Effect of Alkaline Activators on the Mechanical Properties of Geopolymer Mortar

Mohamed Rabie
m.rabie@qu.edu.qa
Department of Civil and Architectural Engineering, Qatar University, Doha, Qatar

Mohammad R. Irshidat
mirshidat@qu.edu.qa
Center for Advanced Materials, Qatar University, Doha, Qatar

Nasser Al Nuaimi
anasser@qu.edu.qa
Center for Advanced Materials, Qatar University, Doha, Qatar

ABSTRACT

Geopolymerization is a process where silica and alumina rich source materials turn into excellent binding materials by the aid of alkali solutions. Materials such as fly ash are by-products in energy power plants. Fly ash is classified based on its constituent materials. Fly ash class F mainly consists of alumina and silica. Compressive strength of class F fly ash geopolymer mortar is influenced by many factors such as fluid to binder ratio, Na2SiO3/NaOH ratio, curing duration, curing temperatures and molarity of the activator solution. The present study investigates the effect of the fluid to binder ratio and Na2SiO3/NaOH ratio on the compressive strength of geopolymer mortar. The curing temperature was fixed to 80 °C. The curing durations investigated was 24h. For each combination, three cubes with dimensions of 50 x 50 x 50 mm were casted. After heat curing in the laboratory oven, the samples were tested on a universal testing machine for the compressive strength. The results showed very high early compressive strength of 66.39 MPa for samples cured at 80 °C and for a duration of 24 hr. The significance of the present study is that it will allow for establishing methods for production of high strength geopolymer mortar that can be used in civil engineering applications, in addition to the environmental advantages of using such source materials to produce binding materials with outstanding mechanical properties.

Keywords: Geopolymer; Fluid to binder ratio; Activator solution; Na2SiO3/NaOH ratio

1 INTRODUCTION

Cement production process requires immense amount of energy and is accountable for 7% carbon dioxide emissions to the atmosphere. It is estimated that production of 1 ton of cement is equivalent to 1 ton of CO2 (Alnahhal et al., 2017; Ng et al., 2018; Singh et al., 2015). There has been an increasing demand to develop a new binding material that can partially or fully replace cement in mortar and concrete. Geopolymerization is a process where three dimensional polymeric chain rings consisting of Si-O-Al-O are formed by alkali, activating the source material that are rich with silica and alumina (Rattanasak & Chindaprasirt, 2009). Binding materials prepared by the geopolymerization process have proven its competency to provide good binding materials, achieving similar or better mechanical properties than cement-based building materials (Görür et al., 2015).

Activator solutions used in production of geopolymer mortar and concrete are mainly potassium and sodium alkaline solutions. The mechanical strength of geopolymer mortar are affected by many factors such as fluid to binder ratio, curing temperature, molarity of the activator solution and the ratio of the Na_2SiO_3 to NaOH. Similarly, the mechanical properties of cement-based mortar and concrete are highly affected by w/c ratio (Rattanasak & Chindaprasirt, 2009). Recent literature has proved that fly ash is efficiently activated by sodium based alkaline activators (Singh et al., 2015).

The present study investigates the effect of fluid to fly ash ratio with multiple variations of the ratio between sodium silicate to sodium hydroxide to the compressive strength of geopolymer mortar.

2 MATERIALS AND METHODS

2.1 Materials

2.1.1 Fly ash

Class F fly ash with chemical compositions is mentioned in Table 1 below complying with QCS 2014 standards. Fly ash passing sieve #200 (75 µm) was used in the mix design for geopolymer mortar.

Table 1: Chemical composition of Fly ash %

Oxide	SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	SO_3	K_2O	Na_2O	Cl-	LOI
%	49.9	17.1	11.8	7.83	4.9	0.42	0.2772	0.1428	0.011	3.5

2.1.2 Alkaline activators

Sodium hydroxide: 12M Sodium hydroxide (NaOH) solution was prepared by mixing 480 gm of NaOH pellets with purity of 99% in one liter of solution. Sodium silicate: Sodium Silicate (Na_2SiO_3) solution was prepared by mixing 47% (Na_2SiO_3) to 53% water. The solutions were prepared separately one day before casting the specimens. Both Sodium hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3) were mixed together prior to mixing it with source materials to produce GPM.

2.1.3 Sand

Commercially available silica sand with grade of 20-30 sand was used conforming to (ASTM Standard C778 2017) for mortar mixing.

2.2 Experimental program

Eight mix designs were prepared to test the compressive strength of GPM. The proportions of the mix designs are depicted in the Table 2.

Table 2: Mix designs for GPM mortar

Sample ID	Fly ash (gm)	Sand (gm)	Alkaline activator/fly ash ratio	Na2sio3/NaOH ratio	Alkaline activator		Added water (ml)
					NaOH solution (gm)	Na2SiO3 solution (gm)	
F1N1	266.7	733.33	0.4	1	53.33	53.33	20
F1N2	266.7	733.33	0.4	1.5	42.67	64.00	20
F1N3	266.7	733.33	0.4	2	35.56	71.11	20
F1N4	266.7	733.33	0.4	2.5	30.48	76.19	20
F2N1	266.7	733.33	0.5	1	66.67	66.67	-
F2N2	266.7	733.33	0.5	1.5	53.33	80.00	-
F2N3	266.7	733.33	0.5	2	44.44	88.89	-
F2N4	266.7	733.33	0.5	2.5	38.10	95.24	-

Fly ash and sand were mixed for 2 minutes at low speed to ensure a homogenous mixture. The alkaline activators were mixed together and then poured into the mixing bowl. The activators solution was mixed with sand and fly ash for 2 minutes at low speed to allow the polymerization reaction between the source materials and the activator solution. The mix was rested for 30 seconds for scraping the materials stuck in the bowl if any, followed by 2 minutes of mixing at medium speed. The flow table test was conducted according to (ASTM Standard C230, 2014) and water was added to improve the workability if needed. After conducting the flow table test the GPM mix was returned in the mixture and mixed for 15 seconds at medium speed. The GPM mixes were casted in 50 mm cubes according to (ASTM Standard C109, 2019). Casted molds were placed in an oven with the curing temperature and duration fixed for all GPM mix designs at 80 ^{o}C and 24 hours respectively. Both curing temperature and duration were selected based on a preliminary study, with similar values reported in the literature. After 24 hours in the oven, GPM cubes were left for 30 minutes to cool down to room temperature and then tested in a universal compression testing machine.

3 RESULTS AND DISCUSSION

3.1 Compressive strength

The average of three specimen cubes were taken for the compressive strength results shown in Table 3. All specimen experienced similar mode of failure as shown in Figure 1. It was noted during testing that the samples encounter an explosive mode of failure. This might be attributed to the strong geopolymerization chain in binding the constituent materials together (Singh, 2018).

Table 3: Compressive strength of GPM

Sample ID	Average compressive strength (MPa)
F1N1	61.12
F1N2	47.94
F1N3	41.70
F1N4	37.67
F2N1	65.70
F2N2	66.18
F2N3	66.39
F2N4	56.64

Figure 1: Compressive strength of GPM cube.

The effect of the alkaline activator/fly ash ratio was noticeable as there was a decreasing trend in the compressive strength for mix designs with alkaline activator/fly ash ratio 0.40 as the Na2sio3/NaOH ratio increased from 1 to 2.5. On the other hand, for mix designs with alkaline activator/fly ash ratio of 0.5 as the Na2sio3/NaOH ratio increased from 1 to 2, the effect on the compressive strength is negligible. However, for sample F2N4 a slight decrease in the compressive strength was reported.

3.2 Flow table test

The flow table test was conducted for all mixes to check the consistency for GPM. It was noted that as the alkaline activator/fly ash ratio increased from 0.4 to 0.5 the flow table results improved without adding additional water to obtain a consistent GPM mix as shown in Figure 2. The flow table test is summarized in Table 4.

Table 4: Flow table results

Sample ID	Flow table (cm)
F1N1	14.25
F1N2	15.63
F1N3	14.94
F1N4	15.31
F2N1	16.25
F2N2	16.50
F2N3	16.06
F2N4	16.13

Figure 2: Flow table test of GPM

4 CONCLUSION

The effect of alkaline activator/fly ash ratio and Na2sio3/NaOH ratio on the mechanical properties of GPM was investigated and the following conclusions were highlighted:

- The effect of alkaline activator/fly ash ratio is a major contributor to the mechanical properties of GPM, as it increases, the compressive strength increases significantly.
- As the Na2sio3/NaOH ratio increases, the compressive strength decreases at low alkaline activator/fly ash ratio. However, this effect is insignificant at higher ratio of alkaline activator/fly ash.
- The higher alkaline activator/fly ash the more consistent the GPM mixes.
- Maximum early compressive strength of 66.39 MPa was achieved by F2N3 alkaline activator/fly ash of 0.5 and Na2sio3/NaOH of 2.
- Fly ash shows very promising results that will ultimately be used in construction and building materials replacing OPC.

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