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The Effect of Lime Addition on the Setting Time and Strength of Ambient Cured Fly Ash Based Geopolymer Binder

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Abstract. One of the limitations of geopolymer as the alternative binders in concrete is the necessity of heat curing. This study aimed to produce fly ash geopolymer binder subjected to ambient curing by adding a small proportion of lime and varying the activator dosage. The Class F fly ash from Mpanau coal-fired power plant was mixed with alkaline solution consists of sodium silicate and sodium hydroxide with Na_2O dosage of 5%, 7%, and 9%. To achieve ambient cured paste, 8%, 9%, and 10% slaked lime was added as the substitute for the fly ash. The setting time test was conducted for each mix and the compressive strength was performed at age of 7, 14 and 28 days. The test result shows that the setting time of the fly ash based geopolymer paste can be controlled by adding a small proportion of slaked lime. The addition of lime increased strength but decreased the setting time.

1 Introduction

Portland cement is the most widely used building material and largely contributes to greenhouse gas emissions. High energy consumption and large amount of raw materials are needed to produce Portland cement, and on the other side significant amount of CO_2 released into the atmosphere. However, as the main ingredient in the manufacture of mortar and concrete, the use of Portland cement in large quantities is unavoidable. Therefore, it is necessary to find an alternative to cement with more environmentally friendly materials.

One alterative is in the form of inorganic polymer binder (geopolymer) that uses materials containing silico-aluminate precursors and inorganic alkali solution as an activator. Geopolymer potentially replace cement as the main ingredient in a concrete mix due to the characteristics of geopolymer concrete, strength and durability which is similar to concrete using Portland cement binder [1]. Low calcium fly ash is a suitable material for geopolymer precursor due to its availability and can be used directly without additional process (burning, grinding etc.)

However previous research shows that one of challenges in the application of low calcium fly ash based geopolymer as binder is its setting process needs relatively high curing temperature 60°C-120°C for 6 - 24 hours [2-7]. This conditions limit the application of geopolymer for precast purposes whilst for normal concrete, the binder should be able to set in room temperature. Addition of calcium to produce ambient cured geopolymer binder has been conducted elsewhere [8-13].

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2 Materials and Methods

Class F fly ash taken from Mpanau power plant and slaked lime were used as binder materials. The chemical composition of the binders can be found in Table 1. Blended sodium silicate solution (15.4% Na_2O ; 32.33% SiO_2) and 15M sodium hydroxide solution were used as chemical activator. The activator dosages (mass ratios of Na_2O in activator solution to binders) were 5%, 7%, and 9% and the modulus of activator (mass ratios of SiO_2 to Na_2O) was kept constant at 1.00. To achieve ambient cured paste, 8%, 9%, and 10% slaked lime was added as the substitute for the fly ash.

Table 1. Properties of the binder materials.

Chemical compositions	Fly ash (%)	Slaked lime (%)
SiO_2	56.04	-
Fe_2O_3	21.27	0.35
AlO_3	12.99	-
CaO	5.18	85.04
K_2O	1.62	1.03
TiO_2	0.90	0.03
MnO	0.26	-
P_2O_5	0.25	-
SrO	-	2.17
Cl	-	1.06
Other oxides	0.57	0.1
LOI	0.94	10.25
Total	100.0	100.0

Initially, water to solid ratio (w/s) of 3.4 were used to prepare the geopolymer paste specimens, however the 7% specimen set too fast and could not be cast into the mold, therefore additional specimens of 7% dosage were prepared using 0.4 w/s. The water content in the w/s calculation is the total water content in sodium silicate solution, sodium hydroxide solution and additional water, whilst the solids are the fly ash, and the solid parts from the sodium silicate and the sodium hydroxide solution. The mix proportions of the geopolymer paste are given in Table 2.

Table 2(a). Mix proportions of geopolymer paste.

Specimens	Na_2O dosage (%)	Binder		Water to solid ratio
		Slaked lime (%)	Fly ash (%)	
G5C8	5	8	92	0.340
G5C9		9	91	0.340
G5C10		10	90	0.340
G7C8	7	8	92	0.340
G7C9		9	91	0.340
G7C10		10	90	0.340

Table 2(b). Mix proportions of geopolymer paste.

Specimens	Na_2O dosage (%)	Binder		Water to solid ratio
		Slaked lime (%)	Fly ash (%)	
G7C8*		8	92	0.400
G7C9*	7	9	91	0.400
G7C10*		10	90	0.400
G9C8		8	92	0.340
G9C9	9	9	91	0.340
G9C10		10	90	0.340

*modified w/s ratio

Fly ash and slaked lime was dry mixed until uniform and mixed with the activator solution for 11 minutes. The paste specimens were then molded into 2.5 cm diameter x 5 cm height plastic cylinders mold. All specimens were cured at an ambient temperature of 30°C and humidity level of 60%. All specimens were demolded and left in the room until the day of testing. The setting time of the geopolymer paste was measured using a Vicat needle according to ASTM C 191-04. Compressive strength tests were conducted in accordance with ASTM C 39 at 7, 14, and 28 days.

3 Results and Discussion

3.1 Effect of lime addition on setting time material

As can be seen in Figure 1, increasing the lime proportion from 8% to 10% significantly decreased the setting time. Different trend was observed on the variation of Na_2O dosages.

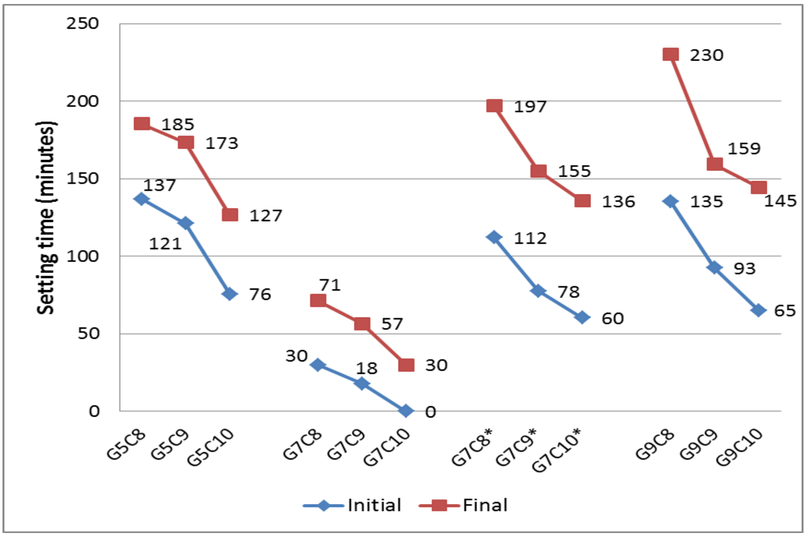

Figure 1. Setting time of geopolymer paste.

At constant w/s ratio, increasing the dosage from 5% to 7% decreased the setting time but further increase from 7% to 9% increased the setting time. The 7% Na_2O specimens with 0.34 w/s ratio had a dry consistency and it was difficult to be molded, as such the w/s ratio was increased to 0.4 which is denoted as G7C8*, G7C9*, and G7C10*. However, even with the increased w/s ratio, the initial setting time was still lower although the final setting time was a little bit higher than the 5% specimens. The cause of this exception in the case of the 7% specimen is not clear. However, it can be said that the setting properties would be influenced in accordance with the interaction between the activator solution and the slaked lime in the binder.

The exact mechanism of hardening of geopolymer with lime addition is not clearly established, however according to Temuujin [12] it depends on many parameters including the aluminosilicate precursors, alkaline activator type and their concentrations and curing temperature. It can be seen from figure 1 that there is a certain value where the increased of Na_2O dosage decreased setting time but beyond the level further increase in Na_2O dosage will increase setting time. The addition of small amount of calcium to the alkali activated binder could accelerate setting, however when the level of addition was high, the effects would be accelerating or retarding depend on the composition of activator, the dissolved species from the solid, and the nature of the calcium [14].

3.2 Effect of lime addition on strength development

Figure 2 shows the compressive strength of fly ash/lime based geopolymer paste with time. At 5% Na_2O, the compressive strength was very low especially for the specimens with 8% and 9% lime. Increasing proportion of lime by 1% increased the strength, although larger increase was obtained by increasing Na_2O dosage. The compressive strength at 7 and 14 days were very low, it was 0 MPa for 5% Na_2O with 8% and 9% lime, 2 – 3 MPa for 7% Na_2O and 4 – 6 MPa for 9% Na_2O dosage. The higher 28 days strength, 8 – 12 MPa was found on the 9% Na_2O specimens. It was also found by other researcher that addition of the hydrated lime up to 10% by weight of binder will improve the mechanical properties of geopolymer paste when cured with water under ambient temperature [12].

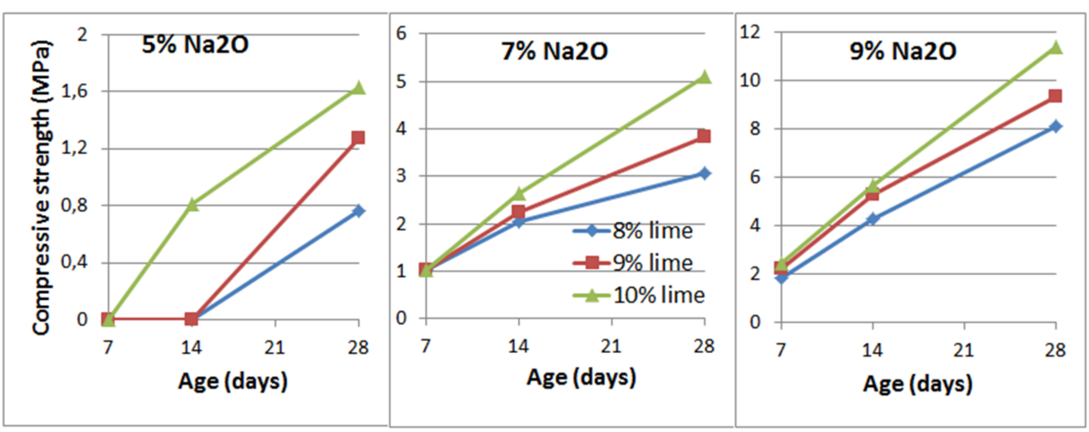

Figure 2. Strength development of geopolymer paste.

4 Conclusions

The test result shows that the setting time of the class F fly ash based geopolymer paste can be controlled by adding a small proportion of slaked lime. The addition of lime increases the strength but decreases the setting time. There is a certain value where the increase of Na_2O dosage decrease setting time. However beyond the level, further increase in Na_2O dosage will increase setting time.

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