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# Optimization of the use of volcanic ash of Mount Sinabung eruption as the substitution for fine aggregate

Rahmi Karolina<sup>a,\*</sup>, Syahrizal<sup>a</sup>, M.Agung Putra<sup>a</sup>, Tito Agung Prasetyo<sup>a</sup><sup>a</sup>Department of Civil Engineering, University of Sumatera Utara, Jl.Perpustakaan No. 1 Kampus USU, Medan 20155, Indonesia

## Abstract

Mount Sinabung is one of the volcanoes which are categorized as an active volcano in the world. Recently, volcanic activities of some volcanoes in Indonesia are increasing causing the increase in natural materials to be spouted from the volcanoes that can be used as construction materials such as sand, rocks and ash. Chemical substances contained in volcanic ash of Mount Sinabung is more dominated by SiO<sub>2</sub> (74.3%), AL<sub>2</sub>O<sub>3</sub> (3.3%), and CaO (1.79) which has been studied in the Research and Industrial Standardization Center, Medan. The content of SiO<sub>2</sub> in the volcanic ash was the basis for this research. The objective of this work is to find out the influence of the volcanic ash as the substitution of fine aggregate.

The variation of volcanic ash used in the research was 5%, 10%, 15%, 20%, 25%, and 100% with two variations treatment process, by curing the hydrocooling and keeping the room temperature within 28 days. The analysis and the method of the research were referred to SNI 03-0347-1989. Based an experimental results the ideal percentage of variation which had met SNI 03-0347-1989 was identified, that is 10%.

Optimum average compressive strength and tensile strength were obtained, 17.19 MPa and 2.67 MPa respectively. Optimum absorption were also studied, 4.142 %.

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*Keywords:* Volcanic Ash; Batako; Absorption; Compressive Strength; Tensile Strength.

## 1. Introduction

Mount Sinabung, which is called *Deleng Sinabung* in Karonese, is one of the active volcanoes in the world; it belongs to the geological type of *Statovolkano*. Mount Sinabung eruption increased to the level of 4 (Alert) on November 24, 2013 since it spat out black, thick smokescreen, followed by sand rain and volcanic ash which covered

\* Corresponding author. E-mail address: [rachmie\\_caroline@yahoo.co.id](mailto:rachmie_caroline@yahoo.co.id)

thousands of hectares of farmers' crops under the radius of six kilometers so that more than 20 thousand people had to be evacuated.

This condition constituted the background for the use of volcanic ash material of Mount Sinabung eruption as the alternative for the substitution of the materials usually used for concrete. The idea was strengthened with the chemical content in the volcanic ash which had the same content as the one in sand and cement ( $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ , and  $\text{CaO}$ ) obtained from the Research and Industrial Standardization Center, Medan. The testing material used was batako (mass-produced brick).

Batako is building material which consists of stones. Its hardening is not through kilning; it is shaped by the mixture of sand, cement, and water at the ratio of 1 cement: 7 sand. It can also be added by other additives and is molded through the process of compaction so that bars are shaped in a certain size. The process is not through kilning or placed in a damp place and protected from direct sunlight or rain. It is molded in such a way that it meets the requirement and can be used as the substitution of brick for a wall.

The objective of the research was to find out whether batako, made from volcanic ash, met the qualification of quality I and quality II and to identify each optimum percentage of volcanic ash which met the requirements of the minimum of compressive strength of massive batako, according to SNI-3-0349-1989 standard.

## 2. Research Method

### 2.1 Materials

Batako is usually made of sand, cement, and water. In this research, the materials used to make batako were cement, water, sand, and volcanic ash.

Volcanic ash is the mineral of volcanic stones, including glass material which is as big as sand and gravels with 2 mm (0.079inch) in diameter from volcanic eruption. These minute ash particles can have section less than 10-3. It is very hard and cannot be dissolved in water so that it is often abrasive and slightly corrosive, and it can conduct electricity when it is wet.

The types of mineral in the volcanic ash depend on the chemical magma of the erupting volcano, by considering that the abundant element in magma is silica ( $\text{SiO}_2$ ) and oxygen. Various kinds of magma from volcano eruption are often explained by the parameter of its silica. Eruption which comes from low energy basalt (basalt: dark frozen stones and fine particles which come from the frozen lava of a volcano) produces specific dark ash which contains 74.3% of silica ( $\text{SiO}_2$ ), 3.31% of aluminum ( $\text{Al}_2\text{O}_3$ ), and 1.79% of calcium oxide ( $\text{CaO}$ ).

Table 1. Chemical content of volcanic ash of Mount Sinabung eruption [1]

No.	Parameter	Result	Unit	Method
1	Silica as $\text{SiO}_2$	74,3	%	Gravimetric
2	Aluminum as $\text{Al}_2\text{O}_3$	3,31	%	Calculation
3	Calcium oxide as $\text{CaO}$	1,79	%	Trimetri

In this research, the volcanic ash material which was used for batako was obtained from Mount Sinabung, about 4,600 meters from its top.

### 2.2 Test specimens

The design for mixing of the material in arranging batako was the ratio of 1 cement: 7 sand. The size of sample from outside view and the testing of absorption were made by using batako testing device of 40 x 20 x 10 cm. Cylinder of 15x30 cm with a 10x10 cm batako piece were used to test the compressive strength, and a 15 x 30 cm cylinder was used to test the tensile strength. The variation of the adding of volcanic ash was done by reducing the amount of sand from 0%, 5%, 10%, 15%, 20%, 25% and 100% of the weight of sand.

### 2.3 Testing the specimens

Some details of the test procedures are as follows:

1. The testing of slump value was came out by using Abrams' pyramid, piercing iron, and pedestal. The mixing process was done manually.

2. The testing for the size and the outside view was done by using a 40 x 20 x 10 cm batako testing device with a sliding bar. The testing was done when batako was 28 days for all variations.
3. The testing for absorption was done by using a 40 x 20 x 10 cm batako test specimen with an oven and a scale. The testing was done when batako was 28 days for all variations.
4. The testing for compressive strength and tensile strength was calculated by using a 15 x 30 cm cylinder sample with a compression machine. The testing was done when batako was 28 days for all variations.

### 3. Results and Discussion

#### 3.1 Visual Testing

Table 2 shows the appearance of visual examination from outside view testing

##### 1. Outside View Testing

Table 2. Result of Visual Examination

Explanation	Batako Variation					
	Normal Batako	Volcanic Ash Batako 5%	Volcanic Ash Batako 10%	Volcanic Ash Batako 15%	Volcanic Ash Batako 20%	Volcanic Ash Batako 25%
<b>Surfaces</b>						
Flatness	flat	flat	flat	flat	flat	flat
Rift	none	none	none	none	none	none
Smoothness	smooth	smooth	smooth	smooth	smooth	smooth
<b>Edges</b>						
Right angle	angle	angle	angle	angle	angle	angle
Acuity	incisive	incisive	incisive	incisive	incisive	incisive
Strength	strong	strong	strong	strong	strong	strong

It is observed that the use of volcanic ash as the substitution of fine aggregate from various variations in this research, produces batako which has flat surface, not rift, smooth and no cavity, and has met the requirement of outside view, according to SNI 03-0349-1989.

##### 2. Sectional Size Examination

After the outside view testing has been examined, the examination on the dimension and section which met the provision of SNI 03-0349-1089 is done by using the average of five pieces of complete batako. A 1 mm accuracy of bar as the measurement instrument is used at least 3 (three) times in different places according to the length, width, and thickness of the sample.

The result of the analysis of the deviation of batako size from various variations of volcanic ash are given in Table 3.

The batako has met the requirement of SNI 03-0349-1989 standard because the volcanic ash has nearly the same particles as those of cement; it could penetrate the sieve No. 200, and the additives for volcanic ash could fill the cavity among the sand which caused batako to be solid so that its surfaces became flat.

From the testing result, it is observed that the condition of the shape and the section does not indicate significant difference; however, since the batako was made manually, its solidity was not uniformed. Besides, the density of the pores in batako would highly influence the solidity of its composition.

Table 3. Result of Visual Examination

Mixing Composition	Length (mm)		Width (mm)		Thickness (mm)	
	Testing Device	SNI 0349-89	Testing Device	SNI 0349-89	Testing Device	SNI 0349-89
Normal Batako	399.9	390 +3	199.7	190 ± 2	99.6	100 ± 2
Volcanic Ash Batako 5%	399.6	-5.0	199.6		99.9	
Volcanic Ash Batako 10%	399.5		199.4		99.7	
Volcanic Ash Batako 15%	399.3		199.9		99.5	
Volcanic Ash Batako 20%	399.3		199.4		99.2	
Volcanic Ash Batako 25%	399.1		199.2		98.9	
Volcanic Ash Batako 100%	399.1		199.2		98.9	
Average Deviation (%)	399.4		199.5		99.4	

### 3.2 Absorption Testing

The result of water absorption testing in batako are given in Table 4.

Table 4. The comparison between the average water absorption and quality requirement

Mixing Composition	Water Absorption (%)		Quality Level
	Testing Device	SNI 03-0349-1989	
Normal Batako	4.142	25	I
Volcanic Ash Batako (5%)	4.011	25	I
Volcanic Ash Batako (10%)	3.520	25	I
Volcanic Ash Batako (15%)	3.109	25	I
Volcanic Ash Batako (20%)	3.383	25	I
Volcanic Ash Batako (25%)	3.172	25	I
Volcanic Ash Batako (100%)	1.820	25	I

From the tested batako composition, it is found that the biggest water absorption in batako obtains in normal batako and in 0% of volcanic ash batako at the absorption value of 4.142%, and the smallest absorption in batako occurs in 100% of volcanic ash batako at the absorption value of 1.820%.

The requirement of water absorption, according to SNI 03-0349-1989, is below 25% of water absorption for quality I level batako. Thus, it is one of the 5 variations which has met the requirement of water absorption, according to SNI 03-0349-1989.

### 3.3 Compressive Strength Testing

The recapitulation of the result of batako compressive strength of seven types of the experimented mixture are shown in Table 5.

The value of the testing of concrete compressive strength for cylinder test specimen with treatment indicated the increase in the value of the maximum of concrete compressive strength in Volcanic Ash Batako at the mixing composition of 10% at the value of the average compressive strength of 17.19 MPa and it decreased to 11.83 MPa.

According to SNI 03-0349-1989, Volcanic Ash Batako of 0% till 25% with treatment belonged to quality I level, Volcanic Ash Batako of 5% with the average compressive strength of 14.42 MPa belonged to quality I level, and Volcanic Ash Batako of 100% with the average compressive strength of 11.21 MPa belonged to quality I level.

Based on the compressive strength data, it was found that volcanic ash batako of 10% with treatment was the ideal composition and the maximum of compressive strength. This increase in compressive strength caused by volcanic ash was dominated by silica arrangement material ( $\text{SiO}_2$ ) which had the superiority as the filling material. Empty cavity in the cement particles would be filled with silica so that it functions as mechanical property and increased its durability. Meanwhile, the decrease in compressive strength in Volcanic Ash Batako of 15% is caused by excessive volcanic ash composition. As the consequence was that the mixture is not homogenous. The cement volume as a

fastening material is not maximal in fastening the aggregate in arranging batako because it is not followed by the addition of cement and the need for water. Its furthermore, workability decreased because water absorption is excessive. This condition is strengthened by visual observation of cylinder test specimen of split tensile testing in the fragment of cylinder testing specimen in volcanic ash which could not be mixed well with other aggregates.

Table 5. Comparison between the average compressive strength and quality requirement

No.	Mixing Composition	Compressive Strength			Quality Level
		Testing Device (MPa)	SNI 03-0349-1989 (kg/cm <sup>2</sup> )	SNI 03-0349-1989 (MPa)	
1	Volcanic Ash Batako (0%)				
	Cube 10x10x10	5,64	40	3,32	III
	Cylinder 15x30 (curing)	13,85	100	8,30	I
	Cylinder 15x30 (without curing)	11,32	100	8,30	I
2	Volcanic Ash Batako (5%)				
	Cube 10x10x10	5,75	40	3,32	III
	Cylinder 15x30 (curing)	14,42	100	8,30	I
	Cylinder 15x30 (without curing)	11,72	100	8,30	I
3	Volcanic Ash Batako (10%)				
	Cube 10x10x10	5,87	70	5,81	II
	Cylinder 15x30 (curing)	17,19	100	8,30	I
	Cylinder 15x30 (without curing)	11,83	100	8,30	I
4	Volcanic Ash Batako (15%)				
	Cube 10x10x10	5,70	70	5,81	II
	Cylinder 15x30 (curing)	11,66	100	8,30	I
	Cylinder 15x30 (without curing)	10,87	100	8,30	I
5	Volcanic Ash Batako (20%)				
	Cube 10x10x10	5,26	40	3,32	III
	Cylinder 15x30 (curing)	11,49	100	8,30	I
	Cylinder 15x30 (without curing)	8,87	100	8,30	I
6	Volcanic Ash Batako (25%)				
	Cube 10x10x10	5,09	40	3,32	III
	Cylinder 15x30 (curing)	10,93	100	8,30	I
	Cylinder 15x30 (without curing)	8,98	100	8,30	I
7	Volcanic Ash Batako (100%)				
	Cube 10x10x10	5,04	40	3,32	III
	Cylinder 15x30 (curing)	11,21	100	8,30	I
	Cylinder 15x30 (without curing)	7,93	70	5,81	II

### 3.4 The Best Composition

The ideal composition is obtained from the result of the comparison of the requirement of quality VI mixing composition, molded as cylinder and batako samples with SNI 03-0349-1989 standard.

The result of the ideal composition is the compressive strength for cylinder test specimen with treatment at the mixing composition of 10% with the average compressive strength of 17.19 MPa. According to SNI 03-0349-1989 quality standard, it belonged to compressive strength Level I at the minimal average of 100 kg/cm<sup>2</sup> and composition.

In the average tensile strength of 2.67 MPa and the average water absorption of 3.52%, according to SNI 03-0349-1989, water absorption below 25% belonged to quality level I batako. The deviation of the average length was 1.123 mm, the deviation of the average width was 1.190 mm, the deviation of the average thickness was 1.313 mm, but they still met the measurement requirement which is in line with SNI 03-0349-1989 standard.

#### 4. Conclusion

The following conclusions are derived from the results reported in the paper.

- a. The water-cement ratio in batako mixture highly influenced the quality of batako. The higher amount water-cement ratio the lower its concrete durability; but if the use of the water-cement ratio is reduced, the durability of the concrete would be better although the processing would be difficult because the making of batako in this research was done manually. Water-cement ratio in this research was 40%.
- b. From the visual test, it was found that the surface of batako was flat in each section because the volcanic ash which had nearly the same particles as the cement could fill the cavity of the sand so that batako became more solid which caused the surface of batako flat.
- c. The use of batako volcanic ash as an additive by replacing some of its weight could increase its absorption. The maximum of absorption in batako in this research was 4.142%.
- d. Based on the compressive strength data, it was found that batako volcanic ash of 10% with treatment was good composition and obtained the maximum of compressive strength. The increase in compressive strength was because volcanic ash was dominated by silica arrangement material (SiO<sub>2</sub>) which was superior as filling material.
- e. From the result of the research above, it was found that volcanic ash could be used as the substitute for fine aggregate in making batako.

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