World of Coal Ash (WOCA) Conference - May 9-12, 2011, in Denver, CO, USA
http://www.flyash.info/

Experimental Evaluation of Self-Cure Geopolymer Concrete for Mass Pour Applications

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KEYWORDS: Fly ash, Geopolymer, mass pour, curing, exothermic polymerization reaction

ABSTRACT

Polymerization reaction temperatures involved with the formation of geopolymer were studied. Thermocouples were embedded in the fresh geopolymer concrete to record temperatures generated by the exothermic polymerization reaction. A preliminary study conducted on a cylindrical concrete specimen demonstrated that the temperature profile developed within the specimen was relatively uniform and that the generated temperatures were somewhat higher than room temperature. In Phase 2 one cubic yard of fresh geopolymer concrete was casted with embedded thermocouples, and the temperature data was collected over a period of two weeks. Test data suggest that temperatures induced during the curing of geopolymer concrete are a function of the volume mixed. By trapping heat generated by the exothermic reaction within the geopolymer mass the need for external heat to ensure curing of the geopolymer concrete is eliminated. Phase III involved simulating the temperature history of the one cubic yard geopolymer block using water bath for geopolymer cylinders of identical mix design. Compressive strength tests revealed that even when cured under heat generated from its own exothermic polymerization reaction, geopolymer concrete can reach compressive strengths of up to 43 MPa, eliminating the need for externally applied heat, a major constraint in field cast applications of geopolymer concrete.

Introduction

The term ‘Geopolymer’ was coined by Davidovits, and describes a cementitious binder formed by alkali metal hydroxide activation of aluminosilicate powder[1&2]. Industrial by-products such as fly ash, rice husk ash or silica fume, or mineral such as kaolinite, mica, garnet, feldspar and clays are used as the source of aluminosilicate powders [3&4]. ASTM class F fly ash could serve as an ideal source material for mass production of geopolymer. Class F fly ash is preferred over class C due to a lower percentage of calcium. Presence of calcium in elevated levels could hinder the polymerization reaction[5] and lead to flash set due to the formation of calcium hydrate products. Several authors have published a considerable amount of research on utilization of fly ash as a source material for making geopolymer [6-9]. To activate the source material Davidovits suggested the use of alkali metal hydroxides (e.g. NaOH or KOH) and many researchers reported utilizing these in their activator solution formulations[10-12]. A study conducted by Palomo et. al.[6] on using alkali silicates in addition to alkaline hydroxides to activate the source material concluded that the use of alkali silicates such as sodium silicate and potassium silicate increases the polymerization reaction rate and also improves the mechanical performance of the outcome geopolymer.

Geopolymer concrete is finding an increasing number of niche applications in the field of civil engineering due to its superior properties when compared with Portland cement concrete. These properties include high compressive strength, excellent strength gain rate, fire resistance, maintenance of structural properties at elevated temperature, chemical stability in highly acidic environments, relatively low cost and multitude environmental benefits [6-8, 13-14]. These excellent properties, over Portland cement concrete, make it a suitable candidate for several applications, especially in the construction industry.

A widely accepted phenomenon in Portland cement is that it attains the strength through hydration reaction, which leads to the formation of C-S-H gel under the presence of water, and therefore Portland cement requires water for curing over a period of 28 days. Whereas, geopolymer gains its strength through rapid exothermic polymerization reaction and therefore requires curing temperatures (typical curing period for geopolymer is 60^0 C for 24 hrs)[5]. The following paper presents the results obtained from an experimental study conducted on temperatures generated by the exothermic polymerization reactions taking place during curing of the fresh geopolymer mix. The temperature data was recorded using embedded thermocouples that were connected to a data acquisition system.

Experimental Procedure

The experimental procedure consisted of three phases, in Phase I, geopolymer concrete cylinder (0.15 m X 0.3 m) was casted with embedded thermocouples to get an estimate of the range of temperatures generated inside the precast geopolymer concrete cylinder. In Phase II, a 0.91m X 0.91 m X 0.91 m (one cubic yard) cube of geopolymer concrete was cast with embedded thermocouples to read the temperatures generated inside the curing concrete in field-like conditions. The temperatures were assumed to be a function of the volume of the geopolymer concrete mass. In Phase III, a number of small cylinders (0.076 m X 0.15 m) and one (0.15 m X 0.3 m) cylinder of geopolymer concrete were casted and cured in water baths following the temperature profile recorded by the thermocouples for the one cubic yard block. Samples were tested at predetermined curing periods to determine the mechanical properties gained by the curing gpc cube over the period of time.

Geopolymer Concrete Mix

A single source of fly ash was used to make geopolymer concrete in all the three phases. Fly ash was obtained from a local coal fired power plant (Dollet Hills power plant operated by Cleco Power LLC.), whose physical and chemical properties are mentioned under the tables 1 and 2. Similar mix design was employed in making geopolymer concrete in all the phases using fly ash, sand and coarse aggregate (pea gravel 9.5 mm avg. size). The activator solution used had a combination of sodium hydroxide and sodium silicate solution. Sodium hydroxide solution was prepared in the laboratory by dissolving 99% pure sodium hydroxide micro-pearls in water. Sodium silicate solution was obtained from PQ Corp. in LA. During mixing fly ash and sodium hydroxide were first mixed for one minute. Then, while continuing mixing sodium silicate, sand, coarse aggregate, and admixtures were added in succession. To ensure homogeneity of the mix, the concrete after adding all the ingredients was mixed for another minute, before placing it in the molds.

Table 1. Chemical composition of fly ash used

Chemical Component	Percent by Wt
SiO_2	59.32
Al_2O_3	19.72
SiO_2/Al_2O_3	3.01
$SiO_2+Al_2O_3$	79.04
CaO	6.90
Fe_2O_3	7.22
MgO	2.23
SO_3	0.36
Na_2O	1.11
K_2O	1.27
TiO_2	1.00
MnO_2	0.18
P_2O_5	0.10
SrO	0.23
BaO	0.22
Moisture content	0.08
Loss On Ignition	0.15

Table 2. Particle size distribution

Size(um)	Percentile
10.00	26.81
20.00	41.65
30.00	51.37
40.00	57.98
45.00	60.87
50.00	63.71
60.00	69.21
70.00	74.00
80.00	77.98
90.00	81.25

Phase I

A 0.15 m X 0.3 m geopolymer concrete cylinder was casted with embedded thermocouples to monitor its internal temperatures (Figure 1). The thermocouples were placed at the top, middle, and bottom portions of the concrete cylinder, with 0.076 m spacing between them. Miniature holes were made in the plastic cylinder mold and the thermocouple wires were passed through them, before filling the mold with fresh concrete mix. The thermocouples were connected to a data acquisition system (Agilent 34970A) to read the temperatures generated inside the concrete. Temperature data were collected over a period of 24 hours.

Figure 1. Geopolymer concrete cylinder with embedded thermocouples

Phase II

To pour 0.91m X 0.91 m X 0.91 m cube (one cubic yard) of geopolymer concrete, a wooden mold was prepared using ply wood. Welded steel reinforcement (No # 3 rebar) was placed inside the mold to provide stability after pouring the concrete and also to aid in the positioning of the thermocouples. A total of six thermocouples were attached to the steel reinforcement, two in each level, to read the temperature at the top middle and the bottom sections of the geopolymer concrete block (Figure 2).

Geopolymer concrete was mixed and poured in layers, with each layer being vibrated using a hand held concrete vibrator to allow uniform distribution of concrete over the block and to facilitate removal of trapped air and voids. The sequence of mixing, pouring and cured sample can be seen in Figure 3. Upon pouring the concrete, an insulating blanket was used to cover the block, which contained the heat generated from the curing geopolymer concrete. The embedded thermocouples were connected to the data acquisition system and the temperature data was collected every five minutes over a period of twelve days.

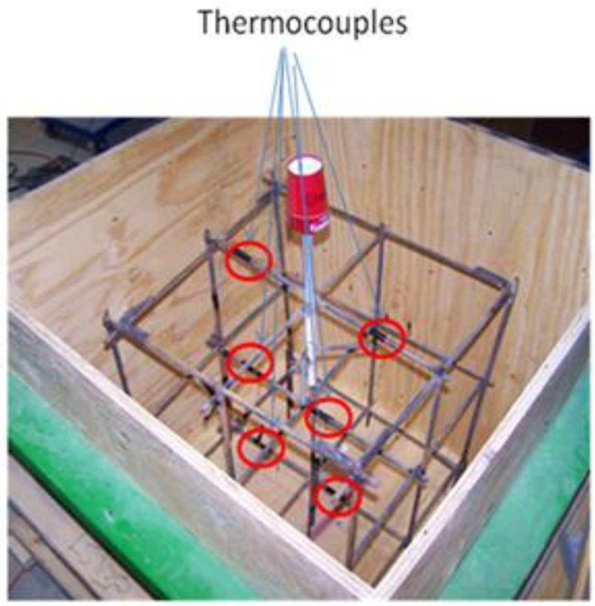

Figure 2. Wooden mold with steel reinforcement and thermocouples.

Figure 3. Sequential order of geopolymer concrete mixing, pouring, finishing and curing.

Phase III

A total of 18 cylinder samples, 0.076 m X 0.15 m, and one cylinder, 0.15 m X 0.3 m sample of geopolymer concrete were cast simultaneously while pouring the cube. Upon pouring the concrete, the cylinders were placed in a hot water bath, the temperature of which was adjusted to follow the trend measured from phase II study (i.e., temperature profile generated by the curing cube). The small cylinders were tested for compressive strength in groups of three after 1, 3, 7, 14, 21 and 28 days of curing. The large cylinder was tested at the end of a 28-day curing period to determine the Poisson's ratio and the elastic modulus of the geopolymer concrete block (Figure 4.).

Figure 4. Pouring of cylinder samples and testing GPC cylinder.

Results

The established temperature profile of the geopolymer concrete cylinder from phase I is depicted in Figure 5. It can be seen that the temperature followed a similar trend in all the three locations, i.e., temperature inside the concrete cylinder was uniform throughout the specimen length. Also, the temperature of fresh geopolymer mix was slightly higher than room temperature (~4°C) immediately following the casting. However, as the geopolymer concrete started setting the temperature dropped approaching the room temperature (25 °C). This drop in temperature took place over a period of 12 hours from the time of placement of the fresh geopolymer mix. Results from the cylinder test suggest that the fresh geopolymer mix undergoes an exothermic reaction during mixing of the ingredients. The degree of temperatures attained by the fresh geopolymer mix is a function of the volume mixed.

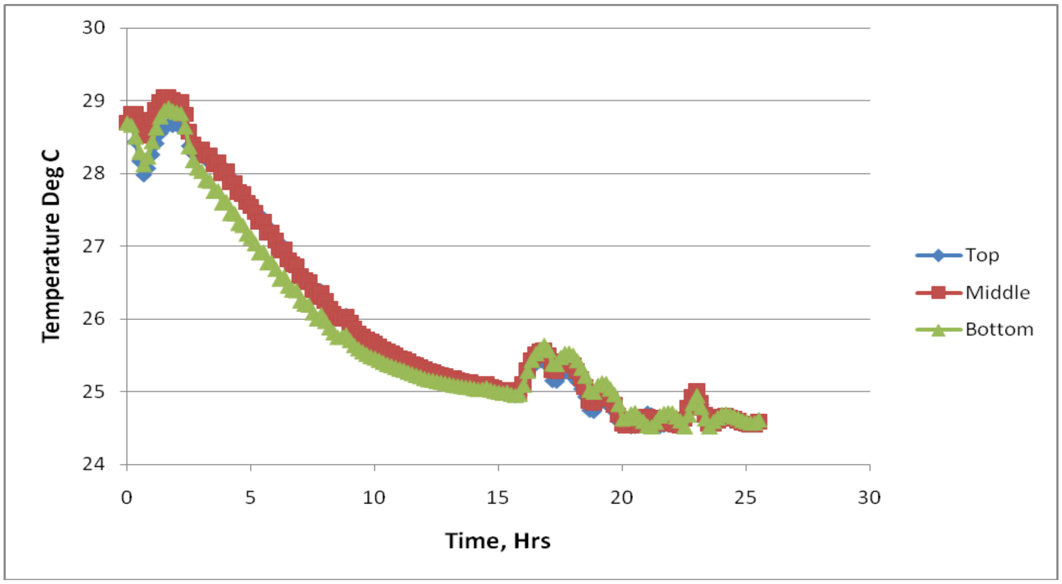

Figure 5. Temperature profile of Geopolymer Concrete Cylinder.

The average temperature profile of the concrete block in three separate locations, obtained from the phase II study are represented in the Figure 6. The temperature data was collected over a period of twelve days. From the temperature data it can be observed that in all three locations temperature measurements followed a similar trend suggesting a uniform distribution of the thermal energy throughout the mass. The average temperature of the fresh geopolymer mix (inside the cube) was around 42°C, well above the room temperature, this rise in temperature was retained for a period of five days, upon which the average temperature of the block appeared to decline at the rate of 2°C per day.

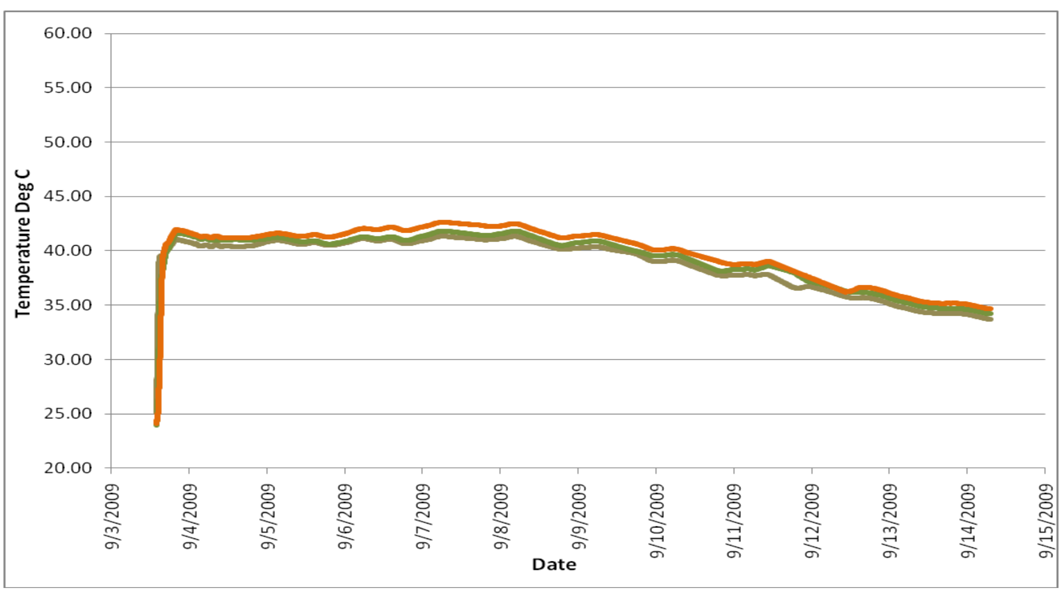

Figure 6. Average temperature profile of gpc cube in three separate locations.

Results obtained from phase II study suggest that their was a definite increase in the temperature with increase in the quantity of the fresh geopolymer mix. To determine whether the heat from the exothermic geopolymerization reaction was sufficient to cure the matrix, compressive strength tests were performed on the cylinderical specimens that were cured with similar temperature history as of the cube. Results from the compressive strength analysis are plotted in figure 7 and are summerized in table 3.

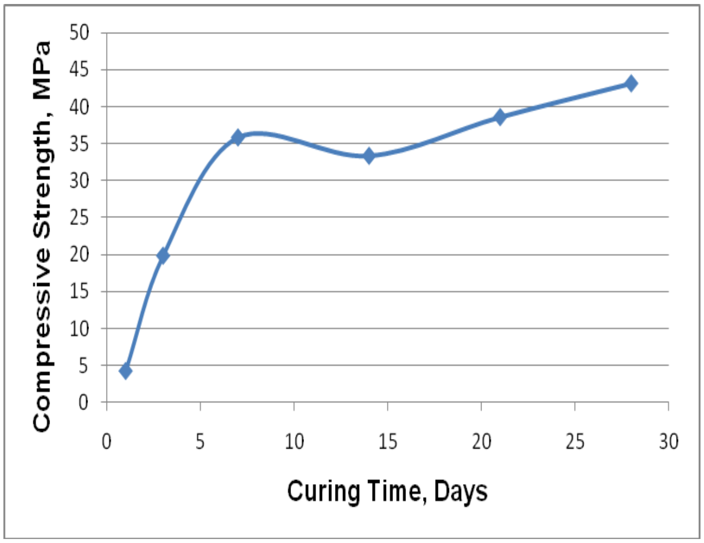

Figure 7. Compressive strength of the cube based on cylinder tests

Table 3. Compressive strength results

Days	Compressive Strength, MPa
1	4.31
3	19.86
7	35.81
14	33.33
21	38.56
28	43.1

Conclusions

Results obtained from phase I study showed that the temperature developed within geopolymer mass is uniform. Phase II study provided the basis to support the assumption that the temperatures generated depend on the amount of concrete mixed. From the compressive strength results it can be observed that the strength of the geopolymer concrete increased with the curing period (except in the case of 14 days, experimental anomaly). Also, the elastic modulus and the Poisson's ratio of the geopolymer concrete at the end of the 28-day curing period were found to be within an acceptable range for a typical concretes used in structural applications (E = 28,000 MPa and 0.121). The above data suggest that in a sustained environment, without any externally applied heat, mass poured cast-in-place geopolymer concrete can acquire the necessary compressive strength required for structural applications.

References

[1] Davidovits J. Jounral of Thermal Analysis, 1991, 37, p.1633–1655.

[2] Davidovits J. In: Proceedings of first international conference on alkaline cements and concretes. KIEV, Ukraine, 1994.

[3] Wallah, S. E., and Rangan, B.V. Curtin University of Technology, Perth, Australia, Research Report GC 2, 2006.

[4] Xu, H, Van Deventer, J. S. J. International Journal of Mineral Processing, 2000, 59, 3, p. 247-266.

[5] Hardjito, D. and Rangan, B. V. Curtin University of Technology, Perth, Australia, Research Report GC 1, 2005.

[6] Palomo, A, Grutzeckb, M. W and Blancoa, M. T. Cement and Concrete Research, 1999, 29, p. 1323–1329,

[7] Bakharev, T. Cement and Concrete Research, 2005, 35, p. 658–670.

[8] Fernandez-Jimenez, A and Palomo, A. Fuel, 2003, 82, 18, p. 2259-2265.

[9] Xu, H and Van Deventer, J. S. J. Minerals Engineering, 2002, 15, p.1131–1139.

[10] Xu, H and Van Deventer, J. S. J. International Journal of Mineral Processing, 2000, 59, 3, p. 247-266.

[11] Kamhangrittirong, P, Suwanvitaya, P, and Suwanvitaya, P. In: International Conference on Pozzolan, Concrete and Geopolymer, Khon Kaen, Thailand, 2006.

[12] Sagoe-Crentsil, K and Trevor, B. In: International Conference on Pozzolan, Concrete and Geopolymer, Khon Kaen, Thailand, 2006.

[13] Diaz, E. I, Allouche, E. N. In: Proceedings of IEEE green technologies conference, Dallas,TX, USA, 2010.

[14] Van Jaarsveld, J. G. S., Van Deventer, J. S. J. and Lukey, G. C. Materials Letters, 2003, 57, p. 1272–1280.