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FIRE RESISTANCE TESTING OF GEOPOLYMER CONCRETE WITH FIRE-RETARDANT COATING AGENT

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ABSTRACT

This research was conducted to determine the effect of increasing temperature on the compressive strength of geopolymer concrete. The specimens used in this study is cylindrical concrete with a diameter of 150 mm and a height of 300 mm and the design compressive strength, f'c is 30 MPa. The variable in this study was the molarity of the NaOH solution in the geopolymer with variations of 4M, 6M, and 8M. Before the compressive strength test, some of the specimens were burned at a temperature of 10000C. In this study, some of the specimens are coated with fire-retardant additives on its surface. The results of this study indicate that the 8M NaoH geopolymer concrete with fire-retardant coating shows highest residual compressive strength at 54.7 %. It can be stated that the molarity value of NaOH and fire-retardant additive coating will be able to provide geopolymer concrete structure resistance to elevated temperature due to fire accident.

Keywords: concrete, geopolymer, molarity, temperature, fire-retardant.

INTRODUCTION

Indonesia is one of the countries with the highest population density in the world. This is also followed by the development of infrastructure development which has increased. Concrete is an important construction material as a material to support infrastructure development needs. Most of the infrastructure construction in Indonesia, whether in the form of high-rise buildings, bridges, dams or airports is made of concrete.

Along with infrastructure development, several problems have emerged, such as the unbalanced rate of infrastructure growth with the development of regulations in the field of fire safety. According to Mantelan (2019) this unbalanced growth rate will eventually cause a large number of building fires [1]. Jakarta as the capital city of Indonesia is one of the most densely populated cities in the world. In 2020 the DKI Jakarta Provincial Fire and Rescue Service reported that there were 243 fires accident or an average of 4 fires accident every day [2]. Fires in buildings can cause various kinds of structural damage, even the heaviest damage is broken or chipped concrete so that the steel reinforcement appears, or even the reinforcement in the concrete is broken or bent and the core concrete can be destroyed.

Arioz (2007), said that concrete has a fairly good ability to withstand the temperature rise that occurs due to fire, because it has a low thermal conductivity [3]. However, according to Neville (2002), at temperatures above 300oC, in general, concrete will begin to experience strength degradation [4]. Several attempts were made to maintain the strength of concrete at high temperatures, among others, by replacing cement with pozzolanic materials [5]. Luhar (2021), said nowadays, the use of geopolymer materials as a heat resistant cement and concrete in tunnels, high-rise buildings, fire-proof panels, refractory, foundries, aeroplanes, ships, etc. is found increased due to their extraordinary resistance against thermal and fire [6]. Better adhesion of geopolymer concrete with steel is informed by several researchers ([7]-[9]). The addition of slag into the concrete mix up to 65% has also been shown to improve the performance of concrete that has been exposed to temperatures above 400oC [10]. In addition, Adefemi et al. [11]also suggested the use of Carbid Waste up to 10% to increase fire resistance up to 14% compared to normal concrete at temperatures up to 500oC.

In addition to the problems mentioned above, there are other problems with concrete, namely the effect of making concrete using Portland cement as raw material. The increasing use of Portland Cement is also getting a lot of attention because it produces greenhouse gas emissions of CO2. This gas is released into the atmosphere freely can cause environmental damage, including global warming. The 2015 United Nations Conference on Climate Change, which produced the Paris Global Warming Agreement, was committed to keeping the world temperature rise at no more than 2oC (two degrees Celsius) in the middle of the 21st century.

This means that every country must take concrete actions so that in the mid-21st century Zero Green House Emission CO2 can be achieved [8,9]. One of the innovations that is now attracting the attention of many researchers is the use of concrete without cement or known as geopolymer concrete. According to Davidovits (1994), geopolymer concrete is a concrete made from natural materials as a binder which has a high silica and alumina content [14]. The content of alumina and silica needs to be dissolved in an alkaline solution so that it can produce a chemical process that can be used as a substitute for binders in concrete mixtures. In addition, other materials used as geopolymer concrete are waste from the coal combustion process (fly ash) so that this geopolymer concrete is environmentally friendly.

In addition, one of the advantages possessed by geopolymer concrete is its fire resistance. Cheng (2003), stated that it is certain that geopolymer concrete has physical, mechanical, and fire resistance characteristics, this also depends on the chemical composition that reacts on the geopolymer [15]. In the manufacture of geopolymers, it was found that the content of K2O in the system plays an important role. With increasing K2O content, the setting time can be increased, the compressive strength can be increased, and the fire resistance characteristics can also be improved.

This study aims to determine the effect of adding a fire-retardant coating additive to geopolymer concrete exposed to high temperatures due to combustion.

METHODOLOGY

Materials and Mix Design

To investigate the compressive strength of geopolymer concrete, some specimens are casted. The specimens are concrete cylinders with 15 cm in diameter and 30 cm in height which are tested at age of 28 days. The specimens that were 28 days old were subjected to a combustion test, and then the remaining compressive strength values were tested. As a comparison, some of the specimens were coated with fire-retardant additives.

The materials used in this research meet some specific standards, either in Indonesia or international. The fly ash used in this mixture comes from Paiton in East Java. Fly ash was tested using Scanning Electron Microscopy (SEM), and X-Ray Fluorescence (XRF). From the results of the two tests, fly ash in this study is categorized as class F fly ash, based on ASTM C618 [16]. Table-1 shows the chemical composition of fly ash obtained from the XRF test results.

The coarse and fine aggregates used in this study came from Sudamanik, Banten, Indonesia. Tests on the physical properties of aggregates are carried out according to ASTM C33/C33M - 18 Standard Specification for Concrete Aggregates [17]. Table-2 shows the physical properties of the aggregates used in this study.

Geopolymer concrete mixtures are designed to achieve the concrete compressive strength of f'_c= 30 MPa. The design slump value is set at 7-10 cm. Concrete mixture proportion is designed under the Indonesian provisions of SNI 7656:2012, "Provisions for Proportioning Normal Concrete Mixture" [18]. Three types of NaOH molarity were used in the mixed design, namely 4M, 6M, and 8M NaOH. The material proportions required per m^3 including the weight of Fly Ash, coarse aggregate, fine aggregate, Na_2SiO_3, NaOH and water are shown in the Table-3.

Table-1. Result of X-Ray Flourecence (XRF).

Compound Name	Concentration (%)
SiO_2	37,385
Fe_2O_3	25,223
CaO	14,084
Al_2SiO_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

Table 2. Physical properties of coarse and fine aggregate

Properties	CA	FA
Unit weight	2,53	2,52
Specific Gravity	1,44	1,41
Materials Finer than 75-m	0,91	3,66
Absorption	2,61	2,78
Abrasion Test	19,89	-
Fineness Modulus	7,81	3,15

Table-3. Concrete mix design (in kg/m^3).

Material	4 M	6 M	8 M
Fine Aggregate	676.95	676.95	676.95
Coarse Aggregate	1152.64	1152.64	1152.64
Fly Ash	366.93	366.93	366.93
Na_2SiO_3	137.6	137.6	137.6
NaOH	6.42	9.2	11.69
Water	39.45	36.69	34.17

In this study, the specimens were cured in two stages, the first stage after the concrete was released from the mold. The concrete would be heated in an oven at 80^{o}C for 4 hours. The second stage, the concrete will be removed from the oven and left in a room with a normal temperature until the time of testing. Figure-1 shows the curing process of concrete in the oven.

Figure-1. Curing process of geopolymer concrete.

Fire Testing

Fire testing was carried out after the specimens was 28 days old. The fire test was carried out using a furnace as shown in Figure-2. Of the total 18 samples of concrete that were tested for fire, 9 samples were given a fire-retardant coating, and 9 others were not given a fire-retardant coating. The combustion temperature is increased according to ASTM E119 “Standard Test Methods for Fire Tests of Building Construction and Materials”[19]. The temperature test curve is shown in Figure-3.

Figure-2. Furnace box for fire testing.

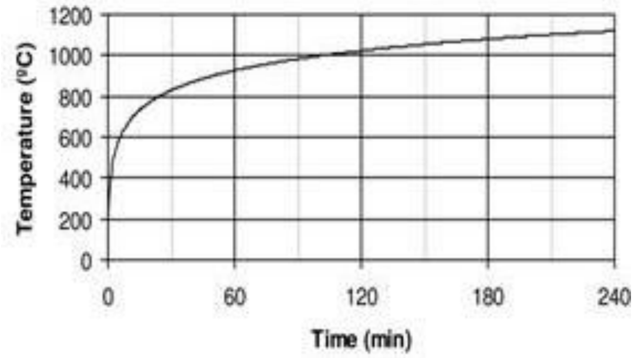

Figure-3. Temperature test curve.

Compressive Strength Test

One of the mechanical properties of concrete is its compressive strength. The compressive strength of geopolymer concrete can be influenced by the age of the geopolymer, the temperature and length of curing time, the water content in the geopolymer. The compressive strength test is carried out according to ASTM C39 “Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens” [20]. The compressive strength of the specimens can be calculated by the equation (1).

$$f'_c = P / A \tag{1}$$

where :

f'_c is concrete compressive strength (N/mm^2)
P is maximum load (N)
A is cross section of specimens (mm^2)

RESULTS AND DISCUSSIONS

Slump Test

The results of the slump test for the three different types of geopolymer concrete mixtures, with different NaOH molarity values, are shown in Figure-4. From these figure, it can be seen that the molarity value has an effect on the slump value, the higher the molarity value, the lower the slump value. It can be explained that the water requirement increases along with the decrease in the NaOH molarity value, so that the concrete mix becomes more liquid. In addition, from the observations, it appears that the mortar with lower molarity shows a tendency to become plastic more quickly.

As shown in Figure-4, the relationship between the molarity of the NaOH solution and the concrete slump value, can be found using the linear regression equation, which gives the result:

$$y = -3x + 28{,}667 \tag{2}$$

where y is the slump value of geopolymer concrete in mm, and x is the molarity of NaOH. The R-square value of the model is 0,9643.

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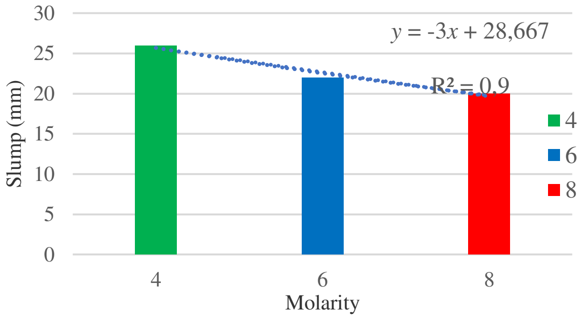

Figure-4. Slump test results.

Compressive Strength Results

The specimen used in this study was cylindrical, with a diameter of 150 mm and a height of 300 mm. There are 3 types of mixtures with different molarity values, a total of 36 samples were used. The compressive strength test was carried out when the concrete was 28 days old, 18 samples undergo the fire test first before the compression test. Three specimen codes are used, namely NC for specimens that are not tested for fire, NCC for specimens that are tested on fire but without being given a fire-retardant coating, and CC for specimens that have undergone a fire test and coated with fire-retardant additive.

The results of the compressive strength testing of all test objects are shown in Table-4 below. Based on the tests that have been carried out, it can be seen that for normal concrete, without fire-test, the targeted f'_c, i.e. 30 MPa, can be achieved by each mixture. Figure 5 shows the comparison of compressive strength results from each molarity of NaoH.

From Figure-5, it can be seen that the compressive strength of the specimens decreased significantly after undergoing the fire test. The value of the compressive strength of the specimens that is given a fire-retardant coating shows a greater value than the compressive strength of the specimens that is not given fire-retardant coating. In addition, it is also seen that the increasing value of NaoH molarity, also increasing the value of the residual compressive strength of the specimens. Furthermore, Figure-6 shows the percentage of residual compressive strength in each test object that has undergone the fire test.

Table-4. Compressive strength test results.

Molarity	Compressive Strength (in MPa)		
	NC	NCC	CC
4M	31.52	8.55	15.42
	30.3	10.7	16.07
	31.77	8.84	14.25
6M	31.43	10.36	13.37
	30.76	10.54	17.33
	31	10.95	16.2
8M	31.95	15.75	17.39
	33.09	16.1	16.26
	32.46	11.75	19.67

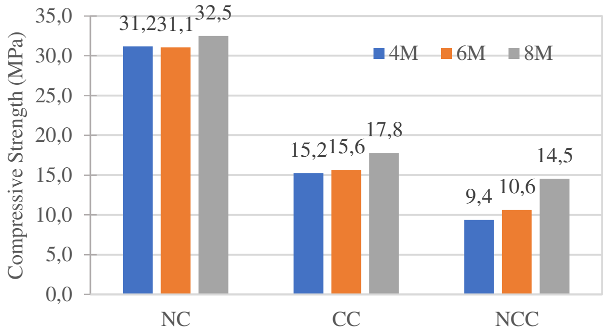

Figure-5. Compressive strength test results.

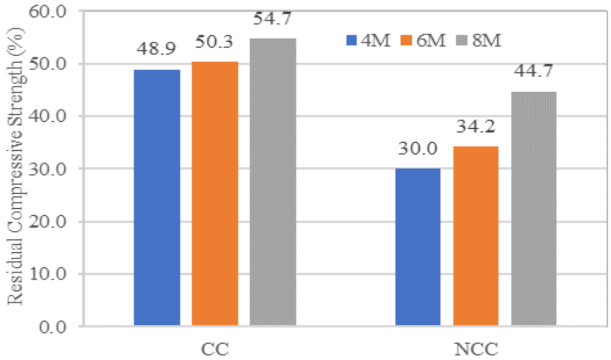

Figure-6. Residual compressive strength.

In addition, in a mixture with a molarity value of 4M, the results showed that after undergoing combustion to a temperature of 1000°C, concrete with fire-retardant coatings have 48.9% residual compressive strength, while concrete without coatings shows less residual compressive strength, i.e. 30 %. For 6M NaoH geopolymer concrete, the results show that after experiencing combustion to a temperature of 1000°C, concrete with fire-retardant coatings have residual compressive strength of 50.3 %, while concrete without coatings the residual compressive strength reach only 34,2%. For 8M NaOH geopolymer concrete, the results showed that after subjected to fire test, concrete that was given a fire-retardant coating have residual compressive strength of 54.7 %, while the concrete without a fire-retardant show less residual compressive strength, i.e 44.7 %

From these results, it can be seen that the molarity of the solution and the addition of fire-retardant coating agents can prevent the rate of decline in the compressive strength of geopolymer concrete. The higher the molarity value, the decrease in post-combustion compressive strength will tend to decrease. In addition, the addition of coating agents has been shown to reduce the decrease in the compressive strength of post-combustion concrete.

CONCLUSIONS

The compressive strength of geopolymer concrete shows that after being burned to a temperature of 1000^{o}C without fire-retardant coating, the concrete compressive strength are decrease, and 8M NaOH has the highest residual compressive strength at 44.7 %. The 8M NaoH geopolymer concrete with fire-retardant coating shows higher residual compressive strength at 54.7 %.

From these results, it can be stated that the molarity value of NaOH and fire-retardant additive coating will be able to provide geopolymer concrete structure resistance to elevated temperature due to fire accident. The slump value will decrease as the NaOH molarity value increases, the relationship between the slump and the molarity of NaOH can be expressed by equation $y = -3x +$ 28,667 where y is the slump value of geopolymer concrete in mm, and x is the molarity of NaOH

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