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Study of Proportional Variation of Geopolymer Concrete which Self Compacting Concrete

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Abstract. The Portland cement production process which is one of the conventional concrete constituent materials always has an impact on producing carbon dioxide (CO_2) which will damage the environment. To maintain the continuity of development, while maintaining the environment, Portland cement substitution can be made with more environmentally friendly materials, namely fly ash. The substitution of fly ash material in concrete is known as geopolymer concrete. Fly ash is one of the industrial waste materials that can be used as geopolymer material. Fly ash is a mineral residue in fine grains produced from coal combustion which is mashed at a power plant power plant [15]. Many cement factories have used fly ash as a mixture in cement, namely Portland Pozzolan Cement or PPC. Because fly ash contains SiO_2, Al_2O_3, P_2O_3, and Fe_2O_3 which are quite high, so fly ash is considered capable of replacing cement completely. This study aims to obtain geopolymer concrete which has the best workability so that it is easy to work on (Workable Geopolymer Concrete / Self Compacting Geopolymer Concrete) and obtain the basic characteristics of geopolymer concrete material in the form of good workability and compressive strength. In this study, geopolymer concrete is composed of coarse aggregate, fine aggregate, fly ash type F, and activators in the form of NaOH and Na_2SiO_3 Be52. In making geopolymer concrete, additional ingredients such as superplastizer are added to increase the workability of geopolymer concrete. From this geopolymer concrete research, the results of concrete compressive strength above fc' 25 MPa and horizontal slump values reached 60 to 80 centimeters.

Keywords: *geopolymer concrete; fly ash; workability; compression strength; horizontal slump*

1. Introduction

With the increasing demand for concrete, cement production will also increase as a basis for making concrete. In the production process the cement emits CO_2 gas which causes a greenhouse effect. Where in one ton of portland cement production will produce about one ton of carbon dioxide gas released into the atmosphere [1, 2, 5]. To reduce the greenhouse effect, a more environmentally friendly cement replacement material is needed. One of the technologies that can be used is geopolymer concrete, which is the synthesis of organic natural materials through the polymerization process where the main ingredients in making geopolymer materials are materials containing silicon and aluminum elements such as iron blast furnace slag, bottom ash, or fly ash, as industrial waste materials. Geopolymer concrete is concrete that is formed not from the results of a hydraulic reaction like conventional concrete, but is formed from chemical reactions [6,7]. Due to the use of fly ash in its manufacture, an activator is needed in the form of Sodium Hydroxide (NaOH) 8M to 14M and Sodium Silicate (Na_2SiO_3) Be52 with a ratio between 0.4 to 2.5 [3]. Geopolymer concrete can be said to be environmentally friendly because it can reduce CO_2 gas up to 20% [2]. However, for the time being, the reference for planning geopolymer concrete mix design is unknown. This is because fly ash has a different chemical composition depending on the type of coal. Therefore, the researcher intends to provide a reference proportion of the comparison of geopolymer concrete materials to be used in determining the mix design of geopolymer concrete using fly ash type F from the Tanjung Jati B Jepara power plant.

Geopolymer concrete is made from a mixture of fly ash, coarse aggregates, fine aggregates, and alkaline activator solutions. If needed, an additional mixture (admixture) is provided in the form of a superplastizer to create a good level of concrete adhesiveness.

There have been many studies conducted to obtain high workability and compressive strength values, but until now there has not been found an optimal composition to achieve this. Therefore, geopolymer concrete research was carried out with the addition of conventional cement and extra water with a certain ratio to get the best workability and compressive strength.

2. Literature Review on Geopolymer Concrete

Self compacting geopolymer concrete (SCGC) is a geopolymer concrete made from fly ash material combined with alkaline activator and aggregate [18,20]. This Self compacting geopolymer concrete must have self-compacting concrete (SCC) workability criteria. To get the working ability of the SCC, extra water and superplasticizer are needed for the geopolymer concrete mixture. The addition of extra water in Geopolymer Concrete has a significant influence on the value of slump flow. Maximum compressive strength is obtained in the mixture without the addition of extra water / fly ash, the more water is added, the smaller the compressive strength produced. The optimal composition can be seen from the aspect of the inconvenience that meets the requirements of Self Compacting Geopolymer Concrete, namely the value of slump flow between 65-80 cm with the use of extra water / fly ash 0.3 with the result of a slump flow value of 67 cm and an average compressive strength of 16.28 MPa [12]. Based on research on the Effects of Polycarboxylate Ether (PCE) Levels on the Mechanical Properties of Fly Ash-Based Geopolymer Concrete, it can be concluded that the higher levels of PCE in geopolymer concrete mixtures cause a decrease in flow values. Adding a superplastizer to a geopolymer concrete can reduce the compressive strength of geopolymer concrete [14,18,20]. Geopolymer concrete with activator of 8M NaOH solution has the greatest compressive strength compared to 6M and 10M NaOH solutions. The use of large enough NaOH affects the workability of geopolymer concrete so that the compressive strength of 10M concrete is smaller than that of 8M geopolymer concrete. Geopolymer concrete has a greater compressive strength than conventional concrete. At 28 days, 8M geopolymer concrete has a compressive strength of 75% greater than conventional concrete [13]. From the results of research conducted by Nico et,.al.[17] showed that geopolymer concrete (BG-1K) had the greatest compressive strength compared to cement concrete. Geopolymer concrete reaches a maximum compressive strength at 56 days, whereas at 90 days geopolymer concrete has a reduced compressive strength.

3. Research Methodology

The research work was conducted experimentally at the Construction and Material Laboratory, Civil Engineering Department, Diponegoro University and followed the steps as outlined in Figure. 1. The variable in this study was the cement ratio set at 5, 10 and 15 percent with super plastizer ratio 2 and 5 percent. The specimens were 100 by 200 mm cylinders tested in compression at the ages of 90 days.

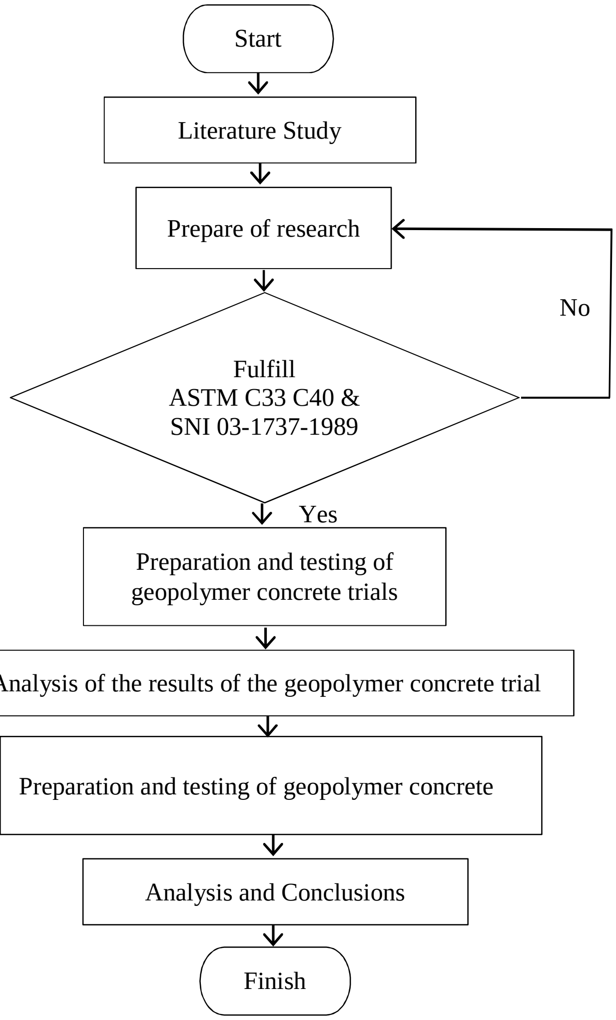

Fig. 1. Research outline

3.1. Chemical composition testing on Fly Ash

Chemical characteristics of the fly ash used can be influenced by the quality of the coal used, the combustion temperature at the power plant, and the time of taking, so that the fly ash that will be used can affect the behavior of the geopolymer concrete. Therefore it is necessary to analyze the composition of the fly ash using the Scanning Electron Microscopy - Energy Dispersive X-Ray (SEM-EDX) test method. The Scanning Electron Mocroscopy (SEM) test analyzes the texture, shape, and size of a nanometer-scale sample and Energy Dispersive X-Ray (EDX) analyzes the composition of the sample quantitatively and qualitatively.

In addition to the SEM-EDX test, the fly ash test also uses the X-Ray Fluorscence (XRF) test, which analyzes the chemical composition and concentration of the elements contained by the spectrometry method. The x-ray energy will be emitted then the intensity and energy of the x-ray will be measured qualitatively (element type) and quantitatively (elemental concentration).

3.2. Mix design of geopolymer concrete

Based on the analysis of the results of the trial of the geopolymer concrete specimens that have been carried out, obtained several results that meet the requirements, namely specimens WGCS-

1,WGCS-2,SCGC-1. From these results, an analysis was carried out to create a mix design for geopolymer concrete specimens. Mix design of geopolymer concrete as follows :

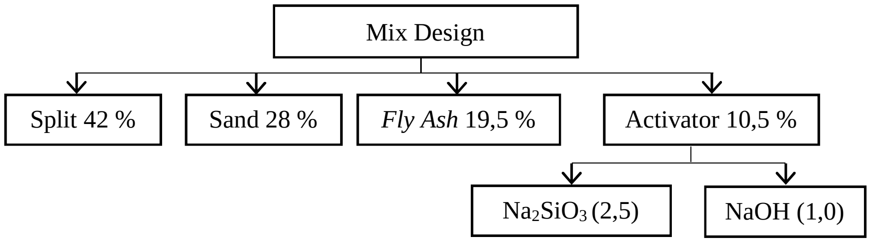

Fig. 2. Mix design of geopolymer

Table 2. Geopolymer concrete composition

Materials	WGCS-1	WGCS-2	SCGC-1
Aggregates : (FA + AA)	70% : 30%	70% : 30%	70% : 30%
Fine Aggregate : Coarse Agg	40% : 60%	40% : 60%	40% : 60%
Binder (FA) : AA (Alkaline Activator)	65% : 35%	65% : 35%	65% : 35%
NaOH (12M) : Na_2SiO_3	1 : 2,5	1 : 2,5	1 : 2,5 (Na2SiO3 Be-52)
Superplastizer-Viscocrete 1003	2% FA	-	2% FA
Superplastizer-MasterGlenium Sky8851	-	5% FA	-

3.3. Horizontal slump test

To find out the good performance of geopolymer concrete with self compacting concrete criteria, a fresh concrete slump test can be performed. The slump test was carried out according to ASTM C143 (United States) procedure, IS: 1199 - 1959 (India) and EN 12350-2 (Europe). Test slump to determine the level of workability of a concrete mixture. The slump test uses the Abraham cone with horizontal slump measurements, as shown in Figure:

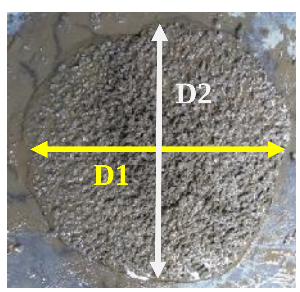

Fig. 3. Horizontal slump test

3.4. Materials

The fly ash used in this research work was originated from PT. Pembangkit Jawa Bali (PJB) PLTU Tanjung Jati B in Jepara. The fly ash has a chemical composition as listed in Table 3.

Table 3. Fly ash PT.PJB PLTUTanjung Jati B – Jepara chemical composition

Parameters	Content (%)	Standardized to					
		ASTM C 618			ACI Part 1 226-3R		
		N	F	C	N	F	C
Silicon dioxide (SiO_2) Aluminum oxide (Al_2O_3) Iron oxide (Fe_2O_3)	**76,87**	70	70	50	-	70	50
Calcium oxide (CaO)	11,48	-	-	-	-	<10	>10
Sulfur trioxide (SO_3)	2,29	4	5	5	-	5	5
Moisture content	0,33	3	3	3	-	3	3
Loss on ignition	1,66	10	6	6	-	6	6
Sodium dioxide (Na_2O)	1,12	-	1,5	1,5	-	1,5	1,5

Examining the chemical composition in accordance with ASTM C618-2010 [16], the *fly ash* from PJB PLTU Tanjung Jati B – Jepara is classified as class F type. The classification is based on the silicon dioxide (SiO_2), aluminum oxide (Al_2O_3) and iron oxide (Fe_2O_3) compounds that comprise a 76,87 % of the total content, thus exceeding the minimum 70 % mandated by the code for the classification of type F fly ash. The activator solution used in this study was sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH). The sodium silicate enhances the polymerization reaction, whiles the sodium hydroxide reacts with the aluminum (Al) and silica (Si) of the fly ash, resulting in a strong bond polymer [10].

3.5. Concrete mix proportions

The mix proportions of basic material for the geopolymer concrete are shown in Table 4.

Table 4. Mix proportions for geopolymer concrete

Remarks	Volumetric Composition
Aggregate to binder and activator	70% to 30%
Coarse to fine aggregates	60% to 40%
Binder (*fly ash*) to activator (Na_2SiO_3 and NaOH)	65% to 35%
Na_2SiO_3 to NaOH (8 to 14 molars)	2,5 to 1

The determination of proportion percentage to the total is as following
Coarse aggregate proportion = 70% x 60% = 42,0 %
Fine aggregate proportion = 70% x 40% = 28,0 %
Binder (fly ash) proportion = 30% x 65% = 19,5 %
Activator proportion = 30% x 35% = 10,5 %

The conventional concrete has an identic material mix proportions. The binder (fly ash) for the geopolymer concrete was here replaced by cement, and the activator by water. The mix proportions of basic material for the controlling concrete are shown in Table 5.

Table 5. Mix proportions for conventional concrete

Remarks	Volumetric Composition
Aggregate to cement and water	70% to 30%
Coarse to fine aggregates	60% to 40%
Cement to water	65% to 35%

4. Result and Analyses

4.1. Characteristics of Fly Ash

Fly ash testing is done using SEM EDX and XRF methods. The results of testing the chemical composition of fly ash material from PLTU Tanjung - Jati B Jepara can be seen in Figure 4 and Table 6

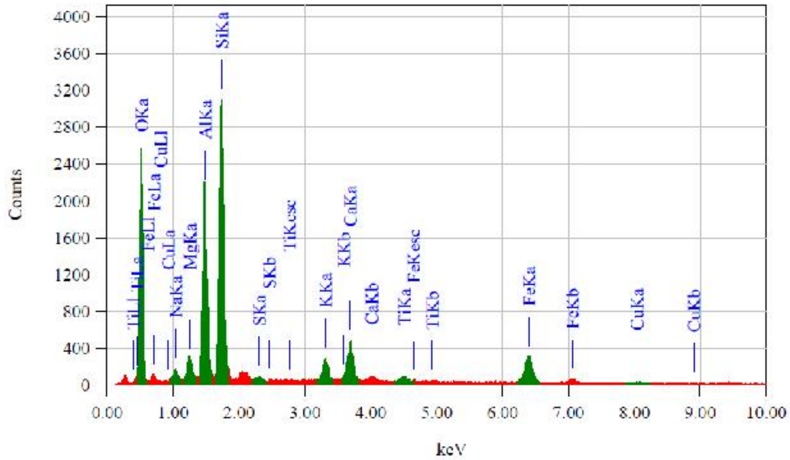

Fig. 4. SEM Analysis of EDX Fly Ash PLTU Tanjung - Jati B Jepara

Table 6. Chemical Composition of Ash Ash PLTU Tanjung - Jati B Jepara

Composition	Percentage (%)	Remarks
Na_2O	1,59	Fly ash PLTU Tanjung - Jati B Jepara is type F fly ash because it contains CaO < 10% and total levels of SiO_2, Al_2O_3, and FeO > 70%.
MgO	2,86	
Al_2O_3	24,95	
SiO_2	46,52	
SO_3	1,13	
K_2O	2,77	
CaO	5,89	
TiO_2	1,36	
FeO	11,81	
CuO	1,12	

4.2. Trial of geopolymer concrete samples

Before conducting geopolymer concrete research, a geopolymer concrete trial is first carried out. It aims to get a mix design with the results of the slump value and compressive strength of concrete in accordance with predetermined limits. Geopolymer concrete specimen will be tested for slump value and compressive strength at 90 days. The test results of geopolymer concrete specimens can be seen in Table 7a and Table 7b.

Table 7a. Trial Test Results for Geopolymer Concrete samples

Code	Age (day)	weight (kg)	Volume (m^3)	Specific gravity (kg/m^3)	Compressive Strength (MPa)	Slump (cm)
WGC1	90	3,730	0,001571	2374,59	47,43	0
WGC2	90	3,700	0,001571	2355,49	35,03	0
WGC3	90	3,710	0,001571	2361,86	33,86	0
WGC4	90	3,750	0,001571	2387,32	29,33	0
WGC5	90	3,800	0,001571	2419,16	-	0
WGC6	90	3,760	0,001571	2393,69	46,30	0
WGC7	90	3,680	0,001571	2342,76	34,42	0
WGC8	90	3,670	0,001571	2336,39	30,02	0
WGC9	90	3,630	0,001571	2310,93	26,59	0
WGC10	90	3,720	0,001571	2368,23	34,67	35,0
WGC11	90	3,690	0,001571	2349,13	31,35	30,2
WGC12	90	3,700	0,001571	2355,49	**30,50**	**28,9**
WGC13	90	3,810	0,001571	2425,52	**26,39**	**28,3**
WGC14	90	3,700	0,001571	2355,49	**31,85**	**28,0**
WGC15	90	3,820	0,001571	2431,89	29,35	34,0
WGC16	90	3,810	0,001571	2425,52	**23,57**	**33,5**
WGC17	90	3,760	0,001571	2393,69	**32,45**	**31,0**
WGC18	90	3,780	0,001571	2406,42	**32,12**	**30,0**
WGC19	90	3,760	0,001571	2393,69	27,02	27,0
WGC20	90	3,720	0,001571	2368,23	23,91	28,0
WGC21	90	3,860	0,001571	2457,35	34,04	0
WGC22	90	3,750	0,001571	2387,32	51,96	0
WGC23	90	3,560	0,001571	2266,37	24,13	0
WGC24	90	3,680	0,001571	2342,76	38,35	0
WGC25	90	3,690	0,001571	2349,13	26,62	0

Source: Analysis Results (Research, 2019)

Table 7b. Trial Test Results for Geopolymer Concrete samples

Code	Age (day)	weight (kg)	Volume (m^3)	Specific gravity (kg/m^3)	Compressive Strength (MPa)	Slump (cm)
WGC26	90	3,810	0,001571	2425,52	28,49	0
WGC27	90	3,640	0,001571	2317,30	25,71	0
WGC28	90	3,720	0,001571	2368,23	15,79	0
WGC29	90	3,770	0,001571	2400,06	27,90	0
WGC30	90	3,830	0,001571	2438,25	40,92	0
WGC31	90	3,720	0,001571	2368,23	44,73	0
WGC32	90	3,550	0,001571	2260,00	17,87	0
WGC33	90	3,640	0,001571	2317,30	25,54	0
WGC34	90	3,810	0,001571	2425,52	21,79	38,0
WGC35	90	3,620	0,001571	2304,56	8,81	46,0
WGC36	90	-	0,001571	-	-	0
WGC37	90	3,710	0,001571	2361,86	12,18	45,0
WGC38	90	3,700	0,001571	2355,49	15,73	41,0

Source: Analysis Results (Research, 2019)

From the results of the geopolymer concrete trial test, various results were obtained, so that the results were taken in accordance with predetermined limits, which have a compressive strength greater than 25 MPa and a minimum slump value of 28 cm. The results are then analyzed to get a mix design that has optimum compressive strength and slump value.

Table 8. WGCS-1 Geopolymer Concrete test sample

Code	Compressive Strength (MPa)	Slump (cm)
WGC12	30,50	28,9
WGC13	26,39	28,3
WGC14	31,85	28,0

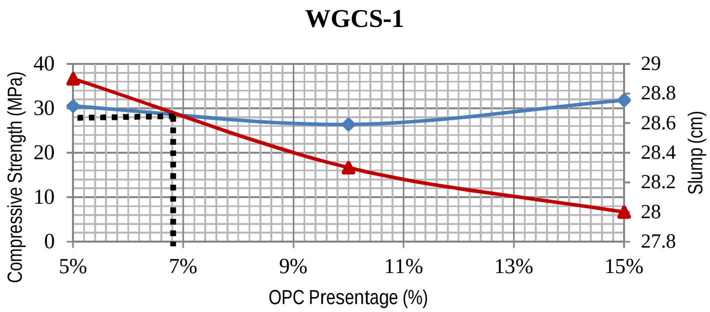

Fig. 5. WGCS-1 Geopolymer Concrete test sample

Table 9. WGCS-2 Geopolymer Concrete test sample

Code	Compressive Strength (MPa)	Slump (cm)
WGC16	23,57	33,5
WGC17	32,45	31,0
WGC18	32,12	30,0

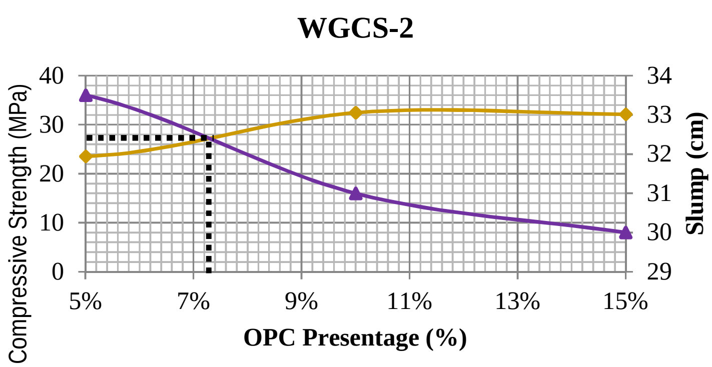

Fig. 6. WGCS-2 Geopolymer Concrete test sample

4.3. Mix design of geopolymer concrete

Based on the results of the analysis of the geopolymer concrete trial, a mix design of the geopolymer concrete specimen is obtained as in Table 10

Table 10. Mix design of geopolymer concrete

Code	Sand : Split (%)	Fly Ash : Alkaline Activator (%)	NaOH : Na_2SiO_3 (%)	OPC (%)	Extra Water (%)	Superplastizer	
						type	%
WGCS-1	40:60	65:35	1:2,5	5,63	11,70	Viscocrete 1003	2
WGCS-2	40:60	65:35	1:2,5	6,60	11,98	Masterglenium Sky 8851	5
SCGC-1	40:60	65:35	1:2,5 **Na_2SiO_3 Be52**	5,63	11,70	Viscocrete 1003	2

Source: Analysis Results (Research, 2019)

The specimens used for testing compressive strength and slump are cylindrical concrete with a size of 10x20 cm. The making of test specimens aims to obtain an optimum mix design in accordance with the results of the analysis of the geopolymer concrete specimen trials. The results of compressive strength and slump testing of geopolymer concrete specimens can be seen in Table 11

Table 11. Test results for geopolymer concrete samples

Code	Uge (day)	Weight (kg)	Volume (m3)	Specific Gravity (kg/m3)	Compressive Strength (MPa)	Slump (cm)
WGCS-1	90	3,700	0,001571	2355,19	31,20	30,0
WGCS-2	90	3,690	0,001571	2349,13	28,31	32,5
SCGC-1	90	3,720	0,001571	2356,20	**32,50**	**65,0**

Source: Analysis Results (Research, 2019)

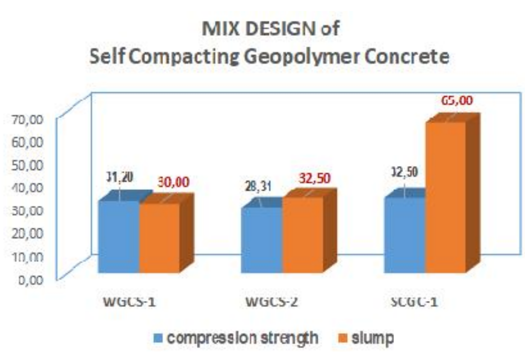

Fig. 7. Test Results for Geopolymer Concrete samples

Based on the test results of geopolymer concrete specimens, it was found that the Mix Design WGCS-1 and WGCS-2 had met the specified limits, namely compressive strength> 25 MPa and a slump value ≥ 30 cm. As for SCGC-1 (Self Compacting Geopolymer Concrete) by changing the type of Na_2SiO_3 to Na_2SiO_3 Be 52 which is more liquid, 32.50 MPa compressive strength and horizontal slump value of 65 cm are obtained.

5. Conclusion

1. To achieve workable geopolymer concrete, extra water is needed to increase the slump value.
2. The type and dosage of superplastizer that is used greatly affects the elasticity and quality of the concrete. Each type of SP has a different dosage to get the optimum slump value and compressive strength. The more doses of SP used, will reduce the quality of concrete and make concrete bleed. If the SP dose is used a little / less, then the expected damage can not be obtained.
3. Comparison of fly ash with alkaline activator affects the slump value and compressive strength of geopolymer concrete.
4. To achieve a geopolymer concrete that can solidify by itself, the type of alkaline activator used (Na_2SiO_3) of the type Na_2SiO_3 Be-52.
5. The result of SCGC-1 geopolymer concrete design mix reaches a minimum compressive strength of 25 MPa and a horizontal slump value of 65 cm.

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