison of adding fly ash and Sinabung ash to limestone towards the soil improvement via CBR value

I P Hastuty¹, Roesyanto¹ and A F Rahman¹

¹Department of Civil Engineering Universitas Sumatera Utara, Medan, Indonesia

ika.hastuty@usu.ac.id

Abstract. Fly ash is categorized as pollutant produced from coal combustion, where the waste produced is around 4% of the total coal usage. This will be extremely dangerous since this waste is produced continuously. Mount Sinabung, which is located in North Sumatera, Indonesia, has erupted since 2010 and released a lot of ash pollution. Sinabung and fly ash can cause environmental and health problems for the people who live near the area. In the other hand, limestone is one of the building materials that can be used for soil improvement. When limestone with clay minerals reacts, it forms a strong and hard gel namely calcium silicate which can coat and bind clay particles and close the pore pores, so that it can reduce the soil plasticity index. This research analyzes the optimum CBR value and the optimum mixture. Variation of the mixture used was 2% and 4% limestone with the addition of 2%, 4%, 6%, 8%, 10%, 12% and 14% fly ash and 2% and 4% limestone with the addition of 2%, 4%, 6%, 8%, 10%, 12% and 14% of Sinabung ash. The result shows that the mixture of limestone and Sinabung ash indicates the bigger value of CBR compared to the limestone and fly ash mixture. Furthermore, the largest CBR value was found in the mixture of 2% limestone and 8% Sinabung ash with 9.01%.

1. Introduction

Clays are mostly composed of microscopic and sub microscopic particles (which cannot be clearly observed with only a standard microscope) in the form of flat plates and are particles of mica, clay minerals, and other very fine minerals. Furthermore, clay is defined as a group of particles with the size of less than 0.002 mm. In terms of minerals, clay soils are those which have certain mineral particles that produce plastic properties on the soil when mixed with water. So, in terms of minerals, soils can also be referred to as non-clay soils, although they consist of very small particles (particles of quartz, feldspar, and mica can be sub microscopic in size, but generally, they cannot cause the plasticity properties from the ground). In terms of size, these particles can indeed be classified as clay particles. The clay soil is not necessarily composed of clay particles only, but can mix with granules of silt and sand and may also have a mixture of organic matter [1, 2]. If subgrade is found in the form of clay which has a carrying capacity and low shear strength, it will experience construction damage on it. So, the subgrade is not in accordance with the technical requirements. In order to meet the requirements, the soil must be repaired, and one way to improve it is by the soil stabilization method.

Soil improvement techniques can be classified into various ways; according to the nature of the process involved, the material added, the desired result and etc. For instance, on the basis of the
process, soil improvement has mechanical stabilization, chemical stabilization, thermal stabilization, and electrical stabilization [3].

CBR (California Bearing Ratio) is a soil carrying capacity experiment developed by the California State Highway Department. The principle of this test is penetration testing by sticking objects into the test object. In this way, the strength of the subgrade or other materials can be assessed to make pavement. Soil strength was tested by CBR test in accordance with SNI-1744-1989. The strength value of the soil is used as a references need to be stabilized after being compared with the specification requirements. The CBR value is the ratio (in percentage) between the pressure required to penetrate the ground with a 3 inch round piston with a speed of 0.05 inch/minute against the pressure needed to penetrate certain standard materials [4, 5].

The purpose of this CBR test is to find the CBR value in the variation of compaction water content. Testing the CBR value of the soil can be conducted in the laboratory. Subgrade for new road construction is original soil, landfill, or dug soil that has been compacted to reach a 95% density of maximum density. Thus, the carrying capacity of the subgrade is the value of the ability of the soil layer to carry the burden after it is compacted. The higher the soil CBR value (subgrade), the thinner the pavement layer will be. While if the smaller the CBR value (low carrying capacity), the thicker the pavement layer will be according to the load to be carried.

1.1. Soil stabilization
Stabilization is one of the soil improvement techniques to make the technical properties of the soil meet the predetermined requirements. In general, stabilization can be carried out mechanically and adding material (chemically). Mechanically is by mixing two or more different grades of soil to obtain material that meets certain strength requirements. This soil mixing can be performed at various places, such as at the project site, at the factory, or at the borrow area. This mixed material is then spread and compacted at the project site. Mechanical stabilization can also be done by digging poor soil in place and replacing it with granular material from other places [6].

In the other way, chemical stabilization can be conducted by adding processed products from the factory which when added to the soil with the right ratio, it will improve the technical properties of the soil, such as strength, texture, workability and plasticity [7]. Several addition materials which can be used are lime, Portland cement, fly ash, bitumen, and others.

1.2. Stabilization with limestone
Lime is one of the building materials that can be used for soil improvement. The use of lime as an additional alternative ingredient in soil improvement can be categorized as chemically soil improvement process [8]. Limestone is the basic ingredient in making lime containing calcium carbonate (CaCO₃), and when it reacts with water, it will produce calcium hydroxide (Ca(OH)₂). The process is called slaking, where this lime will cause a chemical reaction with clay. The lime, which is often used for stabilization materials is quicklime (CaO).

1.3. Stabilization with the ashes of Mount Sinabung
The volcanic ash used in this study was originating from the slopes of Mount Sinabung in the area of Tanah Karo, North Sumatra. Mount Sinabung has erupted since 1600 and has been recently active in 2010. Until now, it still emits volcanic dust, and the latest data from Mount Sinabung erupted was on February 19th, 2018. PVMBG also recorded the last eruption of volcanic dust exposure to the city of Lhokseumawe, which is about 431 km [9]. When it erupts, volcanoes generally emit water vapor (H₂O), carbon dioxide (CO₂), sulfur dioxide (SO₂), hydrochloric acid (HCl), hydrofluoric acid (HF) and volcanic ash into the atmosphere. Volcanic ash released when the volcano erupts several contents such as silica, minerals, and rocks. Volcanic dust is considered as a waste that disturbs the community and can pollute the environment. On the other hand, volcanic dust has high silica content so that it can be used for soil stabilization since silica can improve soil properties.
1.4. Stabilization with fly ash

Fly Ash is an excellent material and has a uniform gradation that comes from the combustion of coal. About 80% of the ash that comes from burning coal through a chimney is called fly ash. Fly ash is a material called pozzolanic material because fly ash contains pozzolanic materials, namely Silica (SiO$_2$), Aluminum Oxide (Al$_2$O$_3$), Iron Oxide (Fe$_2$O$_3$), Magnesium Oxide (MgO), Sulphate (SO$_4$), and Calcium Oxide (CaO) [10]. In a mixture of fly ash with clay, a reaction of them is known as Pozzolanic Reaction. The reaction occurs between calcium elements and silica and aluminium to form a cementing agent. Cementing agent is a hard and rigid mass. The speed of the pozzolanic reaction depends not only on time but also by the concentration of the ingredients that react along with the temperature.

With the addition of fly ash, it will enrich the content of Alumina and Silica in the soil because the gradation of fly ash is greater than clay. So, the addition of fly ash will also make the clay has better gradations and can be easily processed [11, 12]. Furthermore, the heat produced by fly ash can reduce the moisture content of wet soil. The clay soil with pozzolan content reacts with fly ash to form a hard and rigid mass.

2. Research method

The research methodology used was an experimental method at the Soil Mechanics Laboratory, Faculty of Engineering, Universitas Sumatera Utara. The research was conducted on soil samples that were not given stabilization material (native soil) and on the soil which was given chemical stabilization materials in the form of addition of Lime (L), Fly Ash (FA) and Mount Sinabung (SA). With a mixture variation of 2% and 4% lime added with 2%, 4%, 6%, 8%, 10%, 12% and 14% fly ash, and 2% and 4% lime with the addition of 2%, 4%, 6%, 8%, 10%, 12% and 14% of Sinabung ash.

The materials used were lime, Sinabung ash and fly ash. The chemical composition of the material can be seen in table 1.

| Parameter | Limestone (L) | Sinabung Ash (SA) | Fly Ash (FA) |
|-----------|--------------|------------------|--------------|
| SiO$_2$   | 3.03%        | 84.08%           | 58.8%        |
| Al$_2$O$_3$ | 1.53%      | 9.93%            | 1.97%        |
| Fe$_2$O$_3$ | 0.54%      | 0.01%            | 17.3%        |
| CaO        | 51.58%       | 0.14%            | 2.89%        |
| MgO        | 0.81%        | -                | 0.07%        |

3. Research result

The laboratory tests performed for native soil in this research included several testing of Index Properties, such as moisture content test, specific weight test, Atterberg limit test and sieve analysis test. After the clay was mixed with stabilization materials, the Compaction Test and CBR test were conducted.

3.1. The physical properties test of original soil, limestone, Sinabung ash and fly ash

| No | Test          | Original Soil | Limestone | Sinabung ash | Fly Ash |
|----|---------------|---------------|-----------|--------------|--------|
| 1  | Water Content | 24.35%        | -         | -            | -      |
| 2  | Specific Gravity | 2.67          | 2.59      | 2.62         | 2.54   |
| No | Test                        | Original Soil | Limestone | Sinabung ash | Fly Ash |
|----|-----------------------------|---------------|-----------|--------------|---------|
| 3  | Liquid Limit                | 38.15%        | Non plastic | Non plastic  | Non plastic |
| 4  | Plastic Limit               | 17.45%        | Non plastic | Non plastic  | Non plastic |
| 5  | Plasticity Index            | 21.54%        | Non plastic | Non plastic  | Non plastic |
| 6  | Passes Percentage of Sieve no. 200 | 50.19% | 30.05% | 13.80% | 96.25% |

The data obtained from the Index Properties testing of soil samples used have met the minimum requirements and passed sieve no. 200, so that the soil can be classified in A-6 soil types based on AASHTHO. Based on USCS, the soil is included in organic clay with low to moderate plasticity (CL).

3.2. **The physical properties test on soil stabilizer materials**

The result of physical properties tests of soil added with limestone, Sinabung ash and fly ash is described in figure 1, figure 2, figure 3, figure 4, figure 5 and figure 6 below. This was done through the Atterberg Limit test.

![Figure 1](image1.png)  
**Figure 1.** The graph of liquid limit (%) from the mixture of limestone and Sinabung ash.

![Figure 2](image2.png)  
**Figure 2.** The graph of plastic Limit (%) from the mixture of limestone and Sinabung ash.

Based on figure 1, the addition of limestone and Sinabung ash causes a decrease of liquid limit. This is caused by the soil which is experiencing cementation by limestone and Sinabung ash.

![Figure 3](image3.png)  
**Figure 3.** The graph of plasticity index (%) from the mixture of limestone and Sinabung ash.

![Figure 4](image4.png)  
**Figure 4.** The graph of Liquid Limit (%) from the mixture of limestone and fly ash.

The decline of the plastic index, as seen in figure 3 is due to the hydration process of lime added to the soil, which resulted in the reduced swelling potential of the soil. The silica found in Sinabung ash...
when mixed with water forms a paste that binds clay particles and covers the pores of the soil. The same result is seen in figure 7 where the plasticity index value decreases.

Figure 5. The graph of plastic limit (%) from the mixture of limestone and Fly Ash.

Figure 6. The graph of plasticity index (%) from the mixture of limestone and fly ash.

3.3. Compaction test

Based on the compaction test, the relationship of optimum water content and maximum dry weight. The test result is described in table 3 below.

Table 3. The compaction test result of native soil.

| No | Test                  | Result     |
|----|-----------------------|------------|
| 1  | Optimum water content | 21.12%     |
| 2  | Maximum dry density   | r/cm³      |

The result of mechanical properties of soil which had been mixed with the stabilizer is displayed by the figure below.

Figure 7. The relationship of maximum dry weight ($\gamma_d$ maks) of soil with mixture variation of limestone and Sinabung ash.

Figure 8. The relationship of maximum dry weight ($\gamma_d$ maks) of soil with mixture variation of limestone and Fly Ash.

In figure 7 and 8, there is an increase due to the addition of stabilizer material, which results from the addition of limestone and Sinabung ash mixture of 2% limestone + 10% Sinabung ash has the largest maximum dry weight value of 1.562 gr/cm³. While due to the use of limestone and fly ash mixture of 2% lime + 10% Sinabung ash has the largest maximum value of 1.626 gr/cm³. From the variation in the use of 3% and 4% limestone, it is seen that the maximum dry weight obtained is by the use of 2% limestone. The increase occurs because the stabilizer material fills the pore cavity of the soil, which in the original soil conditions is filled with water and air.

The decrease that occurs after a mixture of 10% both Sinabung and fly ash is due to the soil having passed the effective addition of the use of stabilizer materials. Increasing the amount of stabilizer
material will make the ability to bind the original soil is reduced. So, it minimizes the attachment between the grains on the soil, which results in easily broken soil.

![Figure 9](image1.png) **Figure 9.** The relationship between optimum water content ($W_{opt}$) of soil with variation of limestone and Sinabung ash.

![Figure 10](image2.png) **Figure 10.** The relationship between maximum dry weight ($W_{max}$) of soil with variation of limestone and fly ash.

Based on figure 9 and 10, it can be seen that the use of 4% limestone has a greater value compared to 2% limestone. The lowest optimum water content value is at the use of 2% limestone and 10% Sinabung ash which is 19.75%, while the use of 2% limestone with 10% fly ash is 20.21%. The optimum decrease in water content is due to the stabilizing material pressing the water out of the pore so that the water content of the soil is reduced. The bigger number of stabilizer materials used, the lower binding capacity of the mixture becomes. It has been found that the soil-lime mixture compacted in a particular compaction effort will have a lower dry volume weight ($\gamma_{d-max}$) compared to native soil without lime [13]. In addition, the optimum water content (Wopt) also increases with increasing levels of lime.

### 3.4. CBR Test

![Figure 11](image3.png) **Figure 11.** The relationship of CBR with the addition of limestone and Sinabung ash mixture.

![Figure 12](image4.png) **Figure 12.** The relationship of CBR with the addition of limestone and fly ash mixture.

Figures 11 and 12 show the use of limestone and Sinabung ash has a greater CBR value than the use of limestone and fly ash. The largest CBR value is seen at 2% lime + 8% Sinabung ash with a CBR value of 9.01%. In the use of 4% limestone + 8% fly ash, the CBR value obtained is 6.57%. The addition of limestone in the soil can change the texture of the soil where there is a particle reduction of <0.002mm compared to the original soil. Limestone can also bind the soil mixture so that the strength of the soil increases and decreases the value of soil plasticity. The more limestone used in the mixture, the greater the CBR value becomes. Silica has a big role in increasing CBR value since silica is pozzolanic. The pozzolanic process occurs between calcium hydroxide from soil reacting with silica (SiO2) and aluminate (AlO2) from limestone and Sinabung ash to form a binding material composed of calcium silicate or aluminate silicate so that it can bind soil particles.
4. Conclusions
Based on the research result, it can be concluded that the use of limestone and Sinabung ash as stabilizers contribute to the greater CBR value than the use of lime and fly ash. The largest CBR value from the variation of the mixture used was obtained with 4% limestone + 8% Sinabung ash mixture with CBR values reaching 9.01%.

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