The Relationship of Temperature and Compressive Strength on Geopolymer Mortar using Fly Ash-Based

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Abstract. Infrastructure development in Indonesia has increased. Therefore, the use of cement has increased as well. For this reason, it is necessary to replace the replacement cement material with environmentally friendly material. Fly ash is one of the waste materials that can be used as a substitute for cement. The purpose of this paper is to determine the compressive strength values of geopolymer mortars using fly ash-based from different Thermal Power Station and to determine the relationship of temperature curing with the compressive strength on geopolymer mortars using fly ash-based. The fly ash used was obtained from two Thermal Power Station in South Sulawesi, Indonesia. The sample is in the form of a cube with 5 cm x 5 cm size, with variations in room temperature; 65°C, 85°C, and 105°C. Activators used were Na2SiO3 and NaOH with 10 M with a ratio of Na2SiO3 per NaOH of 2. Compressive strength tests were carried out at 28 days. From the results of the study that the compressive strength of geopolymer mortar based on fly ash-Thermal Power Station A is higher than the compressive strength value of geopolymer mortar based on fly ash-Thermal Power Station B. The relationship of compressive strength with curing treatment with geopolymer mortar temperature variations is very significant. The higher the temperature, the higher the compressive strength of the mortar.

1. Introduction

The development of construction that utilizes cement material has increased very rapidly. Cement production follows the increasing market demand as we all know that producing cement will have a negative effect, which is to create CO2 gas. CO2 gas will be delivered during the production of cement, which is very damaging to the air environment. Now it is necessary to find alternatives to cement replacement. Cement replacement is expected to be environmentally friendly and sustainable material.

Researchers have done a lot of research on materials that can replace part or all of cement as a binder in making concrete. As for some materials that have the same cement composition that has been studied by several previous researchers, namely rice husk ash, bagasse ash, and flies ash. Rice husk ash and bagasse ash can be used as cement substitution in concrete. Rice husk ash cannot be used as a substitute for whole cement, but rice husk ash can only replace part of the cement as much as it should not exceed 10% of the amount of cement [1]. Fly ash is a material that can be used as a substitute for cement entirely with a polymerization system [2,3]. Fly ash is an industrial waste that
can be obtained from side products in thermal power plants that use coal as fuel. Fly ash has the same pozzolan properties as cement so that it can replace cement in concrete construction. Fly ash contains SiO$_2$ and Al$_2$O$_3$, which can react with calcium hydroxide, so fly ash can be used instead of cement [4]. The elements fly ash contained can react if given an activator. Activators are single or combined alkaline solutions [5]. It is this alkaline activator that plays an essential role in reacting to the Al and Si elements contained in the fly ash so that it can produce strong polymeric bonds and speed geopolymers up the reaction. The activators commonly used are NaOH (sodium hydroxide), Na$_2$SiO$_3$ (sodium silicate), KOH (potassium hydroxide) with reactive aluminosilicate material [6–9]. The age and temperature variables of curing have an effect on the compressive strength of mortar or geopolymer concrete samples [10]. Besides this, the concentration of activator also has a considerable effect on strength rather than curing temperature and the amount of curing time [5,6,11,12].

Mixtures that have been prepared to make geopolymer materials can be cured at room/room temperature [13]. However, according to Somna K et al. (2011) that the strength is low in geopolymer materials that use fly ash when using room temperature [9]. As research conducted by Bachtiar, E (2018) that concrete content that is not cured or in other words, concrete is placed following room temperature, the strength decreases [14]. Besides, there have been several previous studies which argued that materials made with the polymerization process could achieve maximum strength if curing at temperatures between 40-90°C or more [15–17].

From the previous studies above that fly ash can replace cement because it has the nature of pozzolan. However, due to the different characteristics of fly ash, it is essential to pay attention to the concentration of the activator used. Besides that, the temperature and the amount of curing time used for the production of geopolymer materials need attention. With this basis, researchers are interested in examining how the temperature relationship used in curing on mortar geopolymer is different at 28 days and 56 days.

2. Materials and methods
The material used in this study uses local materials in South Sulawesi, Indonesia. Local materials used are fly ash, sand, water, and activator. The necessary materials used in the manufacture of Geopolymers consist of coal fly ash waste originating from two different power plants in South Sulawesi, Indonesia. The fly ash used comes from two different Thermal Power Station, namely the Jeneponto Thermal Power Station and the Barru Thermal Power Station. The given name is distinguished, namely, fly ash from the Jeneponto power plant named fly Ash A and fly ash from the Barru power plant are named Fly Ash B.

This study is a continuation of previous research by Bachtiar, E et al. (2018) using the same fly ash [2]. The results of the examination of fly ash characterization used by X-Ray Fluorescence (XRF) analysis can be seen in Table 1.

| Code of Fly Ash | Chemical Composition of Fly Ash (%) |
|----------------|------------------------------------|
| fly ash A      | SiO$_2$ 35.880, Fe$_2$O$_3$ 29.200, CaO 23.520, Al$_2$O$_3$ 9.230, K$_2$O 1.030, TiO$_2$ 0.710, BaO 0.270, ZrO$_2$ 0.054 |
| fly ash B      | SiO$_2$ 41.450, Fe$_2$O$_3$ 25.280, CaO 16.190, Al$_2$O$_3$ 11.060, K$_2$O 1.350, TiO$_2$ 1.050, BaO 0.136, ZrO$_2$ 0.069 |

The activator used is a mixture of NaOH and Na$_2$SiO$_3$. The concentration of NaOH used is a mixture of NaOH and Na$_2$SiO$_3$. The concentration of NaOH used was 10 M; the ratio of Na$_2$SiO$_3$ to NaOH was 2. The ratio of the activator to the binder (fly ash) was 0.3. The ratio between fly ash and sand is 1: 2.75. Samples were made with variations in the type of fly ash and temperature variations during maintenance. Fly ash obtained from Jeneponto Thermal Power Station is coded FA. A and fly ash obtained from Barru Thermal Power Station is coded FA.B. Temperature variation consists of several temperatures, namely room temperature ± 25°C, 65°C, 85°C, and 105°C. Samples were made with 8 (eight) variations namely Geopolymer mortar using A fly ash-based which is a cure at an
ambient temperature of ± 25°C (GM_FA.A_T25); Geopolymer mortar using A fly ash-based which is a cure at 65°C (GM_FA.A_T65); Geopolymer mortar using A fly ash-based which is cured with temperature 85°C (GM_FA.A_T85); Geopolymer mortar using A fly ash-based which is a cure with temperature 105°C (GM_FA.A.T105), Geopolymer mortar using B fly ash-based which is curing air with temperature around ± 25°C (GM_FA.B_T25), Geopolymer mortar using B fly ash-based with temperature 65 (GM_FA.B_T65), Geopolymer mortar using B fly ash-based with heat cure 85°C (GM_FA.B.T85), Geopolymer mortar using B fly ash-based with temperature 105°C (GM_FA.B.T105).

The sample was made in the form of cubes 5 cm x 5 cm x 5 cm. Samples that have been made cured by being inserted in the oven in accordance with a predetermined temperature for 24 hours. Then removed in the oven and treated again with room temperature ± 25°C. Specifically, the samples GM_FA.A_25 and GM_FA.A_25 were not included in the oven, but since they were removed in the mold. They were directly treated with laboratory temperature. Compressive strength testing with the Unit Testing Machine (UTM) is done at the age of 7, 14, 28, and 25 days. Tests are carried out based on SNI 03-6825-2002.

3. Result and discussion

3.1. Development of Compressive Strengths on Geopolymer Mortars

The development of mortar/concrete compressive strength generally increases with age. As previous research on concrete using both seawater and freshwater as its mixing water, the development of compressive strength has a relationship with a very significant age. The relationship of compressive strength and age in self-compacting concrete that uses freshwater/seawater as its mixing water forms a nonlinear regression with a correlation of R close to 1 [18].

Compressive strength values obtained from the test results in the laboratory using the UTM (Unit Test Machine). Sample testing was carried out at 7, 14, 28, and 56 days. The results of research on the average compressive strength of three samples in geopolymer mortar using A fly ash-based and geopolymer mortar using B fly ash-based can be seen in figure 1 and figure 2.

![Figure 1](image-url). Compressive strength development of geopolymer mortar using A fly ash-based (GM_FA.A)

Figure 1 shows the development of the average compressive strength values of the three samples along with the age of the geopolymer mortar samples using A fly ash-based. The development of the 4 sample variations GM_FA.A_TCU, GM_FA.A_T65, GM_FA.A_T85, and GM_FA.A_T105 shows an increase in compressive strength often with increasing age of geopolymer mortar samples. Nonetheless, there are differences in the patterns of increase that vary.
Figure 2. Age relationship to the compressive strength of geopolymer mortars using B fly ash-based (GM_FA.B)

Figure 2 shows the development of the average compressive strength values of the three samples along with the age of the geopolymer mortar samples using B fly ash-based. The development of the 4 sample variations GM_FA.B_TCU, GM_FA.B_T65, GM_FA.B_T85, and GM_FA.B_T105 shows an increase in compressive strength often with increasing age of geopolymer mortar samples. Nonetheless, there are differences in the patterns of increase that vary.

Geopolymer mortars that use A fly ash-based and B fly ash-based have in similarity in increasing compressive strength along with increasing mortar life. As in sameness in the development of mortar/concrete that uses cement, there is an increase along with the increasing age of the mortar/concrete. This means that mortar/concrete that uses cement or flies ash as a binder has similarities in increasing compressive strength along with increasing mortar/concrete age. As Erniati et al. (2018), that there was a significant relationship between age and compressive strength, and the increasing compressive strength of mortar, the higher the age of mortar [19].

3.2. Comparison of Compressive Strength between Geopolymer mortar using A Fly Ash-based and B Fly Ash-based

Comparison between the compressive strength of geopolymer mortar A fly ash-based and geopolymer mortar using B fly ash-based can be seen in figure 3, figure 4, figure 5, and figure 6. From the four pictures, they show how the compressive strength value resulting from the use of fly ash A and fly ash B in making Geopolymer mortars which are curing with variations in temperature and without curing.

Figure 3. Comparison of compressive strength values between geopolymer mortar using A fly ash-based and geopolymer mortar using B fly ash-based with cured of air temperature at ± 25°C.
Figure 3 shows the comparison of fly ash A (GM_FA.A) base Geopolymer mortar is greater than Geopolymer mortar using B fly ash based (GM_FA.B), which is curing with room temperature ± 25°C. It can be seen from the figure that since the age of 7, 14, 28, and 56 days, the compressive strength of GM_FA. A sample is greater than the GM_FA.B sample. The average percentage difference in the value of GM_FA.B compressive strength against GM_FA_A compressive strength is 70.56%.

![Figure 3](image)

**Figure 4.** Comparison of compressive strength values between Geopolymer Mortar using A fly ash-based and B fly ash-based with cured at 65°C.

Figure 4 shows the comparison of geopolymer mortar using A fly ash-based (GM_FA.A) is greater than geopolymer mortar using B fly ash-based (GM_FA.B) which is curing at 65°C. Seen in the figure, that at 7, 14, 28 and 56 days old, the compressive strength of the GM_FA. A sample is greater than the GM_FA.B sample. The average percentage difference in the value of the compressive strength of GM_FA.B against the compressive strength of GM_FA_A is 78.31%.

![Figure 4](image)

**GM_C65**: Geopolymer Mortar cured of temperature at 65°C

**GM_FA.A, GM_FA.B**: Geopolymer Mortar using A fly ash-based and B fly ash-based

**Figure 5.** Comparison of compressive strength values between Geopolymer Mortar using A fly ash-based and Geopolymer Mortar using B fly ash-based with cured at 85°C.

Figure 5 shows the comparison of geopolymer mortar using A fly ash-based (GM_FA.A) is greater than geopolymer mortar using B fly ash-based (GM_FA.B) which is curing at 85°C. Seen in the figure, that at 7, 14, 28 and 56 days old, the compressive strength of the GM_FA. A sample is greater than the GM_FA.B sample.

![Figure 5](image)

**GM_C85**: Geopolymer Mortar, cured of temperature at 85°C

**GM_FA.A, GM_FA.B**: Geopolymer Mortar using A fly ash-based and B fly ash-based

Figure 5 shows the comparison of geopolymer mortar GE_FA. A is greater than geopolymer mortar GM_FA.B which is curing at 85°C. It can be seen from the figure that since the age of 7, 14, 28, and 56 days, the compressive strength of GM_FA. A sample is greater than the GM_FA.B sample.
The average percentage difference in the value of GM_FA.B compressive strength against GM_FA_A compressive strength is 78.04%.

Figure 6. Comparison of compressive strength values between geopolymer mortar using A fly Ash based and Geopolymer Mortar B fly Ash-based with cured of temperature at 105°C.

Figure 6 shows the comparison of geopolymer mortar GE_FA. A is greater than geopolymer mortar GM_FA.B which is curing at 105°C. Seen in the figure, that since the age of 7, 14, 28 and 56 days, the compressive strength of the GM_FA. A sample is greater than the GM_FA.B sample. The average percentage is a difference in the value of the compressive strength of GM_FA.B against the compressive strength of GM_FA_A is 77.61%.

The results showed that the compressive strength value produced on geopolymer mortar A fly ash based is greater than B fly ash-based. This can be seen in Fig. 3, Fig. 4, Fig. 5, and Fig. 6. The compressive strength value of geopolymer mortar using A fly ash-based is greater than geopolymer mortar using B fly ash-based at all temperature variations ± 25°C, 65°C, 85°C, and 105°C. The average percentage is the difference in compressive strength of fly ash B against fly ash A due to differences in temperature variations is 76.13%. This difference is probably due to the material of the fly ash, as with the chemical composition of fly ash A and fly ash B, which are different, as in Table 1. Comparison of the amount of chemical composition between SiO2: Fe2O3: CaO: Al2O3 in A fly ash is 1: 1.23 : 1.53: 3.89, while for B fly ash is 1: 1.64: 2.56: 3.75. From this comparison, it can be seen that the CaO content in fly ash B is very large on the value of SiO2.

3.3. Relationship between Temperature and Compressive strength Value of Geopolymer mortar.
The relationship of temperature used in treating geopolymer mortar with compressive strength of geopolymer mortar produced can be seen in Fig. 7 and 8. Fig. 7 shows the temperature relationship used in curing geopolymer mortar and compressive strength of geopolymer mortar at 28 days. While Fig. 8 shows the relationship of the temperature used in curing geopolymer mortar and compressive strength of geopolymer mortar at 56 days.
Fig. 7 (a) shows the relationship between the temperature used for curing geopolymer mortar with the compressive strength of at 28 days. Geopolymer mortar using A fly ash A-based (GM_FA.A_28) produces a nonlinear equation $y = 5.0466 \times 0.338$ and the square root of the value $\sqrt{R}$ which results in a correlation value of $R = 0.9967$. While the geopolymer mortar using B fly ash-based (GM_FA.B_28) produces a nonlinear equation $y = 1.9651 \times 0.2106$ and the square root of the value $\sqrt{R}$ which results in a correlation value of $R = 0.9607$. Fig. 7 (b) shows the relationship between the temperature used for curing geopolymor mortar with the compressive strength of geopolymer mortar at 56 days. For Geopolymer mortar using A fly ash-based (GM_FA.A_56) base produces a nonlinear equation with $y = 5.0774 \times 0.3479$ and the square root of the value $\sqrt{R}$ which results in a correlation value of $R = 0.9828$. While the geopolymer mortar using B fly ash-based (GM_FA.B_56) produces a nonlinear equation $y = 1.7939 \times 0.2496$ and the square root of the value $\sqrt{R}$ which results in a correlation value of $R = 0.9540$. From the two non-linear equations, the correlation value that is close to number 1 is obtained, so that the relationship between the temperature used for curing geopolitical mortar with the pressure of geopolymor mortar at 28 or 56 days is very significant. The higher the temperature used in curing the geopolymor mortar, the higher the compressive strength of the geopolymor mortar produced.

The curing of the material greatly influences the strength of the material. As the Research by Erniati et al. (2018) said that the self-compacting without curing produced the pressure decreased. A Geopolymer mortar has been removed from the mold. It needs nursing care, which is different from mortar, which uses cement as its cylinder. Generally, for mortar and concrete that use cement as a binder, the treatment is either soaked or watered with water. It is different from Geopolymer mortar. It acts as a radiant heat [14]. As a study by Gökhan Görhan and Gökhan Kürklü (2014) have conducted studies on the effect of curing NaOH concentrations at temperatures of 65°C and 85°C, with the result that NaOH concentrations have a clear effect on the mortar properties cured at 85°C [13]. Optimal NaOH concentrations obtained from research by Gökhan Görhan and Gökhan Kürklü (2014) were concentrated in NaOH 6 M, until treatment with temperatures of 85°C for 24 hours [13]. From this, it can be seen that the temperature used in geopolitical mortar curing has a great influence on the pressure of geopolymer mortar greatly. Curing both the mortar and the concrete influences the microstructure of a mortar material. The polymerization process is not maximized in geopolitical mortar working without treatment with the required temperature. The same thing with mortar/ concrete without curing, the hydration process is not maximized so that the structure of the material is not good, and microstructure is too influential in its mechanical properties, porosity, and absorption [20,21].
4. Conclusion
Geopolymer mortar by using fly ash which chemical composition is different, it will produce different strengths of geopolymer mortar as well. The development of compressive strength in mortar geopolymer was along with age. The more increasing age of the geopolitcal mortar has, the more increased the height of the pressure. The relationship between the temperature used in geopolymer mortar treatment with the geopolymer mortar compressive strength is very significant, that is, the higher the treatment temperature, the higher the compressive strength of mortar geopolymer.

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