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Geopolymer Concrete Made From Volcanic Ash of Mount Sinabung

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Abstract: Geopolymer concrete is one of the solutions in an environmentally friendly concrete production process. This research aimed to produce geopolymer concrete from Sinabung volcanic ash, which has high content of SiO_2, and to discover the mechanical behavior of the resulted geopolymer concrete. The geopolymer concrete made was in cylindrical shape with diameter of 10 cm and height of 20 cm height. The mixture component consisted of NaOH and Na_2SiO_3 as alkaline activator. The curing process was conducted in the oven at 60□C for four different variation of time, namely, 4 hours, 8 hours, 12 hours and 24 hours. The mechanical properties were measured by testing the compressive strength and absorption value for the sample aged 7-day, whereas the estimated value for 28-day value was calculated from the conversion formula. The tests referred to SNI 1974:2011 testing regulation and ASTM C39 for compressive strength; and ASTM C642 for absorption test. The results showed that for 7-day aged samples, which were cured for 4 hours, 8 hours, 12 hours and 24 hours, obtained the average of compressive strength of 18.54 MPa, 23.85 MPa, 30.65 MPa and 36.75 MPa, respectively. The estimated calculation showed that concrete continued to increase in compressive strength. The 28-day aged samples showed the maximum compressive strength of 58.79 MPa. However, after 28 days, the concrete was projected to start to slow down. The absorption test results of each variation were 2.65% for 4 hours; 1.67% for 8 hours; 1.38% for 12 hours and 0.58% for 24 hours. Based on these results, it can be concluded that the curing time of 24 hours gave the most optimal compressive strength and the smallest value of absorption test. From the compressive strength result, it can be said that the geopolymer concrete made from Sinabung volcanic ash has high quality of concrete.

Keywords: Geopolymer concrete, sinabung volcanic ash, compressive strength, absorption

1. Introduction

The use of portland cement in building structures with concrete technology results in the emission of CO_2 gas to the air [1]. The increase of CO_2 gas emissions causes global warming, which de-grades the quality of human life. Overall, the world's portland ce-ment production contributes 1.6 million tons or about 7% of CO_2 to the atmosphere [2]. To minimize excessive use of portland cement, green concrete materials are necessary to be discovered.

Regarding the above problem, the production of geopolymer, zero cement concrete, is one of the solutions. Several geopolymer studies have been conducted by using different byproducts in the composi-tions [3]. However, the research still used other base materials rather than the byproduct itself; thus, the research on using the by-product as base materials should be studied further.

One of byproducts that are promising to be used as base material for geopolymer is volcanic ash. Risdanareni et al. [4] produced geopolymer concrete by using Mount Kelud volcanic ash as their base material; however they only employed 50% of the volcanic ash in the concrete [4]. Mount Kelud volcanic ash itself also only has 32.3% by mass of SiO_2, which

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is an important compound to pro-duce concrete. As mentioned in the reference, the main basic ingre-dient of making geopolymer concrete is the composition of materi-als containing lots of silica and aluminum [1].

Based on the above explanation, this study objected to employ Sinabung volcanic ash as the base material for geopolymer concrete and characterize its mechanical properties. Sinabung volcanic ash was chosen due to its high content of SiO_2. Besides, Sinabung volcanic ash contains many chemical compounds that are necessary for yielding geopolymer concrete other than SiO_2, such as alumi-num oxide, iron oxide, calcium oxide and magnesium oxide. These compositions are expected to give considerable properties of geo-polymer concrete. In addition, the application of Sinabung volcanic ash as geopolymer concrete could give some advantages for the communities near Mount Sinabung, especially in the field of con-struction that uses concrete technology. It is projected to reduce the abundance of volcanic ash in areas affected by the eruption of Mount Sinabung which until now is still in active status [5].

The production of geopolymer in this study used Sinabung volcanic ash, which was mixed with Sodium Hydroxide (NaOH) solvent and Silicate solvent (Na_2SiO_3). The sample was in the cylindrical shape with 10 cm of diameter and 20 cm of height. This study pro-vided preliminary results of the application of Sinabung volcanic ash as geopolymer concrete, thus it only tested the 7-day aged sam-ples, which were obtained from various curing time in the oven at 60 C. The tests used were compressive strength test and absorption value test.

2. Materials and Method

2.1 Materials

Sinabung volcanic ash was obtained from Sinabung Mountain, Sumatera Utara, Indonesia. The chemical compositions of this volcanic ash were shown in Table 1. The photograph and the morphology of the volcanic ash were given in Fig.1 and Fig. 2, respectively.

Table 1- Chemical Content of Sinabung Volcanic Ash [6]

No	Parameter	Result	Unit	Method
1	SiO_2	85,6	%	Gravimetry
2	Al_2O_3	0,95	%	Calculation
3	CaO	4,78	%	Gravimetry
4	MgO	4,48	%	Gravimetry
5	Water Content	1,43	%	Gravimetry

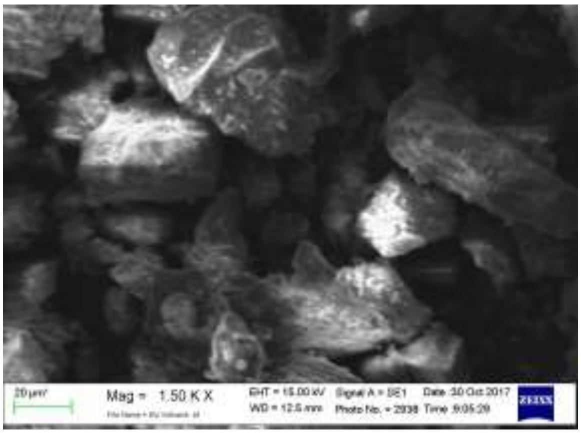

Fig. 1 - SEM Photograph of volcanic ash

Fig. 2 - Photograph of volcanic ash

Other compositions used were fine aggregate (sand), which was obtained from Medan Sunggal with dry, SSD and apparent specific gravity of 2460 kg/m³, 2510 kg/m³ and 2590 kg/m³; coarse aggregate (gravel) is in the form split with maximum size of 20 mm with dry, SSD and apparent specific gravity 0f 2630 kg/m³, 2680 kg/m³ and 2770 kg/m³; Alkaline activators, such as sodium hydroxide NaOH, which is in powder-shaped with a content of 98%; sodium silicate (Na_2SiO_3), which contains 96% of gel-shaped sodium silicate; calcium chloride (CaCl) as accelerator (AC); and Master Ease 3029 as superplasticizer (SP).

Fig. 3 shows the x-ray diffraction pattern between the intensity to the 2Ө angle. From the figure, the pattern of volcanic ash modification nature element (chemical and physical activation). The analysis of X-ray Diffraction tool is intended to know the dase and crystal structure, and crystallinity result of identification of dominant composition on volcanic ash. From the examination results of chemical content above, it is seen that sinabung ash has a very high silica content. This percentage of content indicates that the ash can be used as a substitute for cement in a concrete mix.

From SEM testing of volcanic ash sample above, it can be seen that the morphology of sample is irregular with varying sizes. And the magnitude of the volcanic ash particle distribution from the eruption of Mount Sinabung is 13.49μm - 45.56μm.

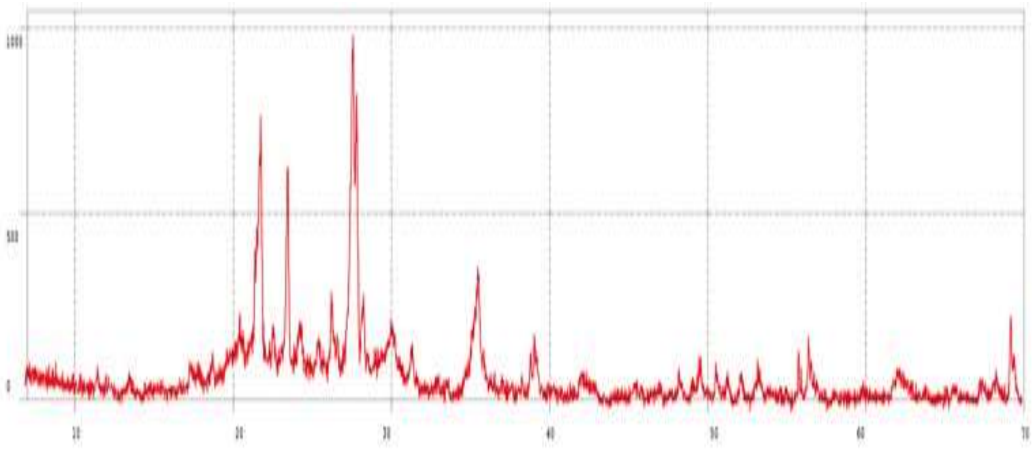

Fig. 3 - Activation Results Pattern of Volcanic Ash Diffraction

2.2 Methods

There are three times trial experiments conducted to find the best composition of geopolymer made from Sinabung volcanic ash (VA). These three times compositions were grouped as shown in Table 2.

Table 2 - Trial Compositions of Geopolymer Concrete Made from Sinabung Volcanic Ash

Code	VA (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Na_2SiO_3 (kg)	NaOH	SP (ml)	AC (ml)	Water (ml)
I	1.043	1.523	1.696	0.261	0.435 kg	21	11	-
II	0.697	1.226	1.955	0.372	73 ml	14	7	180
III	0.697	1.226	1.955	0.372	73 ml	15	-	157

The photograph sample of each group was given in Fig. 4. The compressive test was continued further and the results showed that the sample with code I had the most preferable compressive strength. Thus, based on this result, the composition used was code I.

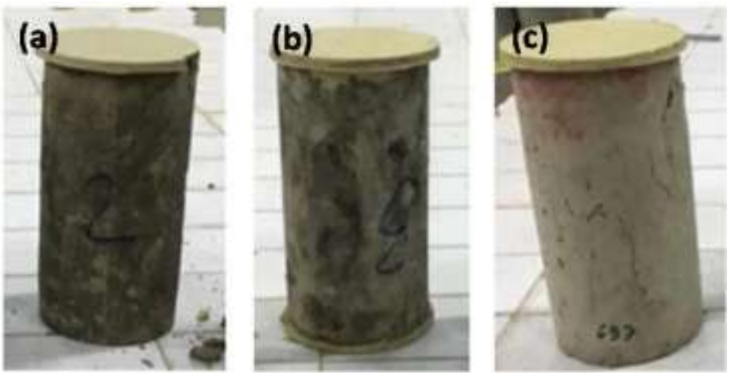

Fig. 4 - Geopolymer concrete from Sinabung volcanic ash with composition of (a) code I; (b) code II; (c) code III

The sample of geopolymer concrete is in cylindrical shape with diameter of 10 cm and height of 20 cm. This sample was designed to give 28-day compressive strength of 30 MPa. Prior to the production of geopolymer concrete, the binder must be made, this study used 14 M of NaOH as the binder. After obtaining 14 M of NaOH, it was cooled down in the room temperature. Then, the mixing of geopolymer concrete was conducted.

The coarse aggregate was put into the stirring plate, after that the fine aggregate was added. The mixture was stirred until obtaining evenly distributed mixture. Sinabung volcanic ash was then inserted into the mixture and stirring process was continued to form homogenous mixture. Na_2SiO_3 and NaOH were poured into the mixture to yield homogeneous mixture, then Master Ease 3029 and accelerator were added into it. After producing homogenous mixture, it was put the cylindrical mold. All cylindrical samples were pounded 25 times every 3 layers. All samples were then left in room temperature for 1 hour until aging or binding occured. Then, the samples were cured in the oven at 60 °C [7] for four different hours, namely, 4 hours, 8 hours, 12 hours and 24 hours. Each variation consists of three samples.

2.3 Testings

The test used to obtain compressive strength value was compression test according to ASTM C39 [8] and SNI 1974:2011 [9]. The test was performed for the samples aged 7-day. The results for 28-day aged samples were obtained from the conversion of concrete compressive strength. The absorption test was conducted based on ASTM C462 [10].

3. Results and Discussion

3.1 Volume Weight of Geopolymer Concrete

The volume weight of concrete is the ratio between the concrete weight and its volume [11]. The average volume weight of the geopolymer concrete made from Sinabung volcanic ash can be seen in Table 3.

Table 3 - Average volume weight of geopolymer concrete made from Sinabung volcanic ash

No.	Number of Sample	Average Volume Weight (kg/m²)
1	3	2257.96
2	3	2307.01
3	3	2311.91
4	3	2295.33

From the obtained results, the volume weight of the geopolymer concrete ranges from 2257.96 kg/m² to 2311.91 kg/m². The examination results of the volume weight of geopolymer concrete include a normal weighted concrete [11].

3.2 Cylinder Compressive Strength of Geopolymer Concrete

The results of compressive strength test within 7-day curing are shown in Table 4. From the results, it can be concluded that the highest quality concrete produced from oven curing variation of 24 hours at 60°C with concrete compressive strength of 38.95 MPa. As mentioned in some references, concrete will experience an increased compressive strength until 28-day age (calculated value was 58.79 MPa), then after 28 days of sample's age, the increase in compressive strength began to slow down. Compare to the results obtained by Risdanareni et al. [4], which only produced the geopolymer concrete with compressive strength of 20.89 MPa [4], geopolymer concrete made from Sinabung volcanic ash gave more preferable compressive strength. It can be explained because Sinabung volcanic ash has higher SiO_2 content. It also can be said that the resulted geopolymer concrete is considerably high quality of concrete because the geopolymer concrete that has compressive strength value more than 40 MPa is a high-quality concrete.

From the test results of geoplymer concrete compressive strength, it is also obtained the conversion value of concrete curing variations of 4 hours, 8 hours, 12 hours and 24 hours. The conversion table for each curing can be seen in Table 5.

3.3 Cylinder Absorption of Geopolymer Concrete

The absorption test was performed at 7 days of sample's age. The results of the average absorption test for the four variations can be seen in Table 6. From Table 6, it is shown that absorption value at oven curing at 60°C temperature for 24 hours yields the smallest absorption percentage. As the absorption value became larger, the compressive strength became smaller. It can occur because of the increase of the number of open pores. More detailed explanation of this absorption test results can be seen in Table 7.

Table 4 - Compressive strength of geoplymer concrete made from Sinabung volcanic ash

No.	Oven Curing Variation (Hours)	Actual Compressive Strength (MPa)	Average Compressive Strength (MPa)
1	BG1 - 4	16.96	
2	BG2 - 4	20.13	18.54
3	BG3 - 4	18.54	
4	BG1 - 8	23.06	
5	BG2 - 8	26.23	23.85
6	BG3 - 8	22.26	
7	BG1 - 12	27.03	
8	BG2 - 12	30.47	30.65
9	BG3 - 12	34.44	
10	BG1 - 24	38.95	
11	BG2 - 24	36.04	36.75
12	BG3 - 24	35.25	

Table 5 - Compresive strength ratio of geoplymer concrete made from Sinabung volcanic ash conversion

Curing Time (Hours)	Compressive Strength Ratio
4	0.50
8	0.65
12	0.83
24	1.00

Table 6 - Absorption of geopolymer concrete made from Sinabung volcanic ash

No.	Number of Sample	Average Absorption Percentage (%)
1	3 (4 Hours)	2.65
2	3 (8 Hours)	1.67
3	3 (12 Hours)	1.38
4	3 (24 Hours)	0.58

Table 7 - Absorption of geopolymer concrete made from Sinabung volcanic ash

No.	Oven Curing Variation (Hours)	Absorption Weight (kg)	Absorption Value (%)
1	BG1 - 4	3,348	2,63
2	BG2 - 4	3,620	2,32
3	BG3 - 4	3,393	3,01
4	BG1 - 8	3,423	1,52
5	BG2 - 8	3,576	1,62
6	BG3 - 8	3,688	1,87
7	BG1 - 12	3,520	1,39
8	BG2 - 12	3,569	1,74
9	BG3 - 12	3,652	1,01
10	BG1 - 24	3,650	0,58
11	BG2 - 24	3,517	0,63
12	BG3 - 24	3,582	0,53

4. Conclusion

In summary, geopolymer concrete made from Sinabung volcanic ash had the most optimal 7-day aged compressive strength with variation of 24 hours of oven curing at 60°C. This result showed that the geopolymer concrete produced in this research was considerably high-quality concrete. Based on the estimated calculation of 28-day age, the geopolymer concrete compressive strength will always increase because of the harder and stronger surface of the concrete structure. In addition, this study also found that the geopolymer concrete had the smallest absorption value for 7-day aged sample with variation of 24 hours of oven curing at 60°C. The greater the absorption value, the less its compressive strength becomes, because the number of open pores is greater than the number of closed pores and vice versa.

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