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The Impact of Steam Curing Temperature and Duration in Increasing the Compressive Strength of Geopolymer Concrete

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ABSTRACT

One of the important steps in the production of geo-polymer concrete is the curing process, because temperature and duration of curing affect the compressive strength of the geo-polymer concrete. This study aims to determine the effect of steam curing temperature and duration on the compressive strength of geo-polymer concrete. All concrete specimens are cylinders with diameter of 15 x 30 cm cured with the steam. The steam temperatures will be controlled from 60 °C, 70 °C, 80 °C, 90 °C and 100 °C and the duration of curing will vary 1 hour to 5 hours. In order to have the normal concrete strength the authors used the mix design of geo-polymer concrete based on the activator solution consist of Sodium Hydroxide (NaOH) 6 Molarity and Sodium Silicate gel (Na2SiO3). The specimens were tested for compressive strength test at the age of 28 days. It can be concluded that the right steam curing method and equipment could increase the compressive strength of geo-polymer concrete up to 100 % compared the concrete specimens cured in the room temperature.

Keywords: Geo-polymer concrete, fly ash, concrete compressive strength, steam curing

INTRODUCTION

In fact, the cement industry sector all over the world contributes about 8-10% of total CO2 emission. This number is quite high and if there is not a special action to reduce the cement production, the CO2 emission will continue to increase along with the rapid development of infrastructure construction in various parts of the world including in Indonesia, which requires a lot of cement as a main component of concrete building materials. To reduce CO2 emissions, civil engineers should take action to use more sustainable concrete materials, one of them is geo-polymer concrete, which was introduced for the first time by Joseph Davidovits. Geo-polymer concrete is a type of concrete that is made by reaction aluminate-silicate with alkali activator. In the production of geo-polymer concrete, the mixing and the curing are the important processes of making good geo-polymer concrete. The curing process and method will influence the geo-polymerization process between fly ash and alkaline solution as the activators. Geo-polymer concrete has a high compressive strength compared to normal concrete in early age. Based on the authors study, the development of the compressive strength of geo-polymer concrete can be described as followings: 76% at 3 days age, 84% at 7 days age and 91% at 14 days compared to the standard compressive strength at 28 days age. It showed, that the polymerization reaction between fly ash and alkaline solution happened mostly in early stage from 0 to 3 days age. In this research the authors will find the method to increase and accelerate the concrete strength by increasing the temperature during the curing time. Steam curing method is chosen as one of the most feasible and practicable methods.

This paper describes the impact of steam curing temperature and duration to the compressive strength of geo-polymer concrete based on the normal concrete strength mix design. Geo-polymer concrete specimens will be cured with steam temperatures of 60 °C, 70 °C, 80 °C, 90 °C and 100 °C for duration time 1 to 4 hours. The concrete specimens will be placed in the self designed by the Authors steam chamber equipped with the steam boiler which will supply the steam according to the planned temperature and duration. After the steam curing process, the concrete specimens will be cured only with the room temperature 24°C - 26°C until 28 days age.

MATERIALS

Fly Ash

The source of the fly ash used for making all the specimens of geo-polymer concrete was from Paiton Power Plant in West Java Indonesia. The specific gravity of the fly ash is 2.4. Figure-1 show Scanning Electron Microscope (SEM) result of fly ash, shape of fly ash is irregular round, with a size of 12.06 - 0.67 μm. Table-1 show X-Ray Fluorescence (XRF) result of fly ash, total percentage of main chemical composition (SiO_2, Al_2O_3 and Fe_2O_3) is more than 70 %. According to ASTM C618, the fly ash can be categorized as class F fly ash.

Table-1. Chemical composition of fly ash.

Oxide	Weight (%)
SiO_2	37.385
Fe_2O_3	25.223
CaO	14.084
Al_2O_3	12.543
K_2O	3.474
TiO_2	2.757
P_2O_5	1.638
MgO	0.855
SO_3	0.853
BaO	0.349
SrO	0.275
Na_2O	0.173
ZrO_2	0.144
ZnO	0.121
Cl	0.048
Rb_2O	0.045
Br	0.016
Y_2O_3	0.015

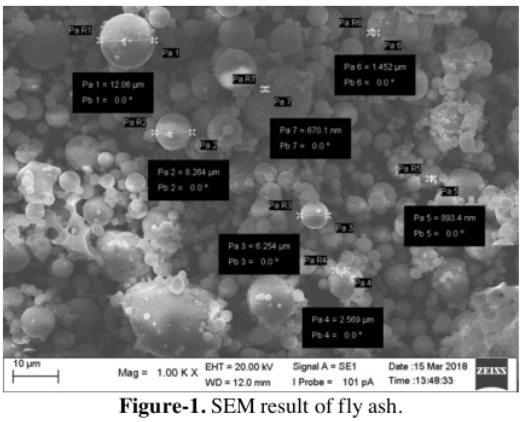


Figure-1. SEM result of fly ash.

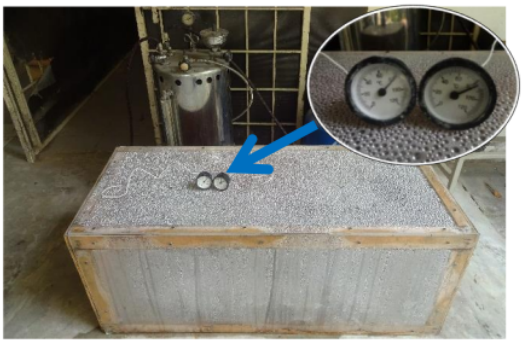


Figure-2. Steam curing process.

Aggregate

The type of coarse aggregate is crushed stone with a maximum size of 12.5 mm with a specific gravity of 2.59 and type of fine aggregate is natural sand with a maximum size of 4.75 mm with a specific gravity of 2.54.

Activator solution

The activator solution used in this mix design is the combination of Sodium Hydroxide (NaOH) and Sodium Silicate gel (Na2SiO3). The Molarity of NaOH is choose to be 6M by dissolving 200 grams NaOH pallet in 1 liter water.

MIX DESIGN

In this research the mix design of the geo-polymer concrete was taken the concrete mix design developed by H. Hardjasaputra as can be seen in the table 2 [4]. There are 6 types of concrete mix design with differences in NaOH Molarity from 2M until 12M. The authors have used the geopolymer concrete mix design based on 6M NaOH Molarity with targeted Normal concrete strength (15 MPa-20 MPa)

MIXING AND CURING CONCRETE

Mixing of specimens concrete

The first process of geo-polymer concrete mixing is the process to mix alkaline activators consisting of NaOH solution and Na2SiO3 gel with the fly ash in the concrete mixer. After the geo-polymer concrete paste is well mixed, then the fine and coarse aggregates can be mixed together thoroughly. Table-3 shows the scheme of the number of the concrete cylinders 15 cm x 30 cm specimens for each planned steam temperature and duration of research.

Steam curing of the geo-polymer concrete specimens

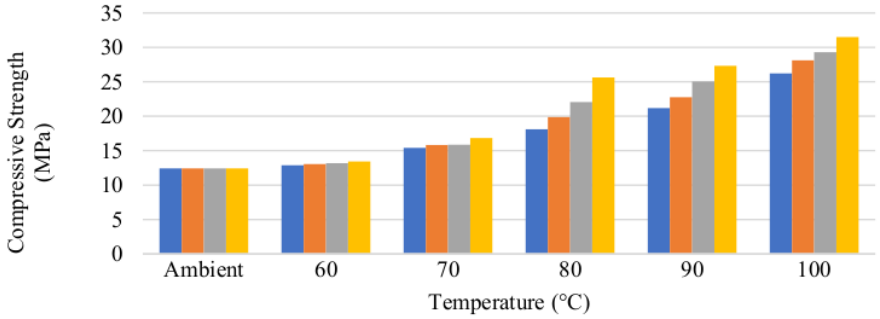
There were two types of concrete curing, which will be applied for all the geo-polymer concrete specimens. 3 concrete cylinder specimens were cured just in room temperature, and the other 60 concrete cylinder specimens were cured under varieties of steam duration and temperature in steam chamber. They were placed in steam chamber and the temperature of the steam chamber were controlled to be 60 °C, 70 °C, 80 °C, 90 °C and 100 °C. The duration of steam curing was taken for 1, 2, 3 and 4 hours. The steam curing was conducted if the concrete cylinder specimens age were already 24 hours. Figure-2 shows the steam chamber, which is equipped with the steam temperature controller.

Table-2. Geopolymer concrete mix design (kg/m3) [4].

No	Material		NaOH Molarity					
			2M	4M	6M	8M	12M	16M
1	Coarse Aggregate	(kg)	849.06	850.84	852.46	853.95	1131.88	1133.70
2	Fine Aggregate	(kg)	723.28	724.79	726.17	727.44	610.03	611.01
3	Fly Ash	(kg)	467.82	468.80	469.69	470.51	429.51	430.20
4	Na_2SiO_3	(kg)	178.94	179.32	179.66	179.97	161.07	161.33
5	NaOH NaOH Pallet	(kg)	4.41	8.37	11.98	15.30	19.01	23.82
	Water	(kg)	55.23	51.40	47.91	44.69	34.68	29.95
	Total	(kg)	2278.75	2283.51	2287.87	2291.87	2386.18	2390.01

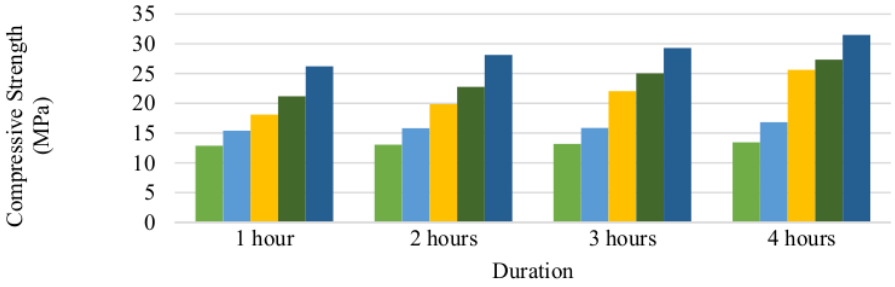
Table-3. The Number of Concrete specimens.

Steam curing duration	Temperature (°C)					
	Non Steam (25)	60	70	80	90	100
1 hour	3	3	3	3	3	3
2 hours	3	3	3	3	3	3
3 hours	3	3	3	3	3	3
4 hours	3	3	3	3	3	3



	Ambient	60	70	80	90	100
Duration 1 hour	12.43	12.88	15.40	18.10	21.18	26.23
Duration 2 hours	12.43	13.06	15.82	19.87	22.77	28.13
Duration 3 hours	12.43	13.18	15.86	22.05	25.04	29.30
Duration 4 hours	12.43	13.44	16.83	25.63	27.33	31.50

Figure-3. Effect of curing duration to the concrete strength.



	1 hour	2 hours	3 hours	4 hours
Temperature (°C) 60	12.88	13.06	13.18	13.44
Temperature (°C) 70	15.40	15.82	15.86	16.83
Temperature (°C) 80	18.10	19.87	22.05	25.63
Temperature (°C) 90	21.18	22.77	25.04	27.33
Temperature (°C) 100	26.23	28.13	29.30	31.50

Figure-4. Effect of curing temperature to the concrete strength.

RESULT AND DISCUSSION

Impact of steam curing duration to the concrete compressive strength

Figure-3 shows the impact of steam curing duration to the concrete compressive strength at age 28 days. It shows that the increasing of concrete strength for the specimens with steam curing 60 °C is not significant for the duration 1 to 4 hours steam curing. The duration of steam curing will be more effective for the steam temperature 80 °C, 90 °C and 100 °C. The 4 hours duration of the steam curing under these steam temperatures could increase the compressive strength up to 30 % compared to 1 hour steam curing duration.

Effect of steam curing temperature to the concrete compressive strength

Figure-4 shows the impact of steam temperature to the concrete compressive strength at age 28 days. It showed that the steam temperature had a big impact to the increasing of concrete strength. Higher steam curing temperature will result higher concrete strength. Only with 1 hour steam curing duration under 100 °C steam temperature the concrete compressive strength could achieved up to 200 % higher strength than the 60 °C steam temperature. See the figure 4 at 1st histogram (12,88 MPa to be 26.33 MPa). The effort to take longer duration time up to 4 hours showed less effective in increasing the compressive strength.

CONCLUSIONS

The temperature and duration of steam curing have significant effect to increasing the compressive strength of geopolymer concrete. Steam curing temperature has bigger impact in increasing the compressive strength compared to curing duration. In curing temperature of 100 °C only with steam curing duration of 1 hour, the compressive strength can increase up to 200 % compared to steam temperature 60 °C. It can be concluded that the high curing temperature can reduce the curing duration in geo-polymer concrete production. It can be concluded that for the best achievement of geo-polymer concrete curing, the steam curing temperature should be taken 80 °C - 100 °C and the steam curing duration should be enough 1hour to 2 hours.

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