Mechanical properties of fly ash-based geopolymer concrete using variation in maximum size of coarse aggregate

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Abstract. The aim of this research was to study the mechanical properties (compressive strength and splitting-tensile strength) of fly ash-based geopolymer concrete using variation in the maximum size of coarse aggregate. The mode of study was laboratory research. Fly ash obtained from Asam-Asam Steam Power Plant, South Kalimantan, Indonesia. The maximum size of coarse aggregate was 10 mm, 20 mm and 30 mm. The geopolymer concrete proportion divided into 3 different mixtures and each contained 400 kg/m³ of fly ash. The alkaline activator used as sodium silicate and 10M sodium hydroxide in the ratio 2:1. The ratio of alkaline activator to fly ash was 0.4. Cylindrical specimens (size 100 mm x 200 mm) counted 10 pieces for each mixture proportion and cured at ambient condition. The test result showed that average of compressive strengths and splitting-tensile strengths for specimens with 10 mm, 20 mm, and 30 mm maximum size of aggregate at the age of 21 days were 11.04 MPa and 6.12 MPa, 10.82 MPa and 5.22 MPa, 10.06 MPa and 4.84 MPa respectively. In conclusion, the greater the maximum size of coarse aggregate, the smaller the value of compressive strength and splitting-tensile strength.

1. Introduction

The use of conventional concrete is very popular in construction because rigid and stronger than other building materials especially in holding dead loads, live loads, and lateral loads. The conventional concrete production uses Portland cement which has been mass-produced all around the world.

However, conventional concrete often gets criticism from environmentalists. Conventional concrete is considered un-environmentally friendly because it produces CO2 from the Portland cement production process. The increasing use of Portland cement can trigger the impact of global warming because in the production of 1 ton of Portland cement will contribute 1 ton of CO2 [1].

Then, the effort to get environmentally friendly concrete is through the development of concrete using inorganic binding materials such as polymer alumina-silicates or also known as geopolymers which are syntheses of geological materials found in nature or materials produced by industrial by-products such as fly ash rich in silica and aluminum content [2].

Approximately ¾ of the volume of concrete consists of aggregates (fine aggregates and coarse aggregates) so that the mechanical properties possessed by concrete are strongly influenced by the gradation of aggregate size. To obtain the optimal compressive strength of concrete it is generally assumed that the size of the coarse aggregate should be ideal [3].
However, the use of coarse aggregates with a size minimum considers less economical because it requires more cement in concrete mixtures. To obtain the concrete mixture with the same level of workability and strength, the amount of cement will decrease as the size of coarse aggregate increases. The reduction in the amount of cement in a mixture will reduce the heat of hydration, the potential of concrete experiencing cracks due to shrinkage or high heat differences [4].

This study aimed (1) to study the workability and setting time of fly ash-based geopolymer concrete, (2) to study the compressive strength of fly ash-based geopolymer concrete using variation in the maximum size of coarse aggregate, (3) to study the splitting-tensile strength of fly ash-based geopolymer concrete using variation in the maximum size of coarse aggregate.

2. Research methodology
The method used is experimental studies, by conducting a laboratory experiment at the Concrete Laboratory of Building Engineering Education Study Program, Department of Technology and Vocational Education, Teaching and Education Faculty, University of Palangka Raya.

2.1. Experimental materials
- Fly ash was obtained from Asam-Asam Steam Power Plant, South Kalimantan, Indonesia.
- Coarse aggregate (the maximum size of coarse aggregate: 10 mm, 20 mm and 30 mm).
- Fine aggregate.
- Sodium hydroxide (NaOH).
- Sodium silicate (Na$_2$SiO$_3$).
- Water.

2.2. Experimental investigation
- Concrete proportion divided into 3 different mixtures.
- Amount of fly ash: 400 kg/m$^3$.
- Alkane solution: Na$_2$SiO$_3$, 10M NaOH, water
- The ratio of Na$_2$SiO$_3$ : NaOH was fixed to 2:1.
- The ratio of alkaline activator to fly ash was 0.4.
- Cylindrical specimens (size 100 mm x 200 mm) counted 10 pieces for each mixture proportion.
- Specimens cured at ambient condition.

2.3. Geopolymer concrete proportion
The design of concrete proportion (Table 1) was based on Modified Guidelines for Geopolymer Concrete Mix Design Using Indian Standard [5].

Table 1. Proportion of geopolymer concrete.

| No. | Material specification | Amount      |
|-----|------------------------|-------------|
| 1.  | Ratio alcaline activator: fly ash | 0,4         |
| 2.  | Ratio NaOH : Na2SiO3   | 1 : 2       |
| 3.  | The amount of alcaline activator = 0.4 x amount of fly ash | 160 Liter/m$^3$ |
| 4.  | NaOH solutions         | 53,333 Liter/m$^3$ |
| 5.  | Na2SiO3 solutions      | 106,667 Liter/m$^3$ |
| 6.  | Solid NaOH (10 M)      | 21,33 Liter/m$^3$ |
| 7.  | Amount of water in NaOH solution (10 M) | 31,99 Liter/m$^3$ |
| 8.  | Amount of additional water (extra water) | 8.0 Liter/m$^3$ |
|     | | 24.0 Liter/m$^3$ |
| 9.  | Fine aggregate content without air content | 644,554 Kg/m$^3$ |
| 10. | Coarse aggregate content without air content | 1438,328 Kg/m$^3$ |
2.4. Making, curing and testing of specimens
The number of specimens used in this study was 30 specimens with variations in maximum sizes of 10 mm, 20 mm and 30 mm. Maintenance of concrete specimens using the ambient curing method, concrete was poured in a mold and allowed to stand for 24 hours at ambient temperature. After that, concrete was removed from the mold and then put into a clipped plastic bag until the test time. The tests of the specimens were compressive strength test at 14, 21 days and split tensile strength test at 14 and 21 days.

3. Results and discussion

3.1. Testing raw material
The raw material for geopolymer concrete (such as fly ash, coarse aggregate and fine aggregate) testing result can be seen at Table 2. Table 3 shows the result of XRF analysis for fly ash. The type of fly ash was F based on the amount of SiO₂, Fe₂O₃ and Al₂O₃ which was very low in Ca, slather Fe, (SiO₂ + Al₂O₃ + Fe₂O₃) > 70 (%) (Classification of fly ash according to standard ASTM C – 618 from 1994).

Table 2. Raw material testing results.

| No. | Testing Type                                      | Value       |
|-----|--------------------------------------------------|-------------|
| 1.  | Specific gravity of fly ash                      | 2.67 gr/cm³ |
| 2.  | Coarse aggregate gradation                       |             |
|     | Fines modulus (max 10 mm)                        | 7.956       |
|     | Fines modulus (max 20 mm)                        | 10.728      |
|     | Fines modulus (max 30 mm)                        | 10.815      |
|     | Combined coarse aggregate gradation              |             |
|     | Fines modulus for combined coarse aggregate (20 mm) | 9.48       |
|     | Fines modulus for combined coarse aggregate (30 mm) | 9.39       |
| 3.  | Water content of coarse aggregate                | 1.71 %      |
| 4.  | Specific gravity and absorption of coarse aggregate | 3.07 %  |
|     | Specific gravity (SSD)                           |             |
|     | Absorption                                       | 0.90 %      |
| 5.  | Fine aggregate gradation (zone 2)                | 3.078       |
| 6.  | Organic impurities of fine aggregate             | 0 – 5%      |
| 7.  | Sludge levels of fine aggregate                  | 2.13 %      |
| 8.  | Water content of fine aggregate                  | 0.786       |
| 9.  | Specific gravity and absorption of fine aggregate | 3.01 %  |
|     | Specific gravity (SSD)                           |             |
|     | Absorption                                       | 1.63 %      |

Table 3. Fly ash XRF analysis results.

| Compound | %  | Compound | %  |
|----------|----|----------|----|
| SiO₂     | 27 | V₂O₅    | 0.05 |
| Fe₂O₃    | 47.2 | Cr₂O₃  | 0.03 |
| Al₂O₃    | 7.2 | MnO     | 0.66 |
| MgO      | 0.84 | CuO    | 0.06 |
| P₂O₅     | 0.47 | ZnO    | 0.09 |
| K₂O      | 0.56 | M₆O₃  | 2.6 |
| CaO      | 11.3 | BaO    | 0.69 |
| TiO₂     | 0.84 | Re₂O₃ | 0.4 |

3.2. Testing of slump and setting time for fresh concrete
The slump and setting time of geopolymer concrete result can be seen at Table 4.
3.3. Testing of geopolymer concrete specimens

3.3.1. Compressive strength test result. The compressive strength of concrete was carried out after the concrete reached the age of 14 and 21 days (Figure 1 and 2). The highest average compressive strength at the age of 14 days obtained for the maximum size of 10 mm coarse aggregate of 9.85 MPa. Then at the age of 21 days, the highest average compressive strength for the maximum size of 10 mm coarse aggregate was 11.04 Mpa. The test results showed that the smaller the maximum size of coarse aggregate, the greater the compressive strength.

This can be influenced by several factors, such as the aggregate size gradation which will affect the density and porosity level of the concrete. The role of aggregate gradation is a factor that must be considered. A good gradation arrangement can produce a maximum density and minimum porosity. A good gradation is a continuous gradation where all sizes of granules are present in the aggregate thus creating heterogeneous granules. Heterogeneous granules will be able to place positions to fill empty cavities according to their size [6].

Furthermore, in addition to consideration of aggregate gradations, it is also necessary to consider the area and the surface roughness of aggregates, especially coarse aggregates, because it can provide adhesion between cement and aggregate to be very strong so that the quality of concrete is better. If the aggregate used is relatively small, it will need more water so more use of binders.

**Table 4.** Slump test and setting time results.

| Max. Corse Agg (mm) | Slump (cm) | Setting time (min) |
|---------------------|------------|--------------------|
| 10                  | 13.2       | 43                 |
| 20                  | 13.8       | 48                 |
| 30                  | 14.2       | 46                 |

**Figure 1.** Relationship between average compressive strength and maximum size of coarse aggregate at 14 days.

**Figure 2.** Relationship between average compressive strength and maximum size of coarse aggregate at 21 days.
The compressive strength value in this study could be influenced by the fines modulus of coarse aggregate because the coarse aggregate produced a less dense concrete mixture (the value exceeded the maximum of fineness modulus standard which was between 7.956 - 10.815). According to the quality requirements of SII.0052-80, "Quality and Test Method of Concrete Aggregate" coarse aggregates with good gradations have fineness modulus between 6-7.1. If the fineness modulus of aggregate is greater then the percentage of passing grading is greater [7]. This happens because the large aggregate granules allow it to withstand the load from the impact of the steel ball, the strength is smaller and more percentages pass through the sieve. The presence of more pore cavities in large aggregates allows the aggregate to break down more easily.

From the results of the compressive strength test, this concrete was non-structural concrete because it has the highest compressive strength value of 11.04 MPa < 14 MPa [8]. The value of the compressive strength of the concrete could be higher by using the steam heating curing. The steam system is very suitable for use because it will increase the polymerization process in the test material so that it can increase the compressive strength and reduce the weight of the volume of light pasta and light fibrous pasta [9]. Using a steam curing treatment system will also provide better initial strength in concrete with pozzolanic compared to conventional (non-steam) concrete, where high-quality concrete strength (K700) in post steam can reach 51%, then reached 52% of the 28 days [10].

3.3.2. Testing tensile strength of geopolymer concrete. Testing the split tensile strength by placing the specimen in the longitudinal direction above the test tool, then the compressive load was applied evenly in the upright direction from above on the entire length of the cylinder and tested after the concrete reached the age of 14 and 21 days. The average test results for each specimen were shown in Figure 3 and Figure 4. From the test results, obtained the highest value of split tensile strength on average at the age of 14 days and 21 days for the maximum size of 10 mm coarse aggregate (5.35 MPa and 6.12 Mpa respectively).

![Figure 3. Relationship between average splitting-tensile strength and maximum size of coarse aggregate at 14 days.](image1)

![Figure 4. Relationship between Average Splitting-Tensile Strength and Maximum Size of Coarse Aggregate at 21 Day.](image2)
The fly ash-based geopolymer concrete using a maximum size of coarse aggregate 20 mm and 30 mm at the age of 14 days experienced a decrease in split tensile strength namely by a decrease of 16.64% from 10-20 mm, and a decrease of 8.52% from 20-30 mm. The geopolymer concrete using a maximum size of coarse aggregate 20 mm and 30 mm at the age of 21 days experienced a decrease in split tensile strength by a decrease of 14.71% from 10-20 mm, and a decrease of 7.28% from 20-30 mm.

4. Conclusion
The workability of fly ash-based geopolymer concrete was applicable (14-15 cm), but the setting time was too fast (below 60 mins).

The smaller the maximum size of coarse aggregate, the greater the compressive strength and split tensile strength of fly ash-based geopolymer concrete.

References
[1] Achmad D and Hidjan A G 2012 Efek Perawatan Terhadap Karakteristik Beton Geopolimer, Poli-Teknologi (Jakarta: Politeknik Negeri Jakarta) 11
[2] Davidovits J 1999 Chemistry of geopolymer system, terminology In Proceeding of geopolymer system, terminology, In proceedings of Geopolymer ’99 International Conferences, France
[3] Bimaputra A 1997 Analisa Pengaruh Ukuran Maksimum Agregat Kasar terhadap Kuat Teken Beton Program Studi Teknik Sipil, Fakultas Teknik Universitas Indonesia
[4] Wicaksana A and Zainudin M A 2011 Pengaruh Bentuk dan Tekstur Agregat terhadap Mutu Beton (Teknik Sipil Bangunan Gedung: Fakultas Teknik Sipil dan Perencanaan, Institut Teknologi Sepuluh Nopember Surabaya)
[5] Anuradha R, Sreevidya V, Venkatasubramani R and Rangan B V 2011 Modified Guidelines for Geopolymer Concrete Mix Design Using Indian Standard (India: Department of Civil Engineering, VLB Janakiammal College of Engineering and Technology Kovaipudur, Coimbatore)
[6] Arbi M H 2012 Pengaruh Agregat Terhadap Mutu Beton (Universitas Almuslim: Matanggulumpangdua-Bireu)
[7] Patrisia Y 2014 Self Compacting Concrete using Fly Ash and Dust Stone as Filler Material Jurnal PTK Balanga 2(1) 70-80
[8] Mindess S and J F Young 1972 Concrete (Prentice-Hall, Inc: New Jersey)
[9] Ardi B, Hanif N, Triwulan, Januarti J E 2013 Pasta Geopolimer Ringan Berserat Berbahan Dasar Lumpur Sidoarjo Bakar Dan Fly Ash Perbandingan 1:3 Dengan Pengembang Foam Jurusan Teknik Sipil, Fakultas Teknik Sipil dan Perencanaan, Institut Teknologi Sepuluh Nopember (ITS)
[10] Rommel E 2011 Pengaruh Pemberian Perawatan Steam Curing Terhadap Kekuatan dan Durabilitas Beton Dengan Semen Pozzolan (Effect of Steam Curing on Strength and Durability Concrete With Cement Pozzolan) (Fakultas Teknik Universitas Muhammadiyah Malang)