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Effect of curing condition on strength of geopolymer concrete

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Abstract. Increasing emphasis on energy conservation and environmental protection has led to the investigation of the alternatives to customary building materials. Some of the significant goals behind understaking such investigations are to reduce the greenhouse gasemissions and minimize the energy required formaterial production.The usage of concrete around the world is second only to water. Ordinary Portland Cement (OPC) is conventionally used as the primary binder to produce concrete. The cement production is a significant industrial activity in terms of its volume and contribution to greenhouse gas emission. Globally, the production of cement contributes at least 5 to 7 % of CO_2. Another major problem of the environment is to dispose off the fly ash, a hazardous waste material, which is produced by thermal power plant by combustion of coal in power generation processes. The geopolymer concrete aims at utilizing the maximum amount of fly ash and reduce CO_2 emission in atmosphere by avoiding use of cement to making concrete. This paper reports an experimental work conducted to investigate the effect of curing conditions on the compressive strength of geopolymer concrete prepared by using fly ash as base material and combination of sodium hydroxide and sodium silicate as alkaline activator.

Keywords: fly ash based geopolymer concrete; alkaline activator, ambient curing; hot curing, compressive strength

1. Introduction

The demand for cement is increasing with the increase in the development of infrastructure taking place all over the world. The process of producing cement is not only highly internal energy intensive, but is also responsible for large emissions of carbon dioxide (CO_2), which is green house gas causing global warming (Mehta 2001, Mc Caffrey 2002). According to one of the studies in the past (Malhotra 1999), the worldwide cement production accounts for almost 7% of the total world CO_2 emissions. The control of such green house gas emission is a major issue for sustainable concrete. In addition to this, about 3 billion tons of the raw materials are needed every year for cement manufacturing, which consumes considerable energy and adversly affect the ecology of the planet. At the same time, the ordinary Portland cement concretes are less durable under certain environmental conditions (Neville 2005). On this backdrop, there is an urgent need

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to find an alternate binder to cement in order to make the construction industry eco friendly and sustainable.

Geopolymer materials represent an innovative technology that is generat¬ing considerable interest in the construction industry, particularly in light of the ongoing emphasis on sustainability. In contrast to the Portland cement, the most geopolymer systems rely on minimally processed natural materials or industrial byproducts to provide the binding agents. Since Portland cement is responsible for upward of 85 percent of the energy and 90 percent of the carbon dioxide (CO2) attributed to a typical ready-mixed concrete, the savings of the potential energy and carbon dioxide through the use of geopolymers can be considerable. Consequently, there is growing interest in geopoytmer application in construction industry. On this backdrop, the geopolymer technology introduced by Davidovits (1994a) provides an alternative binder to the OPC. Geopolymer concretes (GPC) are cementless concrete which utilize by product materials like fly ash in the presence of alkaline solution to produce binders.

This concrete is produced by activating different alumino-silicate based waste materials with highly alkaline solution. The curing of freshly prepared geopolymer concrete is the most crucial aspect and it plays an important role in the entire geopolymerisation process. The proper curing of concrete has a positive effect on the final properties of the geopolymer concrete. The curing of such concrete is mostly carried out at elevated temperatures; however, curing at ambient temperatures is also carried out at times. At ambient temperatures; the reaction of fly ash-based geopolymeric materials is very slow and usually shows a slower setting and strength development. It is believed that higher temperatures activate alumino-silicate phases in the fly ash; therefore, they are generally cured at elevated temperatures between 60℃- 90℃.

2. Brief review of literature

The term ‘geopolymers’ was first introduced to the world by Davidovits (1994 b) of France, thus, inventing area in the field of concrete technology. He explained that geosynthesis is the science of manufacturing artificial rock at a temperature below 100℃ in order to obtain natural characteristics (hardness, longevity and heat stability) of rock. Geopolymers can, thus, be viewed as the mineral polymers resulting from geo-chemistry or geo-synthesis.

The mechanism of geopolymerisation may be considered to occur in three stages (Xu and *van* Deventer 2000) – dissolution, transportation or orientation and polecondensation. The reactions of geopolymerisation take place through a series of exothermic processes (Palomo *et al*. 1999, Davidovits 1999). Cheng and Chiu (2003) observed that unlike conventional organic polymers, glass, ceramic or cement, the geopolymers are formed at low temperatures; and they are non-combustible, heat-resistant, and fire/acid resistant. It was recognized that three sources such as raw materials including fly ash, ground granulated blast furnace slag (GGBS), metakaoline (MK), etc.; inactive fillers (such as sand and crushed granite aggregate) and geopolymer liquor such as Alkali Activator Solution (AAS)are essentially needed for synthesis of geopolymer. Though authors pointed out the steps involved in the chemical process for forming geoploymers, they could not understand fully the exact mechanism of the occurance of setting and hardening of geopolymer.

Fernandez *et al.* (2006) reported that the polymerization process that takes place in geoplymer concrete differs widely from the hydration of portland cement. Ramchandran *el al*. (1992) revealed that the fly ash when used in high volumes in the concrete reduces the alkali aggregate reaction.

Xu and *van* Deventer (2000) investigated the geopolymerisation of 15 natural Al Si minerals. It was found that the minerals with a higher extent of dissolution demonstrated better compressive strength after polymerisation. The percentage of calcium oxide (CaO), potassium oxide (K_2O), the molar ratio of Si-Al in the source material, the type of alkali and the molar ratio of Si/Al in the solution during dissolution had significant effect on the compressive strength.

In the synthesis of geopolymers, there are essentially two types of raw materials, the alumino-silicate containing solids and alkali-silicate solutions. The alumino-silicate solids function as sols in the alkali-silicate liquid medium. The sol-liquid combination will turn into a sol-gel matrix, as is usually done in the sol-gel methodology. The aluminosilicate sources include the commonly used kaolinite, especially, calcined kaolinite, or metakaolinite (Rahier 1997, Barbosa 2000) and other natural alumino-silicate minerals (Xu and *van* Deventer 2002) and industrial waste-based materials, such as ground granulated blast furnace slag (Cheng and Chiu 2003) and fly ash (Lee and *van* Deventer 2002, Palomo 1999, Phair and *van* Deventer, 2001).

van Jaarsveld *et al.* (2002) studied the inter-relationship of parameters that affected the properties of fly ash based geopolymer and reported that the properties of geopolymer were influenced by the incomplete dissolution of the materials involved in geopolymerisation. The water content, curing time and curing temperature affected the properties of geopolymer; specifically the curing condition and calcining temperature influenced the compressive strength. When the samples were cured at $70^{o}C$ for 24 hours, a substantial increase in the compressive strength was observed. The curing for a longer period reduced the compressive strength. Wang Bao-min and Wang Li-jiu (2005) studied the applications of geopolymeric activation techniques of fly ash in conventional cement concretes. The study showed that when weight of fly ash reaches 20%-80% of 32.5 grade cement, M-40 concrete can be prepared with satisfactory properties through using activating techniques such as adding some high-efficiency fly ash activating admixture.

Recently, Alloucher *et al.* (2011) studied the self-curing properties of geopolymer concrete. The study shows that the temperature generated is dependent upon the amount of concrete mixed. The strength of GPC was found to increase with curing period. The modulus of elasticity and Poisson's ratio corresponding to 28 days' curing were found to be within acceptable range for typical concrete used in a structural application. Mustfa *et al*. (2012) based on the experimental work concluded that the Na_2SiO_3/NaOH ratios and NaOH molarities the compressive strength of the fly ash based geopolymer concrete. The Na_2SiO_3/NaOH ratio of 2.5 contributed to the high compressive strength of 57Mpa. The highest NaOH molarity did not necessarily give the highest compressive strength. The geopolymer with 12 M NaOH showed excellent results including a high compressive strength of up to 94.59 MPa corresponding to 7 days' curing.

Even few studies (Hardjito and Rangan 2005, Wallah and Rangan 2006, Bakharev 2005 a,b) indicated that GPCs have high strength with good resistance to chloride penetration, acid attack, etc. and have a very small green house foot print when compared to the conventional concretes. Summing up, there have been many studies carried out extensively supports the potential of GPCs as a prospective construction material (Davidovits 1991, Duxson *et al.* 2007, Bakharev 2005c, Sofi *et al*. 2006). Based on the afore-mentioned review of literature and keeping the gaps in the available literature, the present experimental investigation is aimed at studying the effect of curing conditions, i.e., ambient and temperature curing, on the compressive strength of fly ash based geopolymer concrete.

3. Experimental programme

3.1 Materials

In the present study, low-calcium (Class F) fly ash conforming to IS: 3812 was used as a base material for geopolymer concrete mix. The fly ash was obtained from JSW Power Station, Ratnagiri (Maharashtra).India. The chemical composition of fly ash, as determined by X-Ray Fluorescence (XRF) analysis, is shown in Table 1. Locally available crushed coarse aggregates of maximum size 20 mm and 10 mm, having specific gravity 2.78, are used in the preparation of all the test specimens. All the aggregate were tested in accordance with IS: 383-1970(Reaffirmed 1997). The coarse aggregates were used in saturated surface dry (SSD) condition. The manufactured sand, having specific gravity of 2.68 and the fineness modulus of 2.76, was used as fine aggregate. The fine aggregate was sieved for the size less than 4.75 mm and used in dry condition.

A combination of sodium silicate solution and sodium hydroxide solution is chosen as the alkaline liquid. The sodium hydroxide solids were either a technical grade in flakes form (3 mm), with a specific gravity of 2.130, 98% purity and obtained from Gujarat Chemicals Pvt. Ltd., India.

The sodium hydroxide (NaOH) solution was prepared by dissolving either the flakes or the pellets in water. The mass of NaOH solids in a solution varied depending on the concentration of the solution expressed in terms of molar, M. For instance, NaOH solution with a concentration of 8M consisted of $8 \times 40 = 320$ grams of NaOH solids (in flake or pellet form) per liter of the solution, where 40 was the molecular weight of NaOH. The sodium silicate solution obtained from M/s Bombay Silicate, Mumbai was used. The chemical composition of the sodium silicate solution was Na_2O = 14.7%, SiO_2 = 29.4%, and water 55.9% by mass. The other characteristics of the sodium silicate solution were specific gravity = 1.53 g/cc and viscosity at 20^oC = 400 cp.

3.2 Details of mix proportion

The procedure for mix design was formulated for geopolymer concrete in the present study using the guidelines relevant to that given by IS: 10262-2009. The applicability of existing mix design was examined with the geopolymer concrete. Two kinds of systems were considered in this study- the first one was using 100% replacement of cement by class F fly ash conforming to IS: 3812 (Part –I)-2013 and second one was by replacing 100% of natural sand by manufactured sand. It was analyzed from the test results that the procedure of mix design using IS method itself can be used for the geopolymer concrete with some modification. The details of the mix proportions are given in Table 2.

3.3 Mixing of geopolymer concrete

For mixing, a rotating pan mixer of 75 liters capacity with fixed blades was used. The aggregates were prepared in saturated – surface dry condition and were kept in plastic buckets with lid. , were dry mixed in the pan mixer for about three minutes. The sodium hydroxide solution and sodium silicate solution was mixed together one day prior adding to the dry materials. The liquid part of the mixture, i.e., the sodium silicate solution, the sodium hydroxide solution and water, was added to the solids. The wet mixing usually continued for another four minutes. The fresh fly ash-based geopolymer concrete was grey in colour and shiny in appearance. The mixtures were usually

Fig. 1 Slump measurement of fresh concrete

Fig. 2 Dry materials for making geopolymer concrete

cohesive. The workability of the fresh geopolymer concrete was measured using slump cone test as per IS: 1199- 1959 (Reaffirmed 1999) (Refer Fig. 1).

Fig. 2 shows the dry materials used for making geopolymer concrete whereas Fig. 3 shows the compaction of geoplymer concrete into mould.

3.4 Casting and curing of specimen

All the aggregates were prepared in saturated surface dry condition. Firstly, mixing of dry materials was carried out in a pan type mixer with 0.075 m^3 capacity. After assessing the necessary workability properties as measured by slump cone test, the fresh concrete was placed in steel moulds of dimensions 150 × 150 × 150 mm and the concrete was filled into the mould in layers approximately 50 mm deep. Total numbers of layers were three. Each layer was vibrated by table vibrator. Three cubes were prepared for each test variable. The top surface was leveled using a smooth trowel after compaction. The moulds were then covered by plastic sheets in order to prevent loss of moisture. After casting the moulds without any delay, they were kept in the oven at a specified temperature for a specified period of time in accordance with the test variables selected. At the end of the curing period, the moulds were taken out from the oven and left undisturbed for about 15 minutes. The test specimens were removed from the moulds and left to the air dry condition in the room temperature conditions until tested for direct compression at the specified age of 7 and 28 days.

3.5 Testing of specimen (Compressive strength)

The compressive and tensile strength tests on hardened fly ash-based geopolymer concrete were performed on a 2000 kN capacity hydraulic testing machine in accordance to the relevant Indian standard IS: 516 – 1959 (reaffirmed 2004). On the backdrop of the objective set out in the present investigation, two sets of moulds were prepared. While one set was cured in hot oven at 60^0C, another one was cured at ambient curing. Both the specimens were cured for 7 days and 28 days.

Fig. 3 Slump measurement of fresh concrete

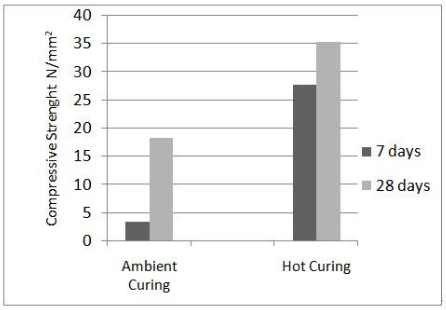

Fig. 4 Variation of compressive strength with age of geopolymer concrete

Table 3The values of compressive strengths (MPa) for various curing conditions

Curing period	Ambient curing		Hot curing	
	Strength	Average	Strength	Average
7 days	3.8	3.94	26.18	26.16
	4.1		25.95	
	3.9		26.64	
28 days	17.34	17.5	36.12	36.2
	17.6		35.98	
	17.56		36.48	

4. Results and discussion

The concrete cubes cast and subsequently, cured for 7 and 28 days', as mentioned in the afore-mentioned section were tested for evaluating its compressive strength. The values of the compressive strength are shown in Table 3.

Similarly, Fig. 4 shows the variation of the compressive strength for ambient curing and hot curing in respect of 7 and 28 days' curing.

It is seen from the results that the strength is on higher side in respect of hot cured specimen. The strength of the hot cured specimen is 564 % higher as compared to that of ambient cured specimen in respect of 7 days' curing. For 28 days' curing period, the corresponding increase is 106 %.

The compressive strength of the hot cured specimen for 7 days curing is about seven times more than the strength of ambient cured sample. Similarly, the strength the hot cured specimen is almost double than that of the ambient cured specimen in respect of 28 days curing. Further, when the increase in strength of specimen with respect to similar curing condition for different curing period is considered, it is found that the strength of the specimen for 28 days' curing period is about four times the strength obtained in respect of 7 days curing. However, in respect of hot curing condition, the increase in strength is not considerable and it is almost 1.4 times more than that obtained for 7 days' curing.

5. Conclusions

The experimental work was carried out to study the effect of curing conditions on the compressive strength of fly ash-based geopolymer concrete. Some of the conclusions deduced from the present study are outlined below.

- The parameters such as curing time and curing temperature significantly affect the compressive strength of the hardened geopolymer concrete.
- The compressive strength increases with the age in either type of curing considered in the study.
- The increase in the strength is considerable in respect of ambient curing as compared to than that in case of hot curing condition.

References

Allouche, E.N., Vaidya, S. and Diaz, E.I. (2011), "Experimental evaluation of self cure geoplymer concrete for mass pour application", *World of Coal Ash (WOCA) Conference (May 9-12), Denver, USA.*

Bakharev, T. (2005a), "Resistance of geopolymer materials to acid attack", *Cement Concrete Res., (Elsevier),* **35**(4), 658-670.

Bakharev, T. (2005b), "Durability of geopolymer materials in sodium and magnesium sulphate solutions", *Cement Concrete Res. (Elsevier),* **35**(6), 1233-1246.

Bakharev, T. (2005c), "Geoplymeric materials prepared using Class F fly ash and elevated temperature curing", *Cement Concrete Res. (Elsevier),* **35**(5), 1224-1223.

Barbosa, V.F., MacKenzie, K.J. and Thaumaturgo, C. (2000), "Synthesis and characterization of materials based on inorganic polymers of alumina and silica: Sodium polysialate polymers", *Int. J. Inorganic Mater.,* **2**(4), 309-317.

Cheng, T.W. and Chiu, J.P. (2003), "Fire resistant geopolymer produced by granulated blast-furnace slag", *Mineral Engineering (Elsevier),* **15**, 205-210.

Davidovits, J. (1991), "Geopolymers: Inorganic polymeric new materials", *J. Thermal Anal.,* **37**, 1633-1656.

Davidovits, J. (1994a), "High-alkali cements for 21st century concretes in concrete technology - Past, present and future", *Proceedings of V. Mohan Malhotra Symposium, Detroit, USA (Ed.: Mehta, P.K.),* ACI SP-**144**, 383-397.

Davidovits, J. (1994b), Properties of geopolymer cements, First Int. Conf. Alkaline Cements and Concretes, Kiev, Ukraine, SRIBM Kiev State Technical University.

Davidovits, J. (1999), Chemistry of geopolymeric systems, An International Conference on Geopolymers, France.

Duxson, P., Fernández, J.A., Provis, J.L., Lukey, G.C., Palomo, A. and *van* Deventer (2007), "Geopolymer technology- The current state of the art", *J. Mater. Sci.*, **42** (9), 2917-2933.

Fernández, J.A., Palomo, A. and López, H.C. (2006), "Engineering properties of alkali activated fly ash concrete", *ACI Mater. J.*, **103**(2), 106-112.

Hardjito, D. and Rangan, B.V. (2005), "Development and properties of low calcium fly ash based geopolymer concrete", *Research Report GC-1, Curtin University of Technology, Perth, Australia.*

IS: 10262- 2009, *Recommended guideline for concrete mix design*, Bureau of Indian Standards, New Delhi.

IS: 1199-1959 (reaffirmed 2004), *Methods of sampling and analysis of concrete,* Bureau of Indian Standards, New Delhi.

IS: 3812-2013, *Testing of physical and chemical properties of fly ash*, Bureau of Indian Standards, New Delhi.

IS: 383- 1970 (reaffirmed 2002), *Indian standard code of practice for specification for coarse and fine aggregates from natural sources for concrete,* Bureau of Indian Standards, New Delhi.

Lee, W.K.W and Deventer, J.S.J. (2002), "The effects of inorganic salt contamination on the strength and durability of geopolymers", *Colloids and Surfaces Phsicochem. Eng. Aspects*, 115-126.

Malhotra, V.M. (1999), "Making concrete greener with fly ash", *ACI Concrete Int.,* **21**(5), 61-66.

McCaffrey, R. (2002), "Climate change and the cement industry", *Global Cement and Lime Magazine (Environmental Special Issue)*, 15-19.

Mehta, P.K. (2001), "Greening of the concrete industry for sustainable development", *ACI Concrete Int.*, **24**(7), 23-28.

Mustafa Al Bakri, A.M., Kamarudin, H., Bnhussain, M., Rafiza, A.R. and Zarina, Y. (2012), "Effect of Na2SiO3/ NaOH ratios and NaOH molarities on compressive strength on fly ash based geopolymer", *ACI Marerials J.*, **109**(5), 503-508.

Neville, A.M. (2000), *Properties of Concrete,* Addison –Wesely Longman Ltd. (Fourth Ed.).

Palomo, A., Grutzeck, M.W. and Blanko, M.T. (1999), "Alkali-activated fly ashes: A cement for the future", *Cement Concrete Res. (Elsevier)*, **29**(8), 1323-1329.

Phair, J.W. and Deventer, J.S. (2001), "Effect of silicate activator pH on the leaching and material characteristic of waste – based inorganic polymer", *Mineral Eng. (Elsevier)*, **14** (3), 289-304.

Rahier, H., Simons, W., Mele, B. and Biesemans, M., (1997), "Low-temperature synthesized aluminosilicate glasses, Part III - Influence of the composition of the silicate solution on production, structure and properties", *J. Mater. Sci.*, **32**, 2237-2247.

Ramchandran, S., Ramakrishnan, V. and Johnston, D. (1992), "Roll of high volume fly ash in controlling alkali-aggregate activity", *Am. Concrete Inst. SP*, **132**, 591-614.

Sofi, D., Deventer, J.S.J., Mendis, P.A. and Lukey, G.C. (2006), "Engineering properties of inorganic polymer concretes (IPCs)", *Cement Concrete Res.*, **37**, 251-257.

Jaarsveld, J.G.S., Deventer, J.S.J. and Luckey, G.C. (2002), "The effect of composition and temperature on the properties of fly ash and Kaolinite based geopolymers", *Chem. Eng. J.*, **89**(1), 63-73.

Wallah, S.E. and Rangan, B.V. (2006), *Low Calcium Fly Ash Based Geopolymer Concrete: Long Term Properties*, Research Report GC 2, Curtin University of Technology, *Perth, Australia.*

Wang, B.M and Wang, L.J. (2005), "Development of studies and applications of activation techniques of fly ash", *Proceedings International Workshop on Sustainable Development and Concrete Technology, Beijing, August 23*, 159-169.

Xu, H. and Deventer, J.S.J. (2000), "The gopolymerisation of alumino- silicate minerals", *Int. J. Mineral Proc.*, **59**(3), 247-266.

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