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# The Application of Different Curing Models to the Strength Development of High Calcium Fly Ash Geopolymer Incorporating Limestone

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**Abstract.** One of the issues in geopolymer specimen is the requirement for heat curing treatment temperature. The use of a material with high calcium content is one alternative to overcome this problem. However, the addition of calcium tends to alter the basic geopolymer matrix being similar to the basic matrix in normal concrete, which requires a water addition during curing process. This research aims to investigate the effect of different curing models to the strength development of fly ash geopolymer specimens with limestone inclusion. Class C fly ash was used as primary material. The blended sodium silicate and 10 Molar NaOH were used as alkaline activator. Three different curing models were applied, i.e. 24-hours water immersion, watering once a day, and watering twice a day, respectively. The results show that the addition of 30% limestone under watering once a day curing models gives the best result with the strength of 32.54 MPa. The limestone inclusion significantly affects the strength development of geopolymer mortar strength. It also slightly increases the water requirement during curing process to achieve its structural integrity. This is might be attributes to the changes in geopolymer matrix due to the addition of limestone.

## 1. Introduction

The use of geopolymer as an alternative material of concrete without cement has been widely studied [1-3]. Geopolymer, which was coined by Davidovits [4], is a material based on fly ash or other material containing silica and aluminate compounds reacted with an alkaline activator. This material is more environmentally friendly material compared to that normal Portland Cement (PC)-based concrete. According to Davidovits [5], the production of 1 ton cement also releases approximately 1 ton of CO<sub>2</sub>, which leads to the concern of global warming problem. In addition, geopolymer does not require a water immersion during curing process due to the matrix characteristic of geopolymer, which is different from the PC concrete. The geopolymer matrix is a polymer compound consisting of silicate and aluminate forming the Si-O-Al geopolymer matrix bonds [5]. However, the main issue of geopolymer is the need for high temperature during the curing process. Geopolymer are not be able to achieve its structural integrity at normal temperatures. This high temperature is required to speed up the process of silicate (Si) and aluminate (Al) reaction in forming the geopolymer matrix. This might attribute to the low calcium content in fly ash material [6-8]. The use of a high calcium compound material is one alternative to overcome this problem [9-10].

However, the limestone addition in geopolymer will promote a new reaction between silicate and calcium. The silicate contents in geopolymer will divide between the two reactions: the reaction between



silicate and aluminate forms a geopolymer matrix, and the reaction between silicate and calcium forms C-S-H gel, similar to that matrix in PC concrete [11-12]. The appearance of the second reaction raises a question as to whether the geopolymer incorporating limestone needs water during the curing process due to the matrix similarity to that of PC concrete.

This paper reports the investigation results on the effect of different curing models to the strength development of fly ash geopolymer specimens with limestone inclusion. Class C fly ash was used as primary material. The blended sodium silicate and 10 Molar sodium hydroxide (NaOH) were used as alkaline activator. The ratios between fly ash and limestone addition were 1.0:0.0, 0.9:0.1, 0.8:0.2, 0.7:0.3, 0.6:0.4, and 0.5:0.5, respectively. Three different water curing models were applied, i.e. 24-hours under water immersion, watered once a day, and watered twice a day. The strength developments of geopolymer specimens were measured in accordance with ASTM Standard [13].

## 2. Research Methodology

### 2.1. Materials

High calcium fly ash from Paiton coal power plant Indonesia was used as fully cement replacement material. It also has a low silicate (12.63%) and high ferrite (51.74%) contents. The chemical compositions of high fly ash are listed in Table 1. While, limestone or calcium carbonate ( $\text{CaCO}_3$ ) was obtained from limestone material distributor. Both material compositions were identified by X-Ray Fluorescence (XRF) test using PANalytical test equipment type Minipal 4.

**Table 1.** Chemical composition of high calcium fly ash and limestone (mass %).

Materials	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	K <sub>2</sub> O	TiO <sub>2</sub>	Mn <sub>2</sub> O <sub>3</sub>	SO <sub>3</sub>
Fly ash class C	15.02	5.31	52.68	17.97	0.05	1.73	0.86	0.39	0.18
Limestone	-	-	0.29	98.42	-	-	-	-	-

The CaO content of 17.97% (> 10%), the total content of SiO<sub>2</sub>+Al<sub>2</sub>O<sub>3</sub>+ Fe<sub>2</sub>O<sub>3</sub> of 73.01% (> 50%), and the SO<sub>3</sub> content of 0.18% categorized the fly ash as high calcium class C fly ash in accordance with ASTM C618 [14]. A blended sodium hydroxide (NaOH) solution and sodium silicate was used as activators.

### 2.2. Mix design

The mix design details of high calcium class fly ash geopolymer incorporating limestone (LFAG) mortars are shown in Table 2.

**Table 2.** Mix proportions of fly ash geopolymer incorporating limestone (LFAG) mortars

Mixture	Portland Cement	Lime stone	Fly ash	Fine sand	Sodium silicate	NaOH 10 M	Water	Curing models
PC	1	-	-	3.0	-	-	0.45	CM1-24h
LFAG 1	-	0.1	0.9	3.0	0.21	0.14	-	CM1-24h, CM2-1X, CM3-2X
LFAG 2	-	0.2	0.8	3.0	0.21	0.14	-	CM1-24h, CM2-1X, CM3-2X
LFAG 3	-	0.3	0.7	3.0	0.21	0.14	-	CM1-24h, CM2-1X, CM3-2X
LFAG 4	-	0.4	0.6	3.0	0.21	0.14	-	CM1-24h, CM2-1X, CM3-2X

Mixture	Portland Cement	Lime stone	Fly ash	Fine sand	Sodium silicate	NaOH 10 M	Water	Curing models
<b>LFAG5</b>	-	0.5	0.5	3.0	0.21	0.14	-	CM1-24h, CM2-1X, CM3-2X

### 2.3. Curing models

Three different curing models were applied for all LFAG mortar specimens. Curing Model 1 (CM1-24h) was applied by immersing the LFAG mortar for 24-hours until prior to be testing. Curing model 2 (CM2-1X) was performed by watering the LFAG specimens once a day, while Curing model 3 was carried out by watering the LFAG specimens twice a day. For control specimen (PC), Curing Model 1 was applied.

### 2.4. Testing mortar specimens

The LFAG mortar specimens were prepared by 5 x 5 x 5 cm<sup>3</sup> cube steel molds. The strength of LFAG mortars were tested by compressive strength test. Universal Testing Machine (UTM) equipment was used in accordance with ASTM C109 [13]. Three mortar geopolymer cubes were tested at the age of 28 days after casting.

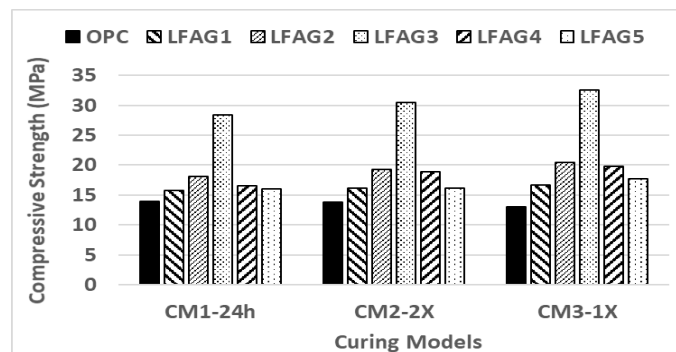
## 3. Results and Discussions

### 3.1. Strength development of LFAG mortars

Table 3 shows the strength development of LFAG mortar specimens for all mixes at 28 days. All geopolymer incorporating limestone specimens exhibit a higher compressive strength compared to that PC-cement based concrete. The highest compressive strength of 32.54 MPa was achieved by LFAG3 specimen with 30% limestone addition by watering the specimen once a day.

**Table 3.** Compressive strength of LFAG mortars at 28 days with different curing models

Mixture	Compressive strength at 28 days (MPa)		
	Curing CM1-24h	Curing CM2-2X	Curing CM3-1X
<b>PC</b>	13.96	13.80	12.97
<b>LFAG1</b>	15.82	16.11	16.65
<b>LFAG2</b>	18.14	19.26	20.50
<b>LFAG3</b>	28.44	30.50	32.54
<b>LFAG4</b>	16.51	18.92	19.81
<b>LFAG5</b>	15.96	16.20	17.70

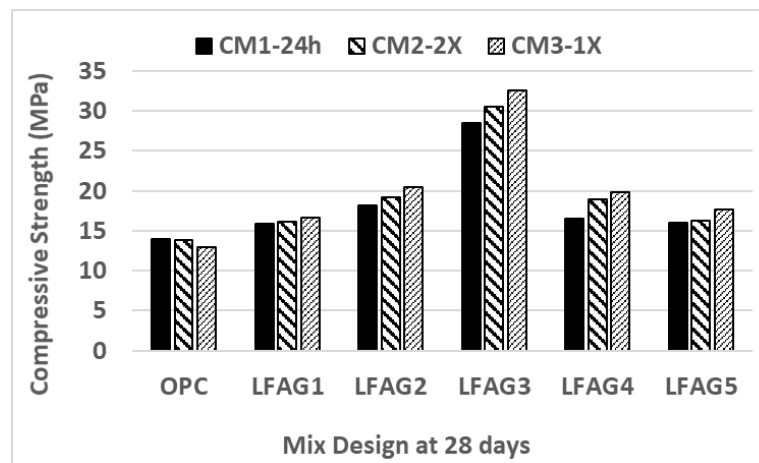


**Figure 1.** The effect of limestone on strength development of LFAG specimens at different curing models at 28 days

Figure 1 demonstrates the effect of limestone inclusion on strength properties of LFAG mortar specimens under with three different curing models, i.e. CM1-24h, CM2-2X, and CM3-1X. The results show that the addition of limestone significantly affects the strength of LFAG specimens. All curing models exhibits a similar strength development patterns along with the limestone inclusion. The highest compressive strength was achieved by LFAG3 with the strength of 28.44 MPa, 30.50 MPa, and 32.54 MPa in all curing models, respectively. However, the further addition of limestone more than 30% tends to reduce strength of LFAG. This might be attributed to the excess un-reacted calcium, which form a calcium hydroxide compounds. According to Sinsiri et al. [15], the calcium hydroxide compound tends to have a concrete expansion and creates a crack, which might lead to the strength reduction at further calcium inclusion. In addition, despite LFAG1 (strength of 15.82 MPa) and LFAG2 (strength of 15.96 MPa) specimens demonstrate the lowest compressive strength test result, LFAG 1 and LFAG 2 still exhibit a slightly better strength performance compared to that PC mortar control.

### 3.2. Effect of curing models on strength development

The effect of different curing models on strength development of LFAG mortar specimens are shown in Figure 2.



**Figure 2.** The effect of curing models on strength development of LFAG mortars at 28 days

Figure 2 demonstrates that the duration of curing process does not significantly affect the strength development of geopolymer incorporating limestone. The longer duration of curing process tends to inhibit the strength development of LFAG specimens. Although the limestone inclusion significantly affects the strength development of LFAG, all mixes under curing model CM1-24h (water immersion for 24-hours) display the lowest compressive strength with the lowest strength of 15.82 MPa. The reduction of water curing duration from 24-hours (CM1-24h) to twice a day watering (CM2-2X) improve the strength of LFAG specimens. A further shorter water curing duration shows a significant increase of strength from 28.44 MPa (LFAG3, CM1-24h) to 32.54 MPa (LFAG3, CM3-1X) with increase of 12.60%. Longer water curing duration, particularly under water immersion curing models, tends to inhibit the strength development of high calcium fly ash geopolymer. According to Rangan [16], water plays no significant role in the chemical reaction in geopolymer mixture. It only contributes to the workability of the geopolymer mixture. This is in contrary to the chemical reaction of water in PC control.

## 4. Conclusions

The effect of different curing models on strength development of high calcium fly ash geopolymer mortar specimens incorporating limestone were experimentally investigated at 28 days age. The main

conclusions that may be drawn based on this research are, (1) The inclusion of limestone significantly affects the strength development of high calcium fly ash geopolymer specimens cured at normal temperature, (2) The optimum strength was achieved by 30% limestone inclusion at 28 days. Further limestone addition tends to reduce the strength of geopolymer incorporating limestone, (3) The use of water curing models does not significantly govern the strength properties of geopolymer incorporating limestone, and (4) The highest compressive strength was obtained by curing model 2 that was performed by watering the LFAG specimens once a day. The longer curing process tends to inhibit the strength development of geopolymer incorporating limestone.

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