MATEC Web of Conferences **270**, 01004 (2019) https://doi.org/10.1051/matecconf/201927001004
ConCERN-2 2018

Experimental study of effect additional water on high performance geopolymer concrete

Rachmansyah[1,*], *Harianto* Hardjasaputra[2], and *Meilanie* Cornelia[2]

[1]Civil Engineering Department, Krida Wacana Christian University, Jakarta, Indonesia
[2]Civil Engineering Department, Pelita Harapan University, Tangerang, Indonesia

Abstract. The Earth Summit 1997 in Kyoto (Japan), industrialized countries agreed to reduce gas emissions by 21% to avoid global warming due to greenhouse effect with the release of CO_2 into the air. From the research result, cement industry sector all over the world contributes about 8 - 10% of total CO_2 emission. This number is quite high and if there is not a special action to reduce, CO_2 emissions will continue to increase along with the rapid development of infrastructure in various parts of the world including in Indonesia. To support greenhouse effect reduction efforts due to CO_2 emissions and environmental conservation, civil engineers in the world are taking steps to achieve Sustainable Concrete Technology, in order to create "Green Concrete". For that reason in the direction of "Green Concrete", innovation is needed to reduce or replace cement in the concrete mixing. The ash waste electrical power generating plants of fly ash is a material containing many SiO_2 and Al_2O_3 which can be used to replace the overall of cement in concrete. Geopolymer concrete is a fly ash-based concrete that replaces the entire cement in its manufacture. Workability in mixing geopolymer concrete is very low, due to the rapid reaction of the alkaline solution when it reacts with fly ash. To improve the workability can be added water at the time of mixing. The fly ash used in the mixing from the Paiton power plant in East Java with grain size 12.06 μm with round granules and chemical composition of fly ash containing SiO2, Al2O3 and Fe2O3 with a total of 75.151%. The planned compressive strength of the concrete is 45 MPa, with a variation of 8M, 12M and 16M NaOH molarity and the ratio of NaOH and Na2SiO3 is 1. Addition of water in concrete mixing with variations of 15, 17.5, 20, 22.5 and 25 liters / m3. The results of this study indicate that the more addition of water in the manufacture of geopolymer concrete can also increase the value of slump, but the excessive addition of water will result in a decrease in the compressive strength of the concrete caused by a decrease in the concentration of the alkaline solution. High molarity values will require additional water to reach the same slump value compared to lower NaOH molarity. With the same mix design, the optimal compressive strength at 8M NaOH was 48.18 MPa with 17.5 liters/m^3 of water added with a slump of 12 cm, for 12M NaOH the optimal compressive strength was 51.65 MPa with the addition of 20 liter/m^3 with 10 cm slump, while for 16M NaOH the optimum compressive strength is 59.70 MPa with 22.5 liters/m^3 of water added with a 5 cm slump. The higher the NaOH molarity will result in a higher compressive strength value and geopolymer concrete compressive strength at early age is higher than conventional concrete.

1 Introduction

The Earth Summit 1997 in Kyoto (Japan), industrialized countries agreed to reduce gas emissions by 21% to avoid global warming due to greenhouse effect with the release of CO2 into the air. From the research result, cement industry sector all over the world contributes about 8 - 10% of total CO_2 emission. This number is quite high and if there is not a special action to reduce, CO_2 emissions will continue to increase along with the rapid development of infrastructure in various parts of the world including in Indonesia, which requires a lot of cement as a component of concrete building materials.

To support efforts to reduce greenhouse effects due to CO2 emissions and environmental conservation, civil engineers in the world take steps to achieve Sustainable Concrete Technology, so that Green Concrete can be created. Green Concrete is a philosophical understanding, not a literal understanding. Now, concrete is the most widely used construction material and is needed in infrastructure development, but also realized as a material that has a major contribution to global warming and has a bad impact on environmental conservation. For this reason, it is necessary to take appropriate steps so that concrete can become a "sustainable construction material", namely as a construction material which, from

* Corresponding author: rachmansyah@ukrida.ac.id

the production process, during the use of the structure, and even after being waste, can continue to run in harmony with the global program for protection and preservation environment.

To support the "Green Concrete" we can take the following actions:

1. Reducing the use of cement in concrete mix designs, with substitution of other pozzolanic substances
2. Looking for new materials to replace cement, where the production process requires low energy;

With these two actions, it is expected that concrete will become a "sustainable construction material". The reduction of cement in the manufacture of concrete can be done by using a partial or whole substitute of cement in concrete which is pozzolanic which contains a lot of SiO_2, such as fly ash which is a waste next to the Steam Coal Power Plant. In addition to reducing the use of cement in the manufacture of concrete, a step that can be done is to look for new materials to replace cement. Geopolymers are environmentally friendly materials that can be used to replace cement in the manufacture of concrete. Geopolymers are more environmentally friendly, because the main material is fly ash which is an industrial waste of Steam Coal Power Plant, besides that in the manufacturing process it only requires low energy at a temperature of 750 °C, unlike in the manufacture of cement which requires large energy up to 1400 °C.

Steam Coal Power Plants in Indonesia still dominate the power generation system and the number will increase along to support the 35,000 MW government program. The various types of power plants in Indonesia will increase coal consumption, based on the 2016 electricity statistics issued by the Directorate General of Electricity of the Ministry of Energy and Mineral Resources of the Republic of Indonesia in early 2017. In Figure 1 it can be seen that Coal Increase in Indonesia from 2009 to 2016.

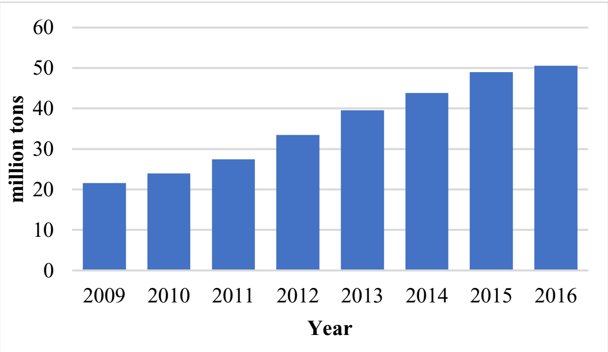


Fig. 1. Coal Consumption in steam coal power plants

Increased use of coal will cause problems to increase coal waste generated during the burning process at the power plant. Waste generated from coal combustion is 5% of coal volume. In 2016, the power plant in Indonesia consumed 50 million tons will produce coal waste of 2.5 million tons and will increase along with the increasing number of power plants in Indonesia. Coal waste is included as a hazardous and toxic waste material that must be specifically managed so as not to cause environmental damage. Management of coal waste at the power plant is done by landfilling and use in the construction field in making concrete even though on a small scale. The construction industry must be encouraged to increase the utilization of coal waste in the manufacture of concrete as an effort to reduce the environmental impacts that occur due to hoarding, besides that coal waste also has high economic value compared to cement. Utilization of coal waste in making concrete by replacing part or all of the cement in concrete.

Concrete Geopolymer made from fly ash are formed from polymerization reactions due to alkali-aluminosilicate reactions that produce strong structural materials such as zeolites [1]. The alkaline solution commonly used is a mixture of Na_2SiO_3 and NaOH, this alkaline solution as an activator that reacts with silica minerals and alumina. Geopolymer concrete can achieve fc '50 MPa concrete compressive strength with flexural strength fcr 7.7 MPa [2]. From the results of these studies indicate that the geopolymer concrete (non -cement) produced can be used as structural concrete.

In the manufacture of geopolymer concrete, the reaction of alkaline solutions with fly ash is faster than the manufacture of cement-based concrete, making the workability level in the manufacture of geopolymer concrete very low. Due to the fast setting time, the concrete mix should be poured as soon as possible into the mold after the mixture is evenly mixed. For increased workability in the manufacture of concrete, water can be added to the manufacture of geopolymer concrete. The increasing use of water in the manufacture of geopolymer concrete will increase manufacturing workability but will result in lowering the compressive strength of the concrete. In this study an experimental study was conducted to determine the effect of adding water to the compressive strength of geopolymer concrete.

2 Geopolymer concrete

Geopolymer concrete is concrete made from fly ash formed from polymerization reactions due to alkali-aluminosilicate reactions that produce strong structured materials such as zeolites [1]. The alkaline solution commonly used is a mixture of Na_2SiO_3 and NaOH, this alkaline solution as an activator that reacts with silica minerals and alumina. Natural minerals that can be used such as kaolin, clay, mica, andalusite, spinel and so on. Other alternatives that can be used are byproducts / waste such as fly ash, silica fume, slag, rice husk ash, red mud and so on. From the many studies that have been done, geopolymer concrete has many advantages from conventional concrete that uses cement, among others, has high initial strength, low shrinkage, freeze-thaw resistance, sulfate resistance, corrosion resistance, acid resistance, resistance against fire and harmless alkali aggregate reactions. In addition to having many advantages from conventional concrete, geopolymer concrete also has several disadvantages such as low workability and manufacturing prices are still relatively expensive, especially in the price of alkaline solutions.

The development of geopolymer in the world is very rapid which can be seen in 2014, the use of geopolymer is quite massive around 40,000 m3 for apron pavement and taxiway at Brisbane West Wellcamp [3]. The airport construction project is the construction that uses the world's largest geopolymer concrete which is carried out by Wagners Company. Whereas in Indonesia many studies have been conducted by academics, one of them by Harianto Hardjasaputra and Esteriana Ekawati in 2017 which produced compressive strength geopolymer concrete reaching fc '50 MPa and flexural strength fcr 7.7 MPa [2]. The results of this study indicate that the geopolymer concrete produced can be used as structural concrete.

3 Materials

Geopolymer concrete materials consist of 3 main materials including fly ash (as a substitute for cement in conventional concrete), aggregate (coarse and fine) and alkaline solution (Na2SiO3 and NaOH as activators).

Fig. 2. Geopolymer concrete materials

3.1 Fly ash

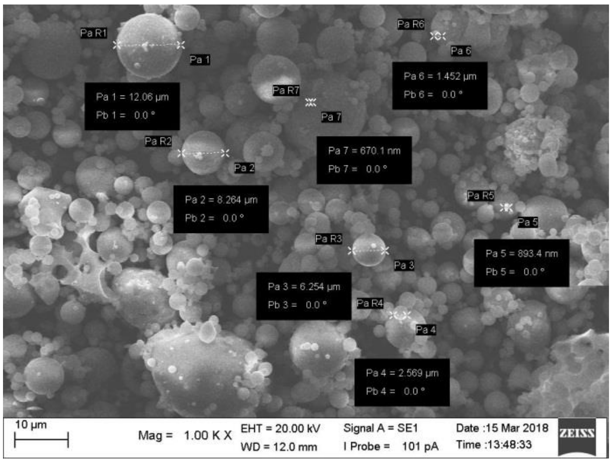


Fig. 3. SEM result

The fly ash used in the mixing from the Paiton power plant in East Java. To determine the size of the granules and the shape of the fly ash Scanning Electron Microscope (SEM) was tested and to determine the chemical composition X-Ray Fluorescence (XRF) was tested. The results of SEM testing showed that the maximum fly ash grain size was 12.06 µm with round granules. XRF test results show the chemical composition of fly ash containing SiO2, Al2O3 and Fe2O3 with a total of 75.151%, meaning that the fly ash tested can be categorized as class F fly ash based on ASTM C 618. This fly ash containing higher CaO will increase compressive strength at an early age but will accelerate the hardening of the concrete [4].

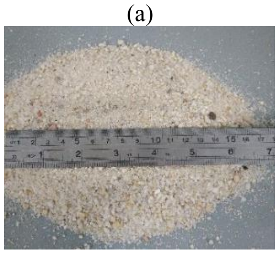
Table 1. Chemical analysis of fly ash

Compound Name	Concentration (%)
SiO2	37,385
Fe2O3	25,223
CaO	14,084
Al2O3	12,543
K2O	3,474
TiO2	2,757
P2O5	1,638
Compound Name	**Concentration (%)**
MgO	0,855
SO3	0,853
BaO	0,349
SrO	0,275
Na2O	0,173
ZrO2	0,144
ZnO	0,121
Cl	0,048
Rb2O	0,045
Br	0,016
Y2O3	0,015

3.2 Aggregate

The coarse aggregate used is crushed stone with a maximum size of 25 mm which has a specific gravity of 2.47. While the fine aggregate uses natural sand with a maximum size of 4.75 mm with a specific gravity of 2.53.

(a)



(b)

Fig. 4. Crushed aggregat (a) and natural sand (b)

3.3 Alkaline solution

The activator/alkali solution used in mixing geopolymer concrete is a combination of NaOH (sodium hydroxide) and Na2SiO3 (sodium silicate). In mixing geopolymer concrete, NaOH molarity consists of 8M, 12M and 16M.

Fig. 5. Alkali solution

4 Mixed design

Because there is no standard used for the design of mixtures on geopolymer concrete. For this research, the design of geopolymer concrete mix will use SNI 03-6468-2000 [5] as the initial reference mixture. The results of the design will be used as the initial design for the manufacture of geopolymer concrete by modifying or replacing the overall cement with fly ash and water with alkaline solutions (NaOH and Na_2SiO_3).

The planned geopolymer concrete quality is 45 MPa with a slump of 75-100 mm, maximum aggregate size of 25 mm, specific gravity of coarse aggregate 2.47 and fine aggregate 2.53, weight of coarse aggregate content of 1565.0 kg/m3 and fine aggregate 1603.5 kg/m3, density of fly ash 2.6, specific gravity of NaOH 1.4 and Na2SiO3 1.6. Can be seen in table 2, the results of geopolymer concrete mix design design by modifying the results of normal concrete mix designs (SNI 03-6468-2000).

Table 2. Proportion of Geopolymer Concrete Mixtures

Material	Normal Concrete (kg/m3)	Geopolimer Concrete (kg/m3)
Cement	546,17	-
Flyash	-	546,17
Coarse Aggregate	1173,75	1173,75
Fine Aggregate	381,30	443,71
Water	185,70	-
NaOH	-	92,85
Na2SiO3	-	92,85

In the manufacture of geopolymer concrete several variations of NaOH molarity from 8M, 12M and 16M were carried out and additional water variations from 15.0 - 27.5 l/m3 which can be seen in tables 3, 4 and 5.

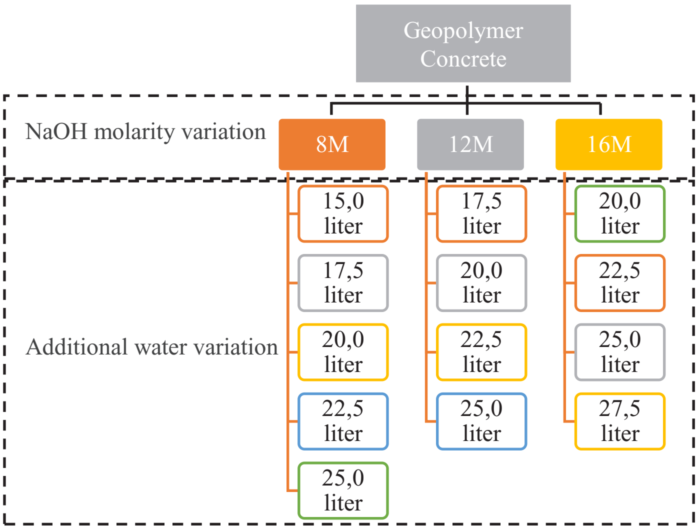


Fig. 6. Mix design variation

Table 3. Proportion of Geopolymer Concrete Mixtures (NaOH 8M)

	45E1	45E2	45E3	45E4	45E5
Flyash	546,17	546,17	546,17	546,17	546,17
Coarse Aggregate	1155,23	1152,14	1149,05	1145,96	1142,88
Fine Aggregate	424,74	421,58	418,41	415,25	412,09
NaOH	92,85	92,85	92,85	92,85	92,85
Na2SiO3	92,85	92,85	92,85	92,85	92,85
Water	15,00	17,50	20,00	22,50	25,00

Table 4. Proportion of Geopolymer Concrete Mixtures (NaOH 12M)

	45F1	45F2	45F3	45F4
Flyash	546,17	546,17	546,17	546,17
Coarse Aggregate	1152,14	1149,05	1145,96	1142,88
Fine Aggregate	421,58	418,41	415,25	412,09
NaOH	92,85	92,85	92,85	92,85
Na2SiO3	92,85	92,85	92,85	92,85
Water	17,50	20,00	22,50	25,00

Table 5. Proportion of Geopolymer Concrete Mixtures (NaOH 16M)

	45G1	45G2	45G3	45G4
Flyash	546,17	546,17	546,17	546,17
Coarse Aggregate	1149,05	1145,96	1142,88	1139,79
Fine Aggregate	418,41	415,25	412,09	408,93
NaOH	92,85	92,85	92,85	92,85
Na2SiO3	92,85	92,85	92,85	92,85
Water	20,00	22,50	25,00	27,50

5 Mixing and curring

Mixing and curing of geopolymer concrete can be seen in tabel 6.

Table 6. Mixing and curing procedure

Step	Time	Procedure
1	0 – 3	Mix the alkaline solution (NaOH, Na2SiO3) and additional water until evenly distributed in the bucket
2	3 – 8	Mix the fly ash in an alkaline solution until evenly distributed
3	8 – 10	Add coarse aggregate and fine aggregate to the mixer and mix until evenly distributed
4	10 – 20	Add the geopolymer paste into the mixer and mix it evenly with the aggregate
5	-	Slump test
6	21 – 22	Mix the mixture before put it in the mold
7	-	The mixture inserted into the mold and compacted
8	-	Curing concrete on the oven at 60-70 °C for 24 ± 4 hours

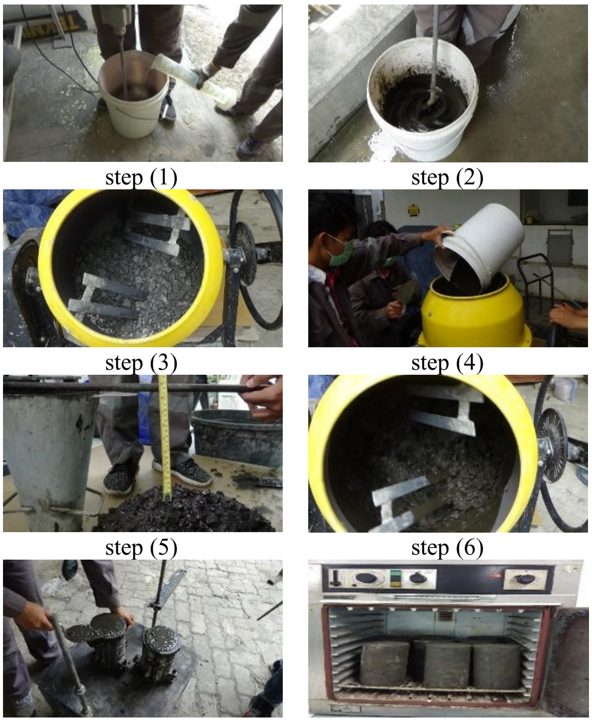


Fig. 7. Mixing and curing procedure

6 Concrete testing

There are two tests on concrete, slump to test the workability of fresh concrete and crushing test to determine the compressive strength of concrete.

Fig. 8. Slump test (a) Crushing test (b)

7 Result

7.1 Effect of slump value with addition of water

The slump obtained when mixing increases with the increase of additional water. The higher the NaOH molarity value requires the addition of more water to reach the desired slump. In figure 9, it can be seen the value of slump with various additional water and different molarity of NaOH.

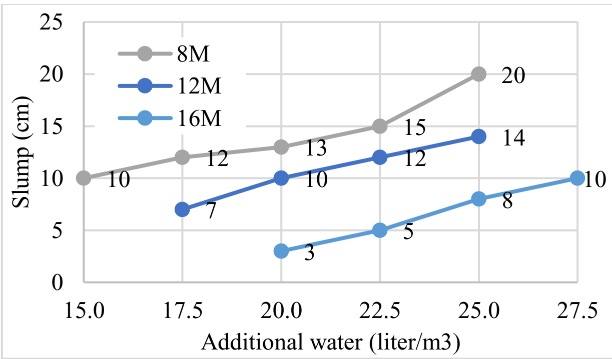


Fig. 9. Relation between additional water, slump and molarity of NaOH

7.2 Relationship between value of compressive strength and addition of water and molarity of naoh

The additional of water with a certain limit in the mixing of geopolymer concrete effects with increased the compressive strength, but the excessive additional water will lead to decreases of compressive strength. The maximum compressive strength for geopolymer concrete with NaOH 8M is 48.18 MPa, 12M is 51,65 MPa and 16M is 59,70 MPa. Increased molarity of NaoH will increased compressive strength. In figure 10, it can be seen the value of compressive strength with various additional water and different molarity of NaOH.

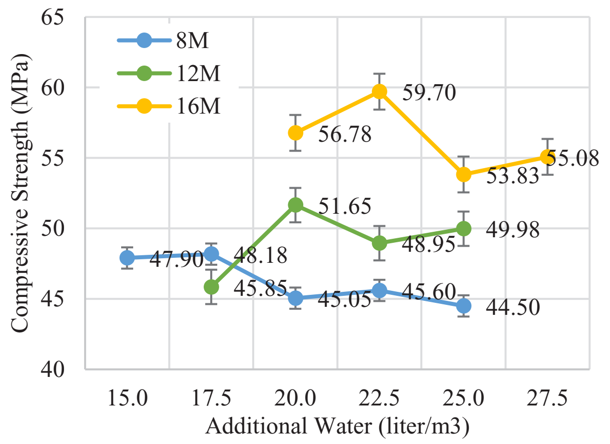


Fig. 10. Relation between additional water, compressive strength and molarity of NaOH

7.3 Increasing geopolymer concrete compressive strength to test age

Geopolymer concrete has a high compressive strength compared to normal concrete in early age. Increasing the compressive strength of geopolymer concrete against the age of testing can be seen in figure 11. The compressive strength of geopolymer concrete at 3 days old was 76.08%, age 7 days 84.60% and 14 days 91.58% from compressive strength 28 days. The increase in the initial compressive strength of geopolymer concrete can occur because the concrete gets curing at a temperature of 60-70 °C, high curing temperatures accelerate the reaction process of flyash with an activator solution or the geopolymerization process that occurs in geopolymer concrete.

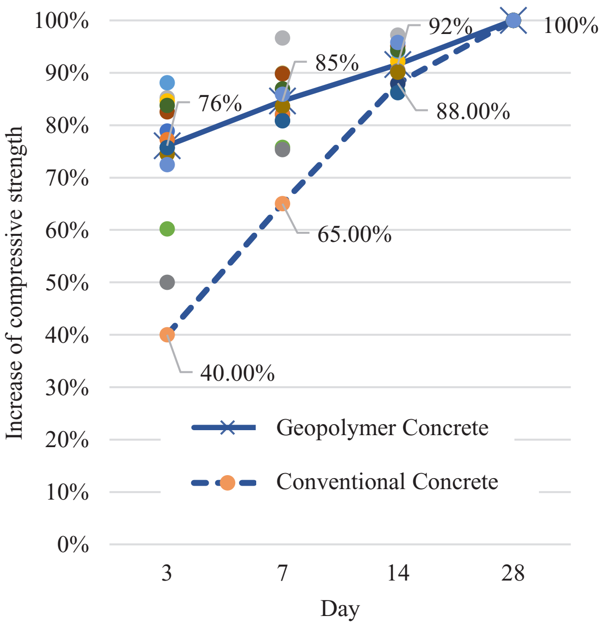


Fig. 11. Relation between additional water, compressive strength and molarity of NaOH

8 Conclusions

1. SNI 6468-2000 can be used to make the initial mix design of geopolymer concrete with several modifications.
2. The increase in additional water in the manufacture of geopolymer concrete will also increase the value of slump.
3. At a certain limit the use of additional water in the manufacture of concrete will increase the value of slump and compressive strength.
4. The higher the NaOH molarity will result in a higher compressive strength value.
5. Increasing the compressive strength of geopolymer concrete at early age is higher than normal concrete.

The Author would like to acknowledge that this research is funded by Directorate for Research and Community Service, Directorate General of Research and Development Strengthening, Ministry of Research, Technology, and Higher Education of the Republic of Indonesia, No.: 021/KM/PNT/2018, 6 March 2018.

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