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ENGINEERING PROPERTIES OF MAE MOH FLY ASH GEOPOLYMER CONCRETE

Smith Songpiriyakij
King Mongkut's Institute of Technology North Bangkok, Thailand

Abstract
Fly ash-based geopolymer concrete and mortar were studied in this work. Sodium hydroxide and sodium silicate solution were used as alkali activators in 7 different miwx proportions. Water was added to control the concrete slump at 200 $\pm$ 25 mm. The same geopolymer pastes of concrete were mixed with sand at the ratio of 1: 2.75 to make mortar. Cube concretes 100 x 100 x 100 mm were used for compressive strength test. All specimens were cured at 2 different temperatures, viz. 25^{o}C and 60 ^{o}C for 24 hours. The specimens were then left at 25^{o}C until the test age. Mortar bars 25 x 25 x 300 mm were cast to study the length change after immersion in 5% sodium sulfate solution. Mortar cubes 50 x 50 x 50 mm were also used to study the change in compressive strength after immersion in 5% $MgSO_4$ solution. Mortars were cured at 60 ^{o}C for 24 hours and left at 25^{o}C. The results show that high alkalis activated geopolymer can be used as cementitious material in place of Portland cement for making concrete. MIX 5 in this study with high Na_2O: SiO_2 and NaOH molarity exhibits 3 day compressive strength higher than 30 MPa and has good resistance to sulfate attack similar to Portland cement type V mortar.

1. Introduction

High alkali activated fly ash concrete gradually earns an interest from material scientists [1,2]. Fly ash is to totally replace manufactured cement to make concrete-like material. This will turn the construction material to the new era. It is an inorganic alumino-silicate polymer synthesized from predominantly silicon and aluminium material of geological origin or by-product materials such as fly ash. Sometimes, it is called geopolymer. Fly ash-based geopolymer is made by mixing fly ash with sodium silicate solution and highly caustic hydroxide solution and cured at 25^{o}C or at higher temperature.

Geopolymer term was first introduced by Davidovits [3]. Utilization of such a material to produce the valuable-added products is of considerable commercial interest.

The exact mechanism on geopolymer setting and hardening is not fully understood. Most proposed mechanisms consist of a dissolution, transportation or poly-condensation. Chemical composition, pressure, and temperature are considered important factors affecting the polymerization. It is normal that different sources of fly ash give different geopolymer properties.

The major source of fly ash in Thailand is from Mae Moh in the northern part of the country. The ash is now used for concrete construction though out the country. Being a lignite fly ash, it contains a high percentage of CaO[4]. It can, however, be classified as type F complied with ASTM C 618. This ash has been successfully used to produce geopolymer

The purpose of this research is to study the effect of chemical composition and curing temperature on the compressive strength of concrete

2. Experimental program

2.1 Materials

Class F fly ash (FA) from Mae Moh power station, 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 solution conformed to TIS: 433-2539 (Na_2O=14.7%, SiO_2=29.4%, Water = 55.9%) were used as the alkali activators.

Table 1 - Chemical composition of fly ash (%)

SiO_2	Al_2O_3	Fe_2O_3	CaO	SO_3	LOI
45.32	20.92	10.7	7.6	1.8	0.2

Concrete proportioning was first trialed following ACI 211.1.. River sand and limestone (max size = 3/8 in.) in saturated surface dry condition were used. The mixtures were adjusted by adding water to obtain the slump of 200 $\pm$ 25 mm. Tap water was used in this test. Table 2 shows mix proportion of concrete.

The same pastes in concrete mixtures were used to make mortar with a fly ash to sand ratio of 1: 2.75. Portland cement type I and V mortars were also made for comparison. The details of mixes are shown in Table 3.

2.2 Mixing and curing

All mixtures were mixed at room temperature. The temperature of all solutions was as ambient (25 ^oC). The specimens were wrapped by plastic sheet to prevent loss of moisture. The samples were cured at 2 different temperatures. The first was cured at 25^oC (-R suffix) and the other was cured at 60 ^oC (-C suffix). They were temperature-cured for 24 hours then left at 25^oC until the tested date.

Table 2 – Mix proportions of concretes

Mix ID	W/B	FA	Agg.	S	W	$Na_2O : SiO_2$	NaOH
		kg/m^3					
1	0.40	514	1056	700	95	127	55(15 M)
2	0.42	514	1056	700	119	79	79(15 M)
3	0.41	514	1056	700	119	79	79(20 M)
4	0.47	475	1056	700	79	158	79(15 M)
5	0.46	475	1056	700	79	158	79(20 M)
6	0.48	475	1056	700	79	119	119(15 M)
7	0.46	475	1056	700	79	119	119(20 M)

w/b = water to binder ratio, FA = fly ash, Agg. = Aggregate, S= sand, W= water

Table 3 - Mix proportions of mortars (g)

Mix ID	Cement	Fly Ash	Sand	$Na_2O : SiO_2$	NaOH		Water	w / b
					15 M	20 M		
1M	0	486.5	1338	113.96	55.3		90.3	0.40
2M	0	486.5	1338	74.2	74.2		112.7	0.42
3M	0	486.5	1338	74.2		74.2	113.05	0.41
4M	0	449.4	1236	149.8	74.2		74.2	0.472
5M	0	449.4	1236	149.8		74.2	74.2	0.46
6M	0	449.4	1236	112.7	112.7		74.2	0.475
7M	0	449.4	1236	112.7		112.7	74.2	0.457
I-40	700	0	1925				280	0.40
V-40	700	0	1925				280	0.40

2.3 Test procedures

Compressive strength of concretes was tested at the age of 1, 3, 7, and 28 days. The mortars immersed in water and 5% $MgSO_4$ solution were tested for compressive strength at 28, 60 and 90 days in accordance with ASTM C 109. Length change of mortar bars immersed in 5% Na_2SO_4 solution was measured as prescribed in ASTM C 490-96. All mortar specimens were cured in the same conditions and immersed in 5% sodium sulfate and 5% magnesium sulfate solution at the age of 2 days.

3. Results and Discussion

Compressive strength of concrete

Compressive strengths of concretes were shown in Table-4. It was found that MIXes 1, 2 and 3 exhibited very low compressive strengths and were not suitable to use as structural concrete even thought they were cured at 60 ^oC. MIXes 4, 5, 6, and 7 gave considerable compressive strengths. For example, MIX 5 with 60^oC cured was 25.7 MPa at one day and increased to 35.8 MPa within 28 days,. It should be noted that no Portland cement involved in these mixtures. Fig.1 clearly shows that higher curing temperature significantly affects the early strength of concrete more than that of the later age. At one day, compressive strength of MIX 5 in normal room condition is 3.4 MPa and it increases to 25.7 MPa when the curing temperature is elevated to 60 ^oC. It is about 7 times higher than those curing at 25^oC.

Table 4 - Compressive strength of concrete

MIX ID	Compressive strength (MPa)							
	Cured at temperature				Cured at 60^oC			
	1-day	3-day	7-day	28-day	1-day	3-day	7-day	28-day
1	0.9	1.3	2.4	3.1	4.1	4.4	4.9	6.6
2	0.6	1.6	2.8	10.9	7.8	10.7	11.6	13.7
3	0.7	0.8	1.6	11.5	8.6	9.4	13.4	16.6
4	1.7	5.5	12.4	26.6	21.1	22.7	25.5	28.9
5	3.4	8.3	16.3	29.7	25.7	32.1	32.9	35.8
6	1.8	4.5	9.1	15.8	17.5	18.7	21.9	24.4
7	1.8	5.4	10.6	21.8	21.6	24.7	27.0	28.4

In order to observe the influence of chemical composition on the compressive strength of concrete, chemical ratios of paste were tabulated in Table 5. Each term is calculated from both solid and liquid parts of the paste. For example, SiO_2 was obtained from both fly ash and sodium silicate solution.

It can be observed that when the Na_2O/SiO_2 increases from 0.115 to 0.182, compressive strength increases as well. However, when this ratio reaches 0.213, compressive strength of concrete becomes lower. The Na_2O/Al_2O_3 ratios can be observed in the same way. As this term increases, the compressive strength increases as well. After the ratio reaches 0.818, compressive strength tends to drop down. It also shows that the increase of water to Na_2O ratio reduces the compressive strength of concrete. Similar result has also reported [4].

Compressive strength of mortars immersed in 5% $MgSO_4$ solution

Compressive strengths of mortars are slightly different to those of concretes. However, MIX 5M still gave the highest compressive strength. To compare with Portland cement type I and type V mortar with w/c = 0.4, it is clear that the compressive strength of mortar I-40 and V-40 immersed in water gave higher strength than other geopolymer mortars indicating that it can withstand $MgSO_4$ attack better than the other mixes. Compressive strength of MIX-5M was 19.8, 22.4 and 25.6 MPa at 28, 60 and 90 days, respectively. After they were immersed in $MgSO_4$, the strength slightly reduced to 17.9, 23.3 and 24.2 MPa at the same ages. MIX V-40 showed good performance as well.

Compressive strength of MIX I-40 reduced dramatically from 35.2 MPa in water cured condition to 23.0 MPa after immersed in 5% $MgSO_4$. Bakharev [5] has found similar results that geopolymer was able to gain compressive strength as age increased in sulphate environment.

Table 5 - Chemical composition ratios of fly ash paste versus compressive strength of concrete at 28 days

MIX ID.	Chemical composition ratios				Compressive strength at 28 days (MPa)	
	Na_2O/SiO_2	SiO_2/Al_2O_3	H_2O/Na_2O	Na_2O/Al_2O_3	25 °C	60°C
1	0.115	4.276	22.135	0.492	3.1	6.6
2	0.139	4.051	20.249	0.563	10.9	13.7
3	0.160	4.051	17.173	0.647	11.5	16.6
4	0.162	4.488	17.648	0.727	26.6	28.9
5	0.182	4.488	15.304	0.818	29.7	35.8
6	0.213	4.285	14.080	0.914	15.8	24.4
7	0.245	4.285	11.804	1.051	21.8	28.4

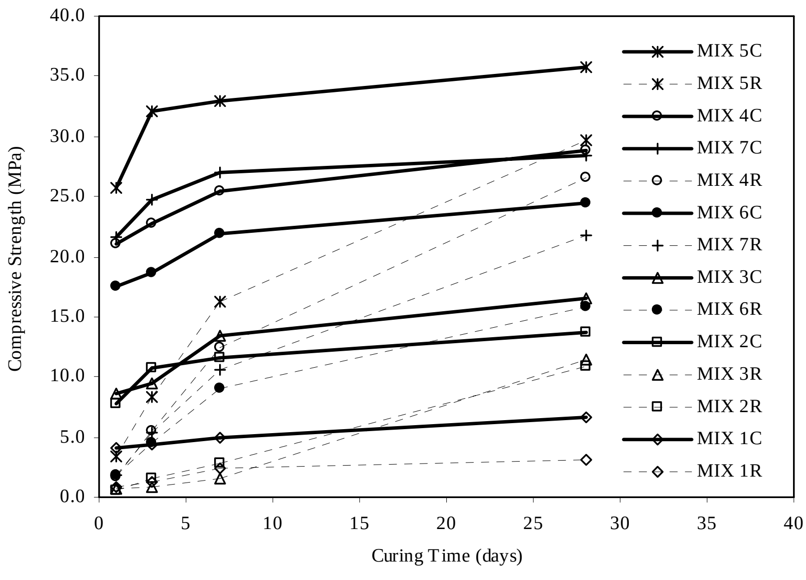

Figure 1 – Relationship between compressive strength and curing time of concrete

Length change of mortar bar exposed to Na_2SO_4

Mortar bars made by Portland cement type I and V were cast with w/c = 0.40 as control samples to compare with those of geopolymer mortars. All samples were soaked in Na_2SO_4 right after demolding. The results are shown in Fig. 2. It reveals that sample I-40 expand at highest rate among all samples. It expands about 0.1% of the original length. MIXes 5M, 6M and V-40 showed better performance. They expand in the range of 0.028 to 0.035% of the original.

Table 6 - Compressive strength of mortars

Mix ID	Compressive strength (MPa) of mortars after immersed					
	28-day		60-day		90-day	
	Water	$MgSO_4$	Water	$MgSO_4$	Water	$MgSO_4$
1M	15.7	**13.2**	17.3	**15.3**	17.7	**15.4**
2M	5.8	**5.0**	6.3	**4.6**	6.6	**2.3**
3M	4.1	**3.9**	5.0	**3.7**	6.2	**2.6**
4M	21.2	**20.4**	21.5	**20.7**	23.2	**14.7**
5M	19.8	**17.9**	22.4	**23.3**	25.6	**24.2**
6M	22.0	**13.8**	23.8	**15.5**	23.4	**15.2**
7M	11.2	**10.9**	12.8	**12.0**	14.4	**12.6**
I-40	31.6	**32.0**	33.1	**27.0**	35.2	**23.0**
V-40	31.5	**31.8**	34.0	**31.1**	37.0	**29.0**

4. Conclusions

From the test results, the following conclusions can be drawn:

1. Curing temperature at 60 ^oC affects early compressive strength of concretes more than those at a later age.
2. Compressive strength of geopolymer concrete seems to depend on chemical ratios of the paste.
3. Length change test of geopolymer mortars show satisfactory performance similar to Portland cement type V mortar.
4. MIX 5 in this work with high Na_2O : SiO_2 and NaOH molarity shows adequate performance in both compressive strength and resistance to sulfate attack.

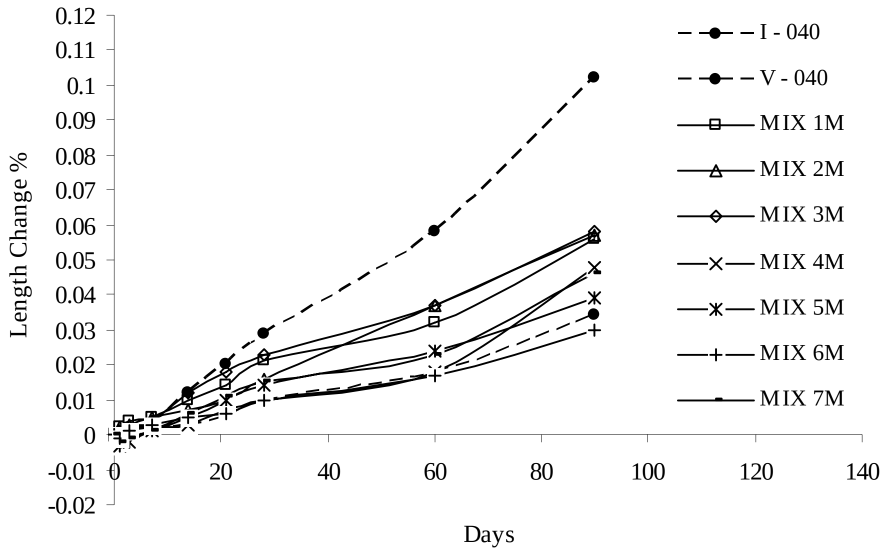

Figure 2 – Length change of mortar bars due to immersed in 5% Na_2SO_4

5. References

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