Effect of Temperature on Compressive Strength of Fly Ash-based Geopolymer Mortar

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ABSTRACT: The purpose of this study is to observe the compressive strength of fly ash-based geopolymer mortar. Sodium hydroxide and sodium silicate solution were used as alkaline activators. The ratios between solution (sodium hydroxide, sodium silicate solution and water) to fly ash were 0.376, 0.386, 0.396 and 0.416 by weight. Mortar cubes of 5 × 5 × 5 cm were cast with a ratio of fly ash to sand of 1 : 2.75 by weight. Mixing temperatures were varied as 25 ˚C, and 45 ˚C. After casting, the samples were divided into two parts. The first was cured at 30˚C and the other was cured at 60 ˚C for 24 hrs. Both were continuously kept at 30 ^{o}C until the tested dates. The compressive strength test was performed at 1, 7 and 28 days. The study showed that higher mixing temperature and higher curing temperature exhibited higher compressive strength in early stages and still develop with longer curing. When the samples were mixed at 25 ˚C and cured at 30˚C, the compressive strength was low at an early stage, but gradually increased and finally, had as high strength as those of higher temperature cured mortars.

KEYWORDS: Fly ash, Geopolymer, effect of temperature

1. INTRODUCTION

Fly ash or coal ash has been partly used to replace cement in concrete industry for a long period because it contributes the beneficial properties to concrete. Fly ash is often incorporated into the ordinary Portland cement as a value adding filler. In this system, fly ash is not highly reactive, but has been shown to improve properties such as workability and durability. Up to 55% of the cement binder can be replaced with fly ash to make normal or high performance concrete. The idea to make concrete without manufactured cement has been pursued but not yet succeeded.

Geopolymer, a new material, gradually earns an interest from material scientists. Fly ash is to replace totally manufactured cement to make concrete-like material. This will turn the construction material to the new era. Geopolymer is an inorganic alumino-silicate polymer synthesized from predominantly silicon and aluminium material of geological origin or by-product materials such as fly ash. Fly ash-based geopolymer is made by mixing fly ash with sodium silicate solution and highly caustic hydroxide solution and cured at room temperature or at higher temperature. Geopolymer was first used by Davidovits [1]. Utilization of such a material to produce the valuable-added products is of considerable commercial interest.

The exact mechanism by which geopolymer setting and hardening occur is not fully understood. Most proposed mechanisms consist of a dissolution, transportation or poly-condensation. Temperature environment is considered as the most factor that affects to any polymerization.

The purpose of this research is to study the effect of mixing temperature and curing temperature on the compressive strength of mortars

2. EXPERIMENTAL PROGRAM

2.1 Materials

Locally available class F fly ash (FA), with specific surface area of 2120 cm^2/g was used as the base material in this work. The chemical composition of the fly ash is given in Table 1. Commercial grade sodium hydroxide in flake form (98% purity) conformed to TIS:150-2518 and sodium silicate solutions conformed to TIS: 433-2539 (Na_2O=14.7%, SiO_2=29.4%, Water = 55.9%)

were used as the alkali activators. Tap water was used in this test.

Table 1 Chemical Composition of Fly Ash (%)

SiO_2	Al_2O_3	Fe_2O_3	CaO	SO_3	LOI
46.2	26.4	10.7	7.6	1.8	0.2

River sand in saturated surface dry condition was employed. All are shown in Figure 1.

2.2 Specimen Preparation

Cube mortar 5x5x5 cm was used in this test. The fly ash to sand ratio was 1:2.75 by weight and the solution to fly ash ratios [Water + NaOH + Na_2O SiO_2] / FA were varied as 0.376, 0.386, 0.396 and 0.416, respectively. An amount of sodium hydroxide and sodium silicate solution were kept constant at 9.6% and 24% at all mixes. The temperature of these solutions was as ambient (25 ^oC) and heated up to 45 ^oC to mix with fly ash. Table 2 shows the mix proportions. All are cured at 2 different temperatures as 30°C and 60°C for 24 hours and room temperature after since until reached the tested days. Aspect of geopolymeric mortar is shown in Figure 2.

Figure 1 Ingredients of Geopolymeric Mortar

Figure 2 Geopolymeric Mortar

Table 2 Detail of Mixes

MIX ID.	FA (g)	Sand (g)	Added Water (g)	NaOH (14 M) (g)	Sodium Silicate Solution (Na_2O=14.7%, SiO_2=29.4%, H_2O = 55.9%) (g)	Total Water Content (g)	Mixing Temp. C°
A	100	275	4	9.6	24	21.64	25
B	100	275	5	9.6	24	22.64	25
C	100	275	6	9.6	24	23.64	25
D	100	275	8	9.6	24	25.64	25
E	100	275	4	9.6	24	21.64	45
F	100	275	5	9.6	24	22.64	45
G	100	275	6	9.6	24	23.64	45
H	100	275	8	9.6	24	25.64	45

3 RESULTS AND DISCUSSION

Broken samples collected from this test are shown in Figure 3. Results and discussion are as follows:

3.1 Compressive Strength of 60 °C Cured Mortars

Mortars which were cured at the temperature of 60 °C for 24 hours had been mixed at two conditions such as; at 25, and 45 °C. Compressive strengths of those were tabulated in Table 3. Compressive strength gain pattern of the mortars was seen the same as traditional mortars. This is not normal compared to other literatures [2,3,4]. Most geopolymeric mortar exhibited very fast compressive strength gain. Almost 100% of its strength should be gain within 7 days. Moreover, strength of mortars in this research was considered low, compared to others' researches [2,3,4]. However, it is shown by Table 3 and Figure 4 and 5 that mixing temperature influences compressive strength of mortar. As the temperature increases, early compressive strength increases as well. For example, sample 25A60 exhibited compressive strength of 93.5 ksc at 1 day. The same mix could give compressive strength of 110.9 ksc when mixing temperature increased to 45 °C. This behavior could be found at all mixes. This effect is not fully recognized at 7 days and 28 days. Some of them have no significant difference in term of compressive strength. It should be more data to conclude that higher curing temperature increases both early and late compressive strength. The highest compressive strength of this series is 327.4 ksc of 45G60 sample.

Table 3 Compressive Strength of Mortar Cured at 60 ˚C

MIX ID.*	Mixing Temp. (˚C)	Compressive Strength (ksc)		
		1 Day	7 Days	28 Days
25A60	25	93.5	137.6	171.1
25B60		102.1	142.7	170.6
25C60		122.9	167.2	207.6
25D60		82.7	167.4	171.7
45E60	45	110.9	155.6	173.9
45F60		149.4	170.0	177.2
45G60		187.1	189.1	327.4
45H60		139.4	168.2	181.3

* First 2 digits = mixing temperature in °C and
Last 2 digits = curing temperature in °C and
The middle identifies mix number

3.2 Compressive Strength of 30 °C Cured Mortars

To compare the effect of curing temperature, mixture B and D were mixed by the same procedure as those in item 3.1 but the samples were left at 30 °C as demolded until the tested days. Results are shown in Table 4 and Figure 6. It is obvious that early compressive strength of the mortars were significantly lower than those cured in 60 °C. For example, sample 25B30 exhibited only 37.1 ksc after 1 day. This is lower than 25B60 about 2.5 times. While sample 45F30 is much more obvious, it gave compressive strength about 8.6 times less than 45F60 at 1 day. It can be concluded that higher curing temperature increases early compressive strength of geopolymeric mortars. The results agreed with Hardjito et al. [5].

At 7 and 28 days of curing, it is surprised that the polymerization reaction still continues. Compressive strength of 25B30 mortar reached 304.0 ksc at 28 days. It is noted that no Portland cement and special curing involved in this mixture.

It should be noted from this test that effect of higher mixing temperature is not always appreciated to compressive strength of mortars. Sample 25B30 and 25D30 gave compressive strength of 37.1 and 31.9 ksc at 1 day, respectively. Compressive strengths of the same mixes were reduced to 17.3 and 10.1 ksc at the same age when mixing temperature was increased to 45 °C. It can be explained that when the mixtures were heated up from 25 °C to 30 °C or 25 °C and 45 °C to 60 °C, compressive strength of mortars tends to increase. Whereas, the mixtures were cooled down from 45 °C to 30 °C, compressive strength of mortars tends to decrease.

Table 4 Compressive Strength of Mortar Cured at 30 °C

MIX ID.*	Mixing Temp. (˚C)	Compressive Strength (kg /cm^2)		
		1 Day	7 Days	28 Days
25B30	25	37.1	185.6	304. 0
25D30		31.9	166.6	207.1
45F30	45	17.3	100.3	201.0
45H30		10.1	34.9	121.9

* First 2 digits = mixing temperature in °C and
Last 2 digits = curing temperature in °C and
The middle identifies mix number

Figure 3 Geopolymeric Mortars

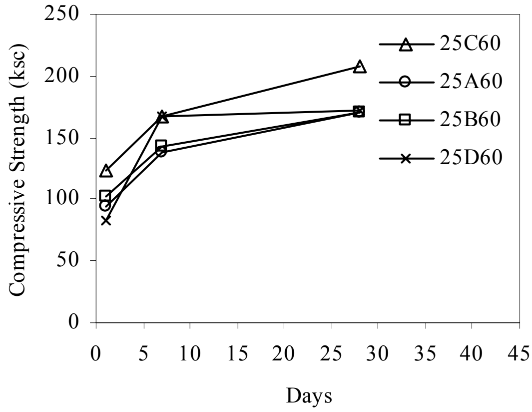

Figure 4 Compressive Strength Geopolymeric mortar mixed at 25 ^oC and cured at 60 ^oC

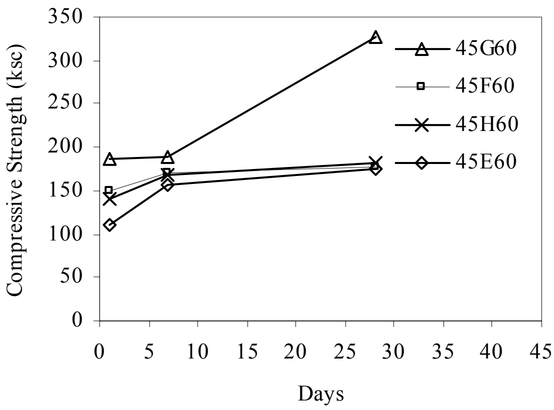

Figure 5 Compressive Strength Geopolymeric mortar mixed at 45 ^oC and cured at 60 ^oC

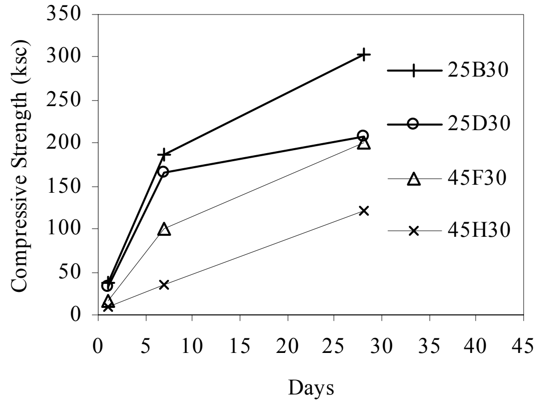

Figure 6 Compressive Strength Geopolymeric mortar mixed at 45 ^oC and cured at 30 ^oC

4. CONCLUSIONS

From the results, the following conclusions can be drawn.

1. Higher curing temperature can enhance early compressive strength of geopolymeric mortars.
2. Higher compressive strength of geopolymeric mortars do not directly depend on higher mixing temperature. High curing temperature must be involved.
3. Curing time does affect compressive strength development of mortar.

5. REFERENCES

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