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Mechanical Properties of Volcanic Ash Based Geopolymer Concrete

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Abstract. This paper presents the result of study on using volcanic ash which obtained from Mount Kelud as fly ash replacement material to produce geopolymer concrete. Test was conducted on geopolymer concrete mixture with 0%, 25%, 50% and 100% fly ash replacement with Kelud volcanic ash. Sodium hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3) were applied as alkaline activator. The mechanical properties was assessed by compressive strength while workability of fresh concrete by slump test. Producing geopolymer concrete with volcanic ash is possible with maximum replacement of up to 50%. Research and development on eco-friendly material such as volcanic ash is very useful to help reconstruction process of volcanic disaster around the world.

Introduction

In last three decades, several researches had been conducted to found alternative material for cement replacement, due to the bad environmental effect of using cement [1,2]. Geopolymer concrete as a new eco-friendly material has been introduced as a promising construction material. Geopolymer material is an inorganic material which contain silica, alumina and alkaline as activator. Fly ash (FA), a material derived from coal combustion wastes which is rich in silica and alumina has been used as raw material to produce geopolymer concrete [3]. In order to find new alternative eco friendly raw material of geopolymer concrete besides fly ash, many researches had been performed. One of promising alternative raw material for producing geopolymer concrete is volcanic ash, due to it similar chemical composition with fly ash. Adding volcanic ash (VA) to geopolymer mixture expected to increase mechanical properties of geopolymer concrete.

As a country that has many activate volcanoes caused Indonesia become familiar with volcanic eruption disaster. The 2011 Kelud mountain eruption that takes placed in Kediri was the most damaging one and released volcanic materials such as volcanic ash in large quantities. Volcanic ash released by the eruption damage over Provence and caused serious environmental pollution. The utilization of volcanic ash as fly ash substitute material was expected can make reconstruction process in disaster area run faster.

Previous research conducted by Risdanareni about the utilization of volcanic material called trass as raw material to produce geopolymer concrete stated that adding 25% trass into geopolymer concrete mixture had still not deliver optimum result[4]. In order to determine the optimum amount of volcanic ash at fly ash based geopolymer concrete mixture, four variations were conducted in range of 0% to 100 % of fly ash replacement with volcanic ash . While concentration of NaOH 12 Molar and activator ratio Na_2SiO_3 / NaOH of 2 was used in this study due to its good mechanical properties owned on fly ash based geopolymer concrete[5].

The aim of this research is obtaining the optimum content of volcanic ash replacement that gives good mechanical properties on fly ash-based geopolymer concrete. In addition, the result of this research are expected to give a good recommendation in utilizing volcanic ash as fly ash replacement material that can accelerate the rehabilitation process after volcanic eruption.

Materials

Fly ash type F obtained from Paiton Power Plant and volcanic ash obtained from Kelud Mountain Kediri was used as raw material. Chemical composition of fly ash and volcanic ash was presented in **Table 1**. Na_2SiO_3 and NaOH was used as an alkali activator. NaOH concentration of 12 molar and ratio between Na_2SiO_3 and NaOH of 2 was used due to its optimum mechanical properties at fly ash-based geopolymer binder [6]. Fine and coarse aggregate were gathered from Lumajang with density of 2175 kg/m^3 and 2700 kg/m^3 respectively. The Coarse aggregate has maximum size of 20 mm.

Table 1. Chemical Composition of Fly ash (FA) and Volcanic Ash (VA)

Particles	FA % by mass	VA % by mass
Al_2O_3	9.3	6.9
SiO_2	25.4	32.3
K_2O	2,18	1,93
CaO	11.3	16.7
TiO_2	2.87	2.01
V_2O_5	0.18	0.11
Cr_2O_3	0.13	0.091
MnO	0.25	0.69
Fe_2O_3	45.45	35.1
NiO	1.28	1.65
CuO	0.19	0.38
ZnO	0.15	0.11
SrO	0.69	1.0
Eu_2O_3	0.3	0.3
Re_2O_7	0.3	0.34

Methods

Mix Design. The specimen of geopolymer concrete is a cylinder with 70 mm diameter and 140 mm height. All specimens were cured in room temperature after remoulding until specific age for compression test. Mix design and labelling of geopolymer concrete is presented in **Table 2**.

Table 2. Mix Design of Geopolymer Concrete

Speciment Code	VA content	FA (gram)	VA (gram)	SP (gram)	Na_2SiO_3 (gram)	NaOH (gram)	Coarse Aggregate (gram)	Fine Aggregate (gram)
BG1	0 %	219.17	0	3.28	51.4	25.7	592.36	296.18
BG2	25%	164.37	54.79	3.28	51.4	25.7	592.36	296.18
BG3	50%	109.58	109.58	3.28	51.4	25.7	592.36	296.18
BG4	100%	0	219.17	3.28	51.4	25.7	592.36	296.18

Laboratorium Test. All tests were held at The Structure and Material Laboratory of UM, Malang. The testing result was the average evaluation of 3 specimens test. ASTM C 39-03 was used as testing code for compressive strength test [7]. All specimens were tested at age of 3, 7, 14, 21 and 28 days.

Fig 1. Laboratorium test for specimens

Result and Discussion

Compressive Strength. Compressive strength of geopolymer concrete in different ages was shown at table 3. While, the effect Volcanic Ash (VA) replacement on compressive strength was shown at figure 2. The result showed that compressive strength of fly ash based geopolymer concrete decrease with an increased content of VA. Concrete type BG2 which has VA content of 25% has optimum compressive strength compared to others. However, the different compressive strength between BG 2 and BG 3 is not significant, so that VA replacement is still suitable up to 50% by binder mass. The decrease of compressive strength probably caused by the less reactivity of Si, Al and Fe on volcanic ash compared to fly ash. It is proven with the tendency of geopolymer concrete compressive strength with high VA content to rise after the age of 28 days. Previous research conducted by Hossain suggested performing curing at elevated temperature in order to increase the particle reactivity of volcanic materials [8].

Table 3. Compressive Strength Of Geopolymer Concrete

Code	Compressive Stregth at Age				
	3	7	14	21	28
BG1	16.15	20.89	26.06	28.35	28.35
BG2	10.42	11.58	21.90	20.96	26.89
BG3	9.56	13.73	18.85	20.79	25.39
BG4	1.46	5.67	5.79	7.28	10.03

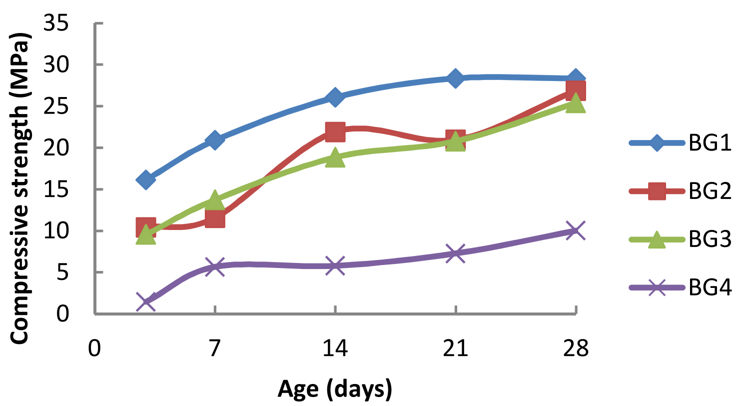

Fig 2. Effect of Volcanic Ash Adding on Compressive Strength

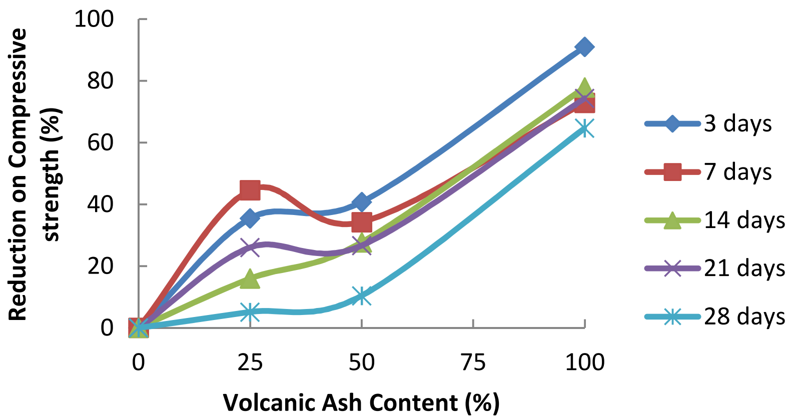

Fig 3. Effect of VA in Compressive Strength Reduction (%)

The effect of VA utilizing in compressive strength reduction of geopolymer concrete is presented in Figure 3. The reduction in compressive strength of geopolymer concrete which has VA content up to 50% was 10% compared to the fly ash-based geopolymer concrete. While the use of VA of 100% caused the compressive strength decreased up to 64%. It can be concluded that the replacement of VA up to 50% by binder mass deliver optimum mechanical properties on geopolymer concrete and can be used as structural concrete due to its high compressive strength. While concrete with 100% VA replacement can only be used as a non-structural concrete due to its low compressive strength. Recommendation amount of VA replacement in geopolymer concrete mixture is a litte bit different to previous recommendation by Ekaputri stated that the optimal VA replacement into normal concrete mixture was 25% [9].This is presuamble to occur because the chemical composition exist in VA is relatively similar to FA compared to OPC , so that the crystal formed is more stable.

Workability. It can be seen at table 4 that the slump value is proportional to the compressive strength of geopolymer concrete. The higher slump value indicated fresh concrete easily molded which result the low possibility of open pores forming in the concrete that led high compressive strength. This result has a good agreement with previous research conducted by Hardjito that the workability of fresh concrete greatly influenced the compressive strength of geopolymer concrete [10]. The effect of adding VA to slump value and compressive strength can be seen in figure 3. From figure 3 it can be seen that the amount of VA content in the mixture is inversely proportional to the value of slump and the compressive strength of geopolymer concrete produced. This is appropriate with previous research by Risdanareni that the addition of volcanic material on geopolymer concrete caused the decrease of concrete workability which can lead to the decrease of compressive strength [4,5].

Table 4. Slump Value and Compressive Strength

Codes	% VA	Slump value (mm)	Compressive Strength (Mpa)
BG1	0	135	28.35
BG2	25	129	25.51
BG3	50	118	25.39
BG4	100	90	10.03

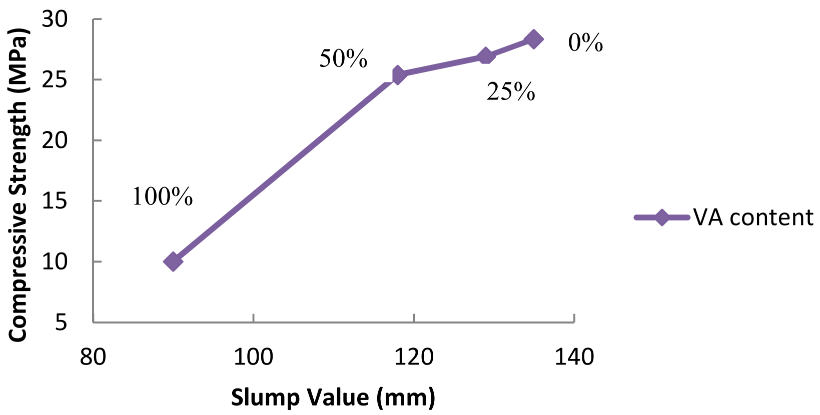

Fig 4. Correlation between Slump Value and Compressive Strength

Conclusion

The results were obtained that increased the amount of volcanic ash can decrease the compressive strength of geopolymer concrete. Test result also evidenced that compressive strength of geopolymer concrete was greatly influenced by the workability of fresh concrete. With these result, it can be suggested that producing geopolymer concrete with VA is possible with maximum replacement of up to 50%. Geopolymer concrete which contains up to 50% VA can be used as structural concrete because it has compressive strength more than 20MPa. While replacement entire FA with VA on geopolymer concrete gives a low compressive strength below 20 MPa, so it can only be used as a non-structural concrete. Research on eco friendly material such as VA as fly ash replacement at concrete industry is an innovative and good idea in order to help reconstruction after volcanic eruption in Indonesia and around the world.

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