Optimum compressive strength of geopolymer concrete in variations comparison of ingredients and mixing time

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Abstract. Concrete has been criticized more recently because of the greenhouse gas (carbon dioxide) emissions it produces in the cement portland production process. With these considerations, a new concrete binder called geopolymer concrete was developed. One of the materials used in the manufacture of geopolymer concrete is fly ash. Using fly ash as a substitute for cement is considered to be able to preserve the environment and reduce development costs. In this study, the specimen used was cylindrical, with a diameter of 15 cm and a height of 30 cm. The concrete compressive strength test was carried out at the age of 28 days. Variations in concrete testing include: Test the strength of the concrete on the variation of the binder ratio: coarse aggregate of 20%:80%, 25%:75%, 30%:70%, 35%:75%, 40%:60% and the variation of stirring time 5 minutes, 7.5 minutes, 10 minutes, 15 minutes. From the test results, it can be concluded that the optimum mixing time for the concrete mix is 7.5 minutes. If it is less than 7.5 minutes it will result in less than maximum binder binding power. And if the mixing time is more than 7.5 minutes it will decrease the adhesion of the binder. Regarding the variation of concrete on the amount of use of fly ash, it can be concluded that the higher the fly ash content, there is a tendency for low compressive strength, this is due to the influence of the water content used in the mixture is obtained based on the weight of fly ash in each variation. So if the weight of fly ash is higher, the water demand will also be higher and it will result in too dilute fresh concrete, so that the compressive strength of the concrete decreases.

1. Introduction
Concrete is a building material that is composed of the main composition of coarse aggregate, fine aggregate, water, and Portland Cement. The concrete material is very important and widely used to build infrastructure such as buildings, bridges, highways, dams, and other infrastructure facilities [1, 2]. There are two important aspects that must be considered that the durability (durability) concrete material itself and the environmental disruption due to the production of Portland Cement. With these considerations, the development of new concrete binder called geopolymer concrete. The main ingredients used for the manufacture of geopolymer concrete are materials that contain many elements of silica, alumina, and lime The material can not be needed added bind water and other chemicals that can bind namely sodium hydroxide and sodium silicate. Silica oxide in the material will react chemically and produce a strong bond polymers [3]. Based on the above considerations, in this study to make concrete geopolymer used binder / replacement for cement is fly ash [4] with the addition of a chemical solution of
Sodium Silicate (Na$_2$SiO$_3$) and Sodium Hydroxide (NaOH) [13] with a variation of the building blocks (20% : 80% to 40% : 60%) and the variation of mixing time (5 to 15 minutes).

2. Method
The method will be used in the implementation of this research was a laboratory experiment. Laboratory research is an activity relating to test the truth of a hypothesis for the effect of, or changes in the relationship. In this study the manufacture of test specimens performed in the laboratory of Civil Engineering University of Muhammadiyah Surakarta, research conducted by the test specimen to determine the compressive strength of geopolymer concrete optimum ratio variation constituent materials (20:80 s / d 40:60) and on the variation of mixing time (5 s / d 15 min). In this study conducted in several stages, the first stage is preparation. In the first stage is to prepare the materials and tools that will be used prior to the study to conform to specifications. The second stage is testing of the materials to be used to determine how much organic matter contained in the sand that will be used as a mixture of mortar. Third stages of planning blend (mix design) and manufacture of test specimens, at this stage of planning designed blend (mix design) with a ratio of aggregate and binder in concrete mix is 20%: 80%; 25%: 75%; 30%: 70%; 35%: 65%; and 40%: 60%. Construction materials to be used shall correspond to the concrete mix design, manufacture concrete mix using the tool Molen minimixer with a capacity of 0.6 m3 equivalent to the manufacture of test specimens 6 cylinder, to obtain a homogeneous mixture results. further testing to determine the level of viscosity slump concrete mix slump planned order value can be achieved. After getting the mix design value slump then poured into the mold, the test object is printed using a printing cylinder diameter of 15 cm and 30 cm high. The fourth stages are treatments of concrete after the concrete has started to harden, treatment by soaking in water under conditions of room temperature for 28 days. The fifth stage is Benda Testing Testing at this stage of testing the strength of concrete with a cylindrical specimen of 15 cm diameter and 30 cm high concrete done at age 28. The sixth stage is the analysis of data is the data that has been obtained from later analyzed and calculated. The latter stages of making conclusions that the data has been obtained and analyzed can be concluded in accordance with the purpose of research.

3. Results and discussion
This section presents the results of research and discussion candidly. The results of the study can be data on the evaluation methods that have been used or additional data taken from other methods. Study research results can contain a summary of the results of a thorough investigation. In that section can also be added to the comparison between the results of research conducted with the results of previous studies wherewith as reference [5–11, 21] Tables and graphs can shown in this section and should be given an explanation / discussion verbally to clarify the presentation of the results found deficiencies or research limitations. If limitation in the research, the analysis needs to be added. The section also allowed to write down the development of future research based on the results obtained.

3.1. Fine Aggregate Testing
Tests conducted to determine the fine aggregate density (specific gravity), aggregate gradation, organic content and the content of the mud.

The results obtained at the time of the study is the organic content by means of sand settling for ± 24 hours with a mixture of NaOH at 3% was obtained the results of organic material orange (2), this suggests that a little sand containing organic substances so that sand does not need to be washed (sand meets the requirements). The test results obtained sand content of mud at 1.04% , while the ISO standards for the content of the mud is a maximum of 5% [12] so that the sand can be used as a mixture of concrete. From the test results on the water
absorption of fine aggregate values obtained absorption (absorption) of 4.17% can be concluded that sand or fine aggregate can be used as a concrete mixture because it meets the requirements in accordance with standard ISO with the requirements of the water absorption of less than 5% [13] Test results on the fine grain sand modulus obtained the value of 3.23, the sand can be used as concrete as included in the fine sand that has requirements in accordance with standard ISO between 1.5 to 3.8 [14]. For the test results obtained SSD density of 2.86, obtained apparent specific gravity of 2.74, while the result of the dry bulk density is 2.46. The test results of fine aggregate gradation in accordance with the requirements of ASTM C33-97 [15, 16] can be seen in Table 1.

| Test Type            | Test Result | Requirements | SNI Standard                           | Annotation |
|----------------------|-------------|--------------|----------------------------------------|------------|
| organic content SSD  | No.2 (Orange) | 1 - 5        | SNI 03-2816-1992 [15]                  | Qualify    |
| SSD Test             | 1.47 < 3.8   |              | -                                      | Qualify    |
| SSD Test             | 2.46 -       | SNI 03-1970-1990 | -                                     |            |
| SSD Test             | 2.86 -       | SNI 03-1970-1990 | -                                     |            |
| SSD Test             | 2.74 -       | SNI 03-1970-1990 | -                                     |            |
| Absorption (%)       | 4.17% < 5%   | SNI 03-1970-1990 | Qualify                              |            |
| Sludge Content       | 1.04% < 5%   | -            | -                                      | Qualify    |
| Fine Agg. Gradation  | Range III    | Range III    | SNI 03-2384-1992 [16]                | Qualify    |
| Fine grain Modulus   | 3.23 1.5-3.8 | -            | -                                      | Qualify    |

3.2. Coarse Aggregate Testing Results
Coarse aggregate examination results taken from Kali Woro, Klaten can be concluded that the test results Saturated Dry weight (Saturated Surface Dry) obtained a value of 2.39. In testing the apparent specific gravity resulting in coarse aggregate of 2.48, bulk density values obtained 2.33. From the test results on the water absorption of coarse aggregate used as a mixture in the concrete, which is 2.51% while the fine grain modulus testing gained 7.37, it can be concluded that the coarse aggregate can be used as a mixture of concrete because it meets the requirements based on SNI [17].

| Test Type          | Test Result | Requirements | SNI Standard [5] | Annotation |
|--------------------|-------------|--------------|------------------|------------|
| Bulk Specific Gravity | 2.33        | SNI 03-1969-1990 | Quality        |            |
| SSD Specific Gravity | 2.39        | SNI 03-1969-1990 | Quality        |            |
| Apparent Specific Gravity | 2.48        | SNI 03-1969-1990 | Quality        |            |
| Absorption (%)     | 2.51 < 3%   | SNI 03-1969-1990 | Quality        |            |
| Fine Grain Modulus | 7.37 5 – 8  | SNI 03-1969-1990 | Quality        |            |

Gradation size max. 20 mm
In range Gradation range SNI 03-1969-1990 Quality
3.3. **Fly Ash Test Result**

Fly ash used in this research comes from PT. Jaya Ready Mix Sukoharjo, which comes from burning coal from coal burning at the Jepara PLTU. This test is carried out to determine the content of the chemical elements in fly ash. In this study, data from fly ash testing was available and obtained from PT. Jaya Ready Mix Sukoharjo which has been done by Sucofindo. The test results that have been obtained can be seen in Table 3.

| Number | Chemical Composition | Percentage (%) |
|--------|----------------------|----------------|
| 1      | SiO$_2$              | 45.27          |
| 2      | Al$_2$O$_3$          | 20.07          |
| 3      | Fe$_2$O$_3$          | 10.59          |
| 4      | TiO$_2$              | 0.82           |
| 5      | CaO                  | 13.32          |
| 6      | MgO                  | 2.83           |
| 7      | K$_2$O               | 1.59           |
| 8      | Na$_2$O              | 0.98           |
| 9      | P$_2$O$_5$           | 0.41           |
| 10     | SO$_3$               | 1.00           |
| 11     | MnO$_2$              | 0.07           |

From the data from the chemical content test results of fly ash in Table 3, it is found that data is dominated by elements of silica, iron and alumina. Of content (SiO$_2$+Fe$_2$O$_3$+Al$_2$O$_3$) obtained by 75.93%. While the limit (SiO$_2$+Fe$_2$O$_3$+Al$_2$O$_3$) class C is minimal 50% and class F (SiO$_2$+Fe$_2$O$_3$+Al$_2$O$_3$) minimal 70%. It can be concluded that fly ash from PT. Jaya Ready Mix is included in class F (ACI Manual of Concrete Practice 1993 Part 1 226.3R-3) [18].

3.4. **Concrete Mix Designing**

In this study, mix design refers to previous research conducted by Ginanjar Bagus Prasetyo [9]. Material requirements are obtained according to the mass ratio of the test object. The results of the mix planning mix can be seen in Table 4.

| Mix | Fine Aggregate | Coarse Aggregate | Water | Fly Ash | Na$_2$SiO$_3$ | NaOH |
|-----|----------------|------------------|-------|---------|---------------|------|
| 1   | 3.73           | 7.461            | 0.518 | 2.07    | 0.519         | 0.208|
| 2   | 3.497          | 6.994            | 0.647 | 2.588   | 0.649         | 0.26 |
| 3   | 3.264          | 6.528            | 0.779 | 3.105   | 0.781         | 0.312|
| 4   | 3.031          | 6.062            | 0.906 | 3.623   | 0.908         | 0.363|
| 5   | 2.8            | 5.6              | 1.035 | 4.14    | 1.04          | 0.416|
| Summary | 16.32        | 32.65            | 3.88  | 15.53   | 3.9           | 1.56 |

From Table 5, the data obtained from the planning of the geopolymer concrete mix for each sample, in this study the use of water requirements used in mixing in the field may be different from the calculation of the use of water requirements in the initial planning of the geopolymer concrete mix. This could have happened because of the difficulty level in the geopolymer mixing process and the influence of the real conditions in the UMS Civil Engineering faculty laboratory.
Table 5: Proportion of concrete mix for each variation of fly ash per 1 m³

| Mix | Fine Aggregate | Coarse Aggregate | Water | Fly Ash | Na₂SiO₃ | NaOH |
|-----|----------------|------------------|-------|---------|---------|------|
| 1   | 55.95          | 111.915          | 7.763 | 31.053  | 7.788   | 3.119|
| 2   | 52.458         | 104.915          | 9.704 | 38.818  | 9.735   | 3.894|
| 3   | 48.96          | 97.92            | 11.679| 46.58   | 11.715  | 4.686|
| 4   | 45.465         | 90.93            | 13.588| 54.351  | 13.613  | 5.445|
| 5   | 42             | 84               | 15.527| 62.103  | 15.593  | 6.237|
| Summary | 244.83 | 489.68 | 58.26 | 232.9 | 58.44 | 23.38 |

So in calculating the mix mix for each concrete sample in the laboratory, the water requirement can be reduced by 10% or 10% added from the initial planning of the geopolymer concrete mix.

3.5. Slump Test Result
This study, the slump value is needed to determine the level of concrete performance of each variation of fly ash content in the concrete mixture.

Table 6: The results of the slump value test

| Binder : Aggregate | Slump value (cm) |
|--------------------|------------------|
|                    | 20 : 80 | 25 : 75 | 30 : 70 | 35 : 75 | 40 : 60 |
| Time               |         |         |         |         |         |
| 5                  | 22.9    | 14.5    | 10.2    | 16.7    | 17.6    |
| 7.5                | 13.4    | 9       | 5.4     | 11      | 13.6    |
| 10                 | 15      | 10.1    | 7       | 13.8    | 14.1    |
| 12.5               | 25.7    | 14      | 13.9    | 16      | 22.4    |
| 15                 | 25.2    | 18.9    | 14.6    | 17.8    | 25      |

From Table 6 shows that the higher the fly ash content, the higher the slump value, this is because the influence of the water content used in this mixture is obtained based on the weight of fly ash used by each variation. So if the weight of fly ash is getting higher, the water demand will also be higher and will result in higher slump value.

3.6. Concrete Compressive Strength Test Results
Testing of the compressive strength of concrete is carried out using a concrete compressive strength testing machine. This test is carried out after measuring the dimensions of the test object to determine the area of the compressed concrete plane. The value of the compressive strength of concrete can be calculated by the formula [20].

\[ f'_c = \frac{P}{A} \]  

with: \( f'_c \): the compressive strength of the concrete produced by the test object (MPa), \( P \): maximum load (N), \( A \): surface area of the sample test (mm²). From the picture above, it can be seen that the length of time for mixing the concrete mix against the compressive strength of the geopolymer concrete. In this study using 5 variations of time in mixing the concrete mix, namely 5 minutes; 7.5 minutes; 10 minutes; 12.5 minutes; and 15 minutes. In geopolymer...
Figure 1: The relationship between the comparison between the average compressive strength of geopolymer concrete and the mixing time

concrete 20: 80, the highest compressive strength is owned by concrete with a variation of mixing time = 7.5 minutes. In geopolymer concrete 25: 75 the highest compressive strength is owned by concrete with a variation of the mixing time = 7.5 minutes. In geopolymer concrete 30: 70, the highest compressive strength is owned by concrete with a variation of mixing time = 7.5 minutes. In geopolymer concrete 35: 75 the highest compressive strength is owned by concrete with a variation of mixing time = 7.5 minutes. And in geopolymer concrete 40: 60 the highest compressive strength is owned by concrete with a variation of the mix time = 7.5 minutes. So it can be concluded that the optimum mixing time for the concrete mix is 7.5 minutes. If it is less than 7.5 minutes it will result in less than maximum binder binding power. And if the mixing time is more than 7.5 minutes it will decrease the adhesion of the binder. This causes the compressive strength of the geopolymer concrete at the time of testing to decrease. As for the variation of concrete on the amount of fly ash use, it can be concluded that the higher the fly ash content, the lower the compressive strength, possibly due to the influence of the water content used in this mixture based on the weight of fly ash used in each variation. So if the weight of fly ash is higher, the water demand will also be higher and it will result in too dilute fresh concrete, so that the compressive strength of the concrete decreases.

4. Conclusion and Recommendation

Based on the results of the analysis and discussion that have been described in the results and discussion, several conclusions were obtained as follows: The highest compressive strength value of geopolymer concrete is 16.648 MPa, at a variation of the mixing time of 7.5 minutes for geopolymer concrete with a variation of 30%: 70% constituent materials. From the research that has been done, it can be concluded that the maximum mixing of geopolymer concrete is 7.5 minutes. The slump values obtained at the time of testing are shown in Table 5. Then the slump in accordance with the specifications in Table 5 is a slump with a value of 5.4 and 7 which can be used as an alternative replacement for repair or maintenance. Because when used in structural work, it can cause corrosion of the reinforcement used. This is due to the nature of the Geopolymer concrete, which in making the mixture uses added materials such as $Na_2SiO_3$ and NaOH. Geopolymer concrete can be used as an alternative to normal concrete, but it is less efficient in terms of work and costs, and is not good for reinforced concrete because the chemicals used have corrosion properties that can damage the reinforcing bars. Therefore geopolymer concrete is more suitable for repair or maintenance only. In the manufacture of
geopolymer concrete, the setting time is very fast. So it is necessary to need an additive to inhibit the initial binding.

For the next research, it is recommended to do room temperature curing with the test object covered with plastic to reduce evaporation. The geopolymer concrete mixing process is recommended at temperatures below 20°C to slow down the setting time of the initial bonding so that the concrete is easily stirred or increases workability. During the work of making geopolymer concrete, you should use protective equipment such as masks and gloves because fly ash and the chemicals used are very harmful to the human body.

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