International Journal of Civil Engineering Research.
ISSN 2278-3652 Volume 5, Number 1 (2014), pp. 21-28

http://www.ripublication.com/ijcer.htm

Geo-polymer Concrete–Green Concrete for the Future—A Review

Sourav Kr. Das[1], Amarendra Kr. Mohapatra[2] and A.K. Rath[*]

[1]Post Graduate Student, School of Civil Engineering, KIIT University, Bhubaneswar, Odisha, India.
[2]School of Civil Engineering, KIIT University, Bhubaneswar, Odisha, India.
[*] School of Civil Engineering, KIIT University, Bhubaneswar, Odisha, India.

Abstract

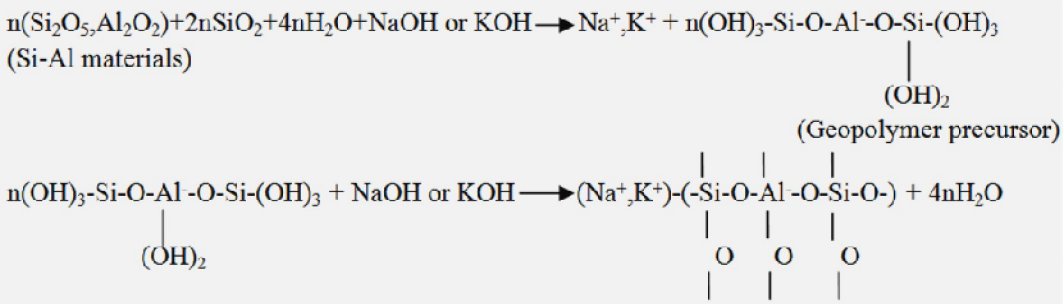
Cements which are used for construction work are generally OPC/PSC or PPC and the production of this kind of cement not only consumes huge amount of the natural resources i.e. limestone and fossils fuel but also produces almost 0.9t of CO_2 for 1t cement clinker production. Also world cement production generates 2.8 billion ton man-made greenhouse gas annually. Geo-polymer concrete is totally different in materials and chemistry which is synthesized from waste material like fly-ash(Class F or C), rice husk along with binding solution which is free of cement. This paper gives an overall view of the process and parameters which effect the geo-polymer concrete till date. It is an inorganic 3D polymer which is synthesized by activation of alumino-silicate source like fly ash or GGBS(waste materials). Due to its high mechanical properties combined with substantial chemical resistance (magnesium or sulphate attack), low shrinkage and creep and environment friendly nature (very less amount of CO_2 production in comparison with OPC), it is a novel construction material for future. Till date it was seen that the strength of geo-polymer concrete mostly depends on the molarities of the alkaline liquid (NaOH or KOH) and ratios of $SiO_2$and Na_2O, H_2O and Na_2O, Si and Al, water to geo-polymer solids by mass in the total alkaline solution. It was seen that geo-polymer concrete made of fully Fly-ash or partial replacement by GGBS results with 80% reduction in CO_2 emission compared to OPC, although the alkaline solution to some extent pollutes the environment. Exhaustive studies in various processes and parameters show that geo-

polymer concrete is superior to cement concrete, which is a very good candidate material for future.

Keyword: Geopolymer, concrete, SiO_2/Na_2O, H_2O/Na_2O, Mixing procedure, molarity, strength.

1. Introduction

Geo-polymer materials represent an innovative technology that is generating huge amount of interest in the construction industry considering sustainable material. Although geo-polymer concrete is a new technology but the use of this technology has started from the time of pyramids though that time it did not come in the front of the researchers like now to grasp their interest in it. The name "Geo-polymer" was coined by Prof. J. Davidovits in 1978 and he found that the polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals, that results in 3D polymeric chain and ring structure consisting of Si-O-Al-O bonds. The main concept behind this geopolymer is the polymerization of the Si-O-Al-O bond which develops when Al-Si source materials like Fly ash or rice husk is mixed with alkaline activating solution (NaOH or KOH solution with Na_2SiO_3 or K_2SiO_3). The geopolymer can be in the form of -Si-O-Al-O- or –Si-O-Al-O-Si-O- or –Si-O-Al-O-Si-O-Si-O-. The chemical reaction behind the formation of geopolymer areas is as follows



From the above equation it's clear that water doesn't plays any role in the polymerization process because it was expels from the chemical reaction.

2. Materials

2.1. Sodium Hydroxide

Generally NaOH is available in market in pellets or flakes form with 96% to 98% purity where the cost of the product depends on the purity of the material. The solution of NaOH was formed by dissolving it in water with different molarity. It is recommended that the NaOH solution should be made 24 hours before casting and should be used with 36 hours of mixing the pellets with water as after that it is converted to semi-solid state.

2.2. Sodium Silicate

It is also known as waterglass which is available in the market in gel form. The ratio of SiO_2 and Na_2O in sodium silicate gel highly effect the strength of geopolymer concrete. Mainly it is seen that a ratio ranging from 2 to 2.5 gives a satisfactory result.

2.3. Alkaline Liquid

According to Prof. J. Davidovits the alkaline liquid should be made prior to one day before mixing because at the time of mixing of Na_2SiO_3 with NaOH solution it generates a huge amount of heat and the polymerization takes place by reacting with one another, which will act as a binder in the geopolymer concrete.

2.4. Coarse Aggregate

Coarse aggregates used in case of cement concrete can be used in case of Geo-polymer concrete (GPC) also where the coarse aggregate should conform to IS-383-1970.

2.5. Fine Aggregate

In place of sand we can also use bottom ash which can be a replacement of sand. Up to a level of 20% replacement of sand gives a good compressive strength.

2.6. Mixing procedure

Rattanasak *et al* [1].proposed that the mixing of geopolymer is of two types i.e. normal mixing & separate mixing. In case of normal mixing fly ash, sodium hydroxide solution & sodium silicate solution and aggregate are mixed at a time but in case of separate mixing the fly ash was first mixed with the sodium hydroxide solution for the first 10 minutes and then the sodium silicate solution with aggregate is mixed with the above mix. Different test results show that the separate mix gives a higher strength in comparison with the normal mix. Although many authors consider that the mixing should be as follows:- first the fly ash, coarse aggregate and fine aggregate should be mixed properly and after proper dry mix then the sodium hydroxide and the sodium silicate solution should be added to the dry mix according to the proper proportions required to attain a good compressive strength and then the mix should be properly compacted in three layers using the standard tamping rod and by vibrating table[2.3.4].

3. Different Parameters of Geo-polymerisation

3.1. Fineness of Fly Ash

The fineness of fly ash gives a major impact on the strength of the geopolymer concrete where it is seen that a processed fly ash with fineness of 542 m^2/kg shows a result of 80 MPa[14] with 24hrs continuous curing at 90^0C. With a lower fineness the strength decreases.

3.2. Temperature imposed to Activator

Generally in the process of geopolymer concrete the polymerization takes place when the elevated temperature is applied to the mix after a rest period of 3 hour to 2 day but if we provide temperature to the alkaline solution prior to casting of concrete, a satisfactory result is obtained but with a particular temperature only. With a temperature of 45^0C produced a maximum compressive strength of 47 MPa[16]. The alkaline solution was kept on that temperature for 24 hours before mixing it with the dry mix of fly ash and coarse aggregate and fine aggregate.

3.3. Molarity

Molarity of NaOH solution plays a vital role in the strength of geopolymer concrete. With a higher concentration of NaOH solution a higher compressive strength can be achieved. There are various test by taking different molarities of NaOH solution starting from 8M. A satisfactory result was obtained at a molarity of 16M beyond which the test results fall down. From 8M to 16M[20] there was a rise in the compressive strength for all mixes. According to previous studies[9] it was found that with the higher concentration of NaOH solution i.e. above 10M, a lower rate of polymerization takes place and resulting in a decreased strength. But Tushar *et al.*[10] stated that the highest compressive strength of geopolymer was affected when a 16M NaOH solution is used.

3.4. Curing

Curing temperature is an important factor till now for the strength point of view of geo-polymer concrete. The main polymerization process or the chemical reaction of geopolymer concrete takes place with the temperature imposed to it during the curing. It may attain almost its 70% strength with in the first 3 to 4 hours of hot curing[4]. Longer curing time enhanced the polymerization process and results in a higher compressive strength[11]. The rate of increase of strength is rapid in the initial 24 hours of curing beyond that the gain of strength was moderate so the specimens should be cured for 24 hours only which will sufficient enough. With an elevated curing temperature setting time decreases. Till now very few quantity of paper is observed where the curing is done in ambient temperature. Generally the curing which is done for geopolymer is hot steam curing or normal hot curing in oven with in a temperature of 60^0C-90^0C for 24 hours. Though a curing temperature of 60^0C is more effective than other temperature or can be said is the optimum curing temperature. Beyond 60^0C it doesn't affect the polymerization process so much. Results demonstrate that the compressive strength of dry cured geopolymer concrete is 15% more than the steam cured geopolymer concrete. Ambient temperature curing is effective if the fly ash content is partially replaced by GBFS[12]. It gives a strength up to 55Mpa at 28 days with a mix proportion of alkaline activator solution as 40% of total binder, slag as 30% of total binder and the ratio of sodium silicate and sodium hydroxide solution as 2.5[15].

3.5. Fly ash and Alkaline activator ratio

Previous studies[6,7] stated that the higher fly ash content with a higher alkaline activator content gives a high compressive strength than the lower one. A ratio of 3.3 to 4.0 can be used to obtain a better result. Sathonawaphak *et al.*[8]further stated that geopolymer with a ratio of 1.4 to 2.3 provides a high compressive strength of 42 to 52Mpa. A ratio of 2.0 gives a result of 71MPa[21].

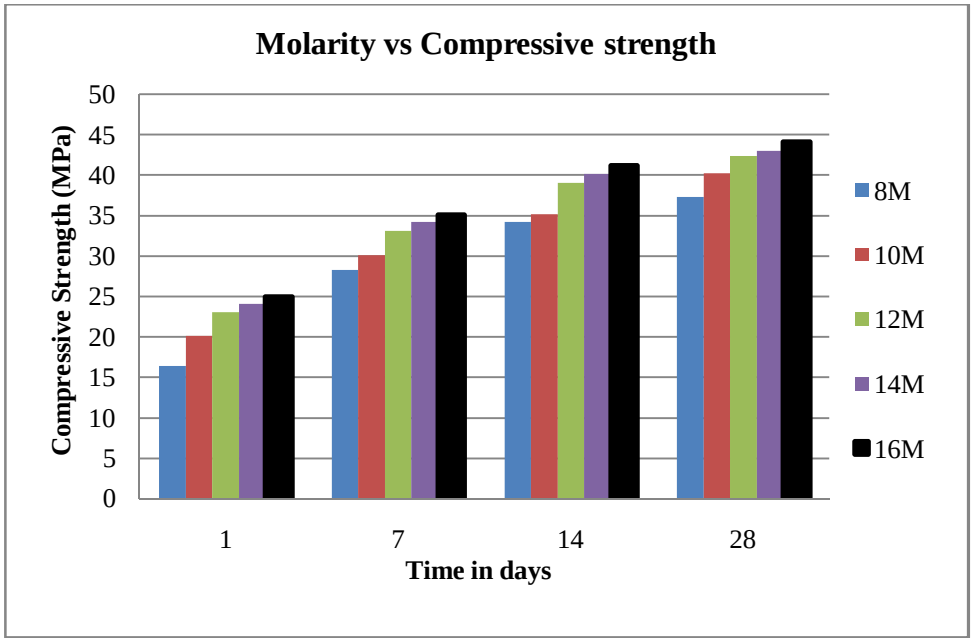


Figure 1: Strength gain with variation in molarities[20]

3.6. Water to geopolymer solids ratio

In this parameter the total mass of water is the sum of the mass of water contained in the sodium silicate solution, the mass of the water use in the making of the sodium hydroxide solution and the mass of extra water, if any, present in the mixture. The mass of geopolymer solids is the sum of the mass of fly ash, the mass of sodium hydroxide solids used to make the sodium hydroxide solution and the mass of solids in the sodium silicate solution i.e. the mass of Na_2O & SiO_2. A ratio of 0.17 to 0.18 provides a moderate result[22], above 0.18 the results decrease continuously.

3.7. Sodium silicate to Sodium hydroxide ratio

Earlier researchers concluded that a ratio of 1.0 of Na_2SiO_3 & NaOHgives a compressive strength up to 70MPa. One paper concluded that a ratio of 2.5 gives a higher compressive strength than the 0.4. Sathonawaphak *et al.* further stated that geopolymer with a ratio of 1.5 gives the optimum result which was 48Mpa. A ratio of 2.5 gives a result of 71MPa[21].

4. Economic Analysis

Low calcium fly ash based geopolymer concrete has several benefits over conventional cement concrete. First is the price of one ton fly ash is just a fraction of the price of one ton cement. The price of the alkaline solution a little bit high but the overall price of GPC is almost 10% to 20% less than the same quantity of cement concrete[22]. In accordance with the above fact the full use of fly ash also curbs down the carbon dioxide release to the atmosphere. Furthermore, it is very little drying shrinkage, low creep, excellent sulphate and magnesium resistance and good acid resistance which properties yield additional benefits when it is used in infrastructure applications[22].

5. Conclusion

This paper presented a brief overall review on geopolymer concrete with its different ingredients, mixing proportions of them, mixing procedure and economical benefits. Higher the fineness of fly ash gives a higher compressive strength because of more surface area with more Si-Al bond for polymerization. With a higher Na_2O/SiO_2 gives a higher strength, generally with a ratio of 2.5. Generally heat cured geopolymer concrete gives higher strength but it can be obtained at ambient temperature by replacing fly ash content by GBFS. Geopolymer concrete has excellent properties as discussed earlier so it can be very useful for rehabilitation and retrofitting works. It can also be used in road works because of its very early attainment of strength. The economic benefits and contribution of geopolymer concrete to sustainable development have also been outlined.

As because the geopolymer concrete is a whole new concept of structural concrete with a new technology and since no Indian Standards are available so a detailed study on the chemistry behind the polymerization is needed. So a new method can be there rather than the conventional mixing procedure which is obtained for the mixing of geopolymer concrete.

References

[1] U. Rattanasak and P.Chindaprasirt, (2009), Influence of NaOH solution on the synthesis of fly ash geopolymer, Minerals Eng., **22,** pp 1073-1078.

[2] J.C.Swanepoel and C.A.Strydom, (2002), Utilisation of fly ash in a geopolymeric material, Appl. Geochem., 17,*8*, pp-1143-1148.

[3] T.W.Cheng and J.P.Chiu, (2003), Fire-resistant geopolymer produced by granulated blast furnace slag, Minerals Eng., **16,** 205-210.

[4] D.L.Y.Kong and J.G.Sanjayan, (*2010),* Effect of elevated temperatures geopolymer paste, mortar and Concrete, Cement Concrete, **40** , 334-339.

[5] A.Palomo, M.W.Grutzeck and M.T.Blanco, (1999), Alkali-activated fly ashes a cement for the future Cement Concrete, **29,** 1323-1329.

[6] D. Hardjito, S. Wallah, M. Sumajouw and V. B. Rangan, (2004), On the development of fly ash-based geopolymer concrete, ACI Materials Journal , **101**, 467-472.

[7] R. Sathia, K.G.Babu and M. Santhanam, In: *Durability Study of Low Calcium Fly Ash Geopolymer Concrete*, (The 3rd ACF International Conference-ACF/VCA,2008).

[8] A. Sathonsaowaphak, P. Chindaprasirt and K. Pimaraksa, (2009), Workability and strength of lignite bottom ash geopolymer mortar, J. Hazard. Mater., **168,** *1***,** 44-50.

[9] S. Alonso and A Palomo, (2001), Alkaline activation of metakaolin and calcium hydroxide mixtures: influence of temperature, activator concentration and solids ratio, Mater. Lett., 47, *1-2*, pp.-55-62.

[10] T.K.Mandal et al., In: Study on the Strength of Fly Ash-Based Geopolymer Concrete (700032, Jadavpur university : Kolkata), P.1.

[11] B.V. Rangan, Low *Calcium Fly-Ash-Based Geopolymer Concrete*, Faculty of Engineering (CurtinUniversity of Technology, Perth, Australia, 2008).

[12] P. Nath and P. Sarkar, Geopolymer concrete for ambient curing temperature.

[13] R. Anuradha, V. Sreevidya, R. Venkatasubramani and B.V. Rangan, (2012), Modified guideline for Geopolymer Concrete mix design using Indian Standard, *AJCE*, **13**, *3*, pp- 353-364.

[14] S.S. Jamkar, Y.M.Ghugal and S.V.Patankar, (2013) , Effect of Fly-ash Fineness on Workability and Compressive Strength of Geo-polymer Concrete, The Indian Concrete Journal, pp:57-62.

[15] P. Nath, P.K.Sarkar, Geo-polymer Concrete for Ambient Temperature", Department of Civil Engineering, Curtain University, Kent Street,. Bentley, WA, 6102, Australia.

[16] DebabrataDutta, SumanChakrabarty, Chandan Bose, SomnathGhosh, (2012) ,Evaluation of Geo-polymer properties with temperature imposed on activator prior mixing with fly ash, IJCSE, **3** , *1* , ,

[17] D. Hardijito, (2005),Studies of fly ash-based geopolymer concrete. PhD Thesis, Curtin university of Technology, Perth, Australia.

[18] M.I. AbdulAleem, P.D.Arumairaj, (2012), Geo-polymer Concrete- A Review, IJESET, **1**, *2*, pp: 118-122.

[19] S.E. Wallah, B.V. Rangan, (2006), Low calcium fly ash based geo-polymer concrete: Long term properties", Research report GL2, Curtin University of Technology, Australia.

[20] D.B. Raijiwala and H.S.Patil, (2011), Geopolymer Concrete : A Concrete of Next Decade, JERS, **2**, *1*, pp.- 19-25.

[21] A.M.Mustafa Al Bakri, H.Kamarudin, Y.Zarina, (2012) , The processing Characteristic and properties of Fly Ash based Geopolymer Concrete, Mater. Sci. , **30,** 90-97.

[22] N.A. Lloyd and B.V.Rangan, (2010), Geopolymer Concrete with Fly Ash, Second Int. Conference on Sustainable Construction Materials and Technologies, June 28- June 30, Universita Politecnicadelle Marche, Ancona, Italy.