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 (CO₂) 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 SiO₂, Al₂O₃, P₂O₅, and Fe₂O₃ 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 Sodium Hydroxide (NaOH) 8M to 14M and Sodium Silicate (Na₂SiO₃) Be52 with a ratio between 0.4 to 2.5 [3]. Geopolymer concrete can be said to be environmentally friendly because it can reduce CO₂ gas up to 20% [2]. However, for the time being, the reference for planning geopolymer 

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 CO₂ 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 (Na₂SiO₃) Be52 with a ratio between 0.4 to 2.5 [3]. Geopolymer concrete can be said to be environmentally friendly because it can reduce CO₂ 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 superplastizer ratio 2 and 5 percent. The specimens were 100 by 200 mm cylinders tested in compression at the ages of 90 days.
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-
From these results, an analysis was carried out to create a mix design for geopolymer concrete specimens. Mix design of geopolymer concrete as follows:

![Mix Design Diagram]

**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) : Na₂SiO₃                    | 1 : 2.5 | 1 : 2.5 | 1 : 2.5 (Na₂SiO₃ Be-52) |
| Superplastizer-Viscocrete 1003          | 2% FA  | -      | 2% FA  |
| Superplastizer-MasterGlenium            | -      | 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:

![Slump Test Diagram]

**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.

![Fly Ash Composition Diagram]

**Table 3. Chemical composition of fly ash**
Table 3. Fly ash PT.PJB PLTU Tanjung 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 (SiO₂)      |             | 70              | 70       | 50       | -        | 70       | 50       |
| Aluminum oxide (Al₂O₃)      | 76.87       | 4               | 5        | 5        | -        | 5        | 5        |
| Iron oxide (Fe₂O₃)          |             | 33              | 3        | 3        | -        | 3        | 3        |
| Calcium oxide (CaO)         | 11.48       | -               | -        | -        | <10      | >10      |
| Sulfur trioxide (SO₃)       | 2.29        | 3               | 5        | 6        | -        | 6        | 6        |
| Moisture content            | 1.66        | 1.5             | 1.5      | -        | 1.5      | 1.5      |
| Sodium dioxide (Na₂O)       | 1.12        | -               | 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 (SiO₂), aluminum oxide (Al₂O₃) and iron oxide (Fe₂O₃) 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 (Na₂SiO₃) 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 (Na₂SiO₃ and NaOH) | 65% to 35% |
| Na₂SiO₃ 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 identical 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](image)

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

| Composition | Percentage (%) | Remarks |
|-------------|----------------|---------|
| Na2O        | 1.59           |         |
| MgO         | 2.86           |         |
| Al2O3       | 24.95          |         |
| SiO2        | 46.52          |         |
| SO3         | 1.13           |         |
| K2O         | 2.77           |         |
| CaO         | 5.89           |         |
| TiO2        | 1.36           |         |
| FeO         | 11.81          |         |
| CuO         | 1.12           |         |

Fly ash PLTU Tanjung - Jati B Jepara is type F fly ash because it contains CaO < 10% and total levels of SiO2, Al2O3, and FeO > 70%.

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 (m³) | Specific gravity (kg/m³) | 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        | 3,810       | 0.001571    | 2431.89                  | 29,35                     | 34,0       |
| 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                  | 26,26                     | 0          |

Source: Analysis Results (Research, 2019)

Table 7b. Trial Test Results for Geopolymer Concrete samples

| Code  | Age (day) | weight (kg) | Volume (m³) | Specific gravity (kg/m³) | 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.

| Code     | Sand : Split (%) | Fly Ash : Alkaline Activator (%) | NaOH : Na₂SiO₃ (%) | 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 Na₂SiO₃ 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.

| 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                  | **32.5**                  | **65.0**   |

Source: Analysis Results (Research, 2019)

Fig. 7. Test Results for Geopolymer Concrete samples

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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 Na₂SiO₃ to Na₂SiO₃ 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 (Na₂SiO₃) of the type Na₂SiO₃ 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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