

Geopolymer Concrete: Leading the World Towards a Sustainable Future

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Abstract- Concrete is the most widely used construction material after water. It requires large amount of OPC as binder material, but production of OPC involves huge energy consumption, destruction of natural resources and emission of large quantities of green house and pollutant gases like CO₂ and NO_x. In order to significantly reduce CO₂ emissions (which are major contributor to global warming and climate change) by cement industry, we need an eco-binder which can partially or fully replace OPC in concrete. Geopolymer technology has been proved to be promising one in this context. This paper describes test results obtained on large number of Geopolymer concrete units by various researchers around the world and illustrates methods adopted for preparation, mixing, curing of eco- concrete, mechanical properties of GPC, and other useful properties like shrinkage, creep, fire and chemical resistance. Basic Properties of Geopolymer Concrete and OPC concrete based on test results are being compared. Economic benefits, recent developments and applications of geopolymer concrete are also discussed.

Keywords: *Geopolymer concrete; fly ash; blast furnace slag; NaOH; KOH; curing; precast concrete; HySSIL; sustainable.*

INTRODUCTION

The global problems associated with us in today's world like environmental pollution, global warming (and hence climate change) are threats to sustainable future of this planet. Global warming is caused by emissions of green house gases like methane, carbon-dioxide (CO₂) to the atmosphere. Contribution of CO₂ is appreciable accounting for about 65% of global warming. Concrete is most widely used construction material after water, and conventionally it is produced using OPC as primary binder material. So with increasing demand and usage of concrete, production of OPC also demands an increase. Moreover in manufacturing of cement CO₂ is released. It has been estimated that 1 ton of OPC production emits about 1 ton of CO₂ and world cement production generates 2.8 billion ton man-made greenhouse gases annually. Efforts are being made to replace OPC partially or fully as binder material in concrete so as to reduce carbon emissions into atmosphere. An achievement in this regard is the development of **Geopolymer technology** which utilizes wastes from various industries like fly ash, blast furnace slag, rice husk ash, silica fume etc. with alkaline medium to replace cement in concrete. This novel eco-friendly technology using geopolymer as eco- binder is considered to be promising in reducing CO₂ emissions caused by cement industries.

GEPOLYMERS

The term "Geopolymer" was coined by a French materials scientist named Prof. Joseph Davidovits in 1978. He proposed that an alkaline liquid could be used to react with Silicon (Si) and Aluminium (Al) present in a source material of geological origin or by-products such as fly ash, blast furnace slag, and rice husk ash to produce binders. These are essentially inorganic aluminosilicate polymers synthesized from a (fast) chemical process called "**Polymerization.**"

That is why Davidovits called them geopolymers.

CONSTITUENTS OF GEOPOLYMER

There are two main constituents of geopolymer namely, the source material and the alkaline liquid. Source material should be rich in Si and Al. These could be natural material like kaolinite or alternatively by-products such as fly ash, blast furnace slag, rice husk ash etc. Several minerals and industrial wastes have been investigated in past as source materials. Metakaolin (Davidovits 1999), fly ash (N A Lloyd and B V Rangan 2010; M F Nuruddin et al. 2011; Prof. M.A.Bhosale and Prof N.N.Shinde 2012; S H Sanni et al. 2013; Sourav Kr. Das et al. 2014; Yasir Sofi and Iftekar Gull 2015), GGBS with or without fly ash (L Krishnan et al. 2014; T.V Srinivas Murthy 2014; A R Krishnaraja et al. 2014) have been studied as source materials.

The alkaline liquids are from soluble alkali metals generally sodium (Na) and potassium (K). The alkaline liquids are formed from the combinations of sodium hydroxide (**NaOH**) and sodium silicate or potassium hydroxide (**KOH**) and potassium silicate. Most commonly used alkaline activator is combination of NaOH and Na₂SO₃. Generally NaOH is available in the market in pellets or flakes form with 96% to 98% purity. Solution of NaOH is formed by dissolving these pellets in water to obtain a solution of particular molarity. It is strongly recommended that the sodium hydroxide solution must be prepared 24 hours prior to use and also if it exceeds 36 hours it terminate to semi solid state (R Anuradha et al. 2011), So the prepared solution should be used within this time. Sodium silicate is available in gel form in market. It is also diluted with water and then mixed with NaOH to form alkaline activator liquid.

PREPARATION OF GEOPOLYMER CONCRETE MIX

Since no specific codal guidelines are available for design of GPC mixes, Geopolymer concrete can be manufactured by using conventional techniques used in the manufacture of OPC concrete (N A Lloyd and B V Rangan 2010). R Anuradha et al. (2011) prepared mix using mix design procedure given in IS 10262- 2009. Arbitrary guidelines may be followed as per past researches to form the mix.

Firstly source material and aggregates are mixed dry and then alkaline liquid solution is added to them, thus forming a new material called **Geopolymer concrete**. Chemically Si and Al oxides present in the source materials like fly ash, blast furnace slag, or rice husk ash reacts with alkaline liquid to form geopolymer paste which acts as a binder material for coarse and fine aggregates to form GPC. In 99.9% researches NaOH with Na_2SO_3 has been used to form alkaline activator. When the two solutions are mixed together they start to react i.e. (polymerization takes place) it liberate large amount of heat so it is recommended to leave it for about 24 hours thus the alkaline liquid is get ready as binding agent (Davidovits 2002; B V Rangan 2008). For mix proportions in their experiments most of the authors took total volume occupied by fine and coarse aggregates as 77% (L Krishnan et al. 2014; Shankar H Sanni et al. 2013; Yasir Sofi et al. 2015). Fresh concrete is obtained after a proper mixing of about 3-5 minutes. Workability of fresh geo-concrete can be measured by conventional slump test as per IS 516:1959. For making test samples Compaction can done by usual methods as for OPC concrete.

Results have shown that molarity of NaOH, sodium silicate to sodium hydroxide ratio, and alkaline liquid to source material ratio plays very important role in mechanical properties of hardened GPC. Conclusions from some of the test results are as follows:

- With increase in concentration of NaOH strength increases (Yasir Sofi , Iftekar Gull 2015; T V Srinivas Murthy et al. 2014; M A Bhosale, N N shinde 2012).
- Strength increases with increase in sodium silicate to sodium hydroxide ratio up to 2.5 (optimum), below or above 2.5 strength it decreases (Yasir Sofi et al. 2015; T V Srinivas Murthy et al. 2014; A K Rath et al. 2014).
- With increasing alkaline liquid to source material ratio strength decreases (Yasir Sofi et al. 2015).

CURING OF GEOPOLYMER CONCRETE

There can be two methods of curing namely Ambient curing and Heat curing. In ambient curing samples are left at prevailing temperature for 24 hours, heat generated from environment is absorbed by the polymeric material to initiate the reaction. Whereas heat curing can be done either by steam curing or dry oven curing for 24 hours. For steam curing, samples are firstly wrapped by plastic covering then steam is applied to the samples. In dry oven curing also Geopolymer concrete specimens should be wrapped during curing at elevated temperatures in a dry environment (in the oven) to prevent excessive evaporation (Hardjito and B V Rangan 2005). Although Many

researchers have worked on ambient cured GPC (M F Nuruddin et al. 2011; A R Krishnaraja 2014) but it is effective if the fly ash content is partially replaced by GGBFS (Manjunath and Giridhar 2011; Sourav Kr. Das et al. 2014).

N A Llyod and B V Rangan (2010) recommend Heat curing of fly ash based GPC, as it substantially assists the chemical reaction that occurs in geopolymer paste, they also commented that both curing time and curing temperature affects the compressive strength of GPC.

Conclusions regarding the effect of curing temperature and time by various authors can be summarized as below-

- GPC can develop high strength in early age under high curing temperature (Hardjito et al. 2005; Nasvi et al. 2012; T V Srinivas Murthy and A K Rai 2014; M R Nagral et al. 2014).
- Curing temperature of 60^oc is most effective and is regarded as optimum curing temperature (A K Rath et al. 2014).
- Results demonstrate that the compressive strength of dry cured GPC is more than steam cured (Hardjito and Rangan, 2005) and ambient cured GPC(S H sanni et al. 2013; M F Nuruddin et al. 2011).
- Longer curing time improved the polymerization process resulting in higher compressive strength (Lloyd and Rangan 2010; M R Nagral et al. 2014) although beyond 24 hours gain in strength is moderate.

COMPARISON OF MECHANICAL PROPERTIES OF GPC AND OPC CONCRETE BASED ON EXPERIMENTAL INVESTIGATIONS

COMPRESSIVE STRENGTH

Compressive strength is one of the most important and useful properties of concrete. In most of the structural applications concrete is subjected primarily to compressive stresses. In GPC compressive strength depends upon many factors such as curing temperature, curing time, molarity of alkaline activator, mixing ratios. Standard specimens are tested to determine compressive strength of the mix. Results from different test are listed below-

- GPC gains its final strength in 7 days which is 4 times faster than OPC concrete. In 3 days gain in strength is more than 50% (Yasir Sofi and Iftekar Gull 2015).
- Compressive strength of the mix with 50% GGBS in place of cement gives better results than conventional concrete (A R Krishnaraja et al. 2014).
- Geopolymer concrete prepared from a combination of fly ash and MIRHA (Microwave Incinerated Rice Husk ash) showed better results than OPC concrete and non-blended GPC (M F Nuruddin et al. 2011).
- Percentage increase in compressive strength of M20 , M30 and M40 grades GPC as compared to OPC concrete at 7 days is approx 54%, 40%, 20% respectively and at 28 days it is approx 16%, 10%, 2% (R Malathy 2009).
- The percentage increase in compressive strength values of geopolymer concrete at 7, 28, 56 and 90 days are 107.8%, 17.2%, 16.3% and 15.7% respectively (B Rajini and A V Narshimha Rao 2014).

SPLIT TENSILE STRENGTH

In addition to compressive strength tensile strength is another important property of concrete as a structural material. As in case of OPC concrete in GPC also tensile strength is a fraction of its compressive strength. Cylindrical standard samples are tested as per IS 516- 1999 to assess split tensile strength. Results as per many researches are compared below for OPC and GPC-

- GPC has higher tensile strength than that for OPC concrete. As a result, it improves section capacity, delays the first crack appearance and decreases percentage of reinforcement to be used (M Muttashar et al. 2014)
- Olivia and Nikraz (2012) indicated that the tensile strength of GPC is about 8 to 12% greater than of OPC concrete.
- As per T V Srinivas Murthy and Dr. Ajeet Kr. Rai (2014) Split tensile strength of GGBS based GPC is 18 to 24% higher than conventional concrete (M50).
- Percentage increase in tensile strength of M20, M30 and M40 grades GPC as compared to OPC concrete at 28 days is approx 16%, 10%, 6% respectively (R Malathy 2009).
- Geopolymer concrete blended with 100% GGBS shown maximum split tensile strength values at all curing periods and the values are greater than that of the conventional concrete (M45). The percentage increase in split tensile strength values of geopolymer concrete at 7, 28, 56 and 90 days are 23.76%, 3.48%, 8.83% and 13.09% respectively (B Rajini and A V Narshimha Rao 2014).

FLEXURAL STRENGTH

In addition to compressive and tensile strength of concrete, flexural strength is the third important property. This property is used in estimating the loads at which flexure cracks develop in the member. This test is performed on standard beam specimen. A comparison of Results for OPC and GPC from different test are listed below-

- Flexural Strength of GPC increases over ordinary OPC concrete by 1.6 times (D B Rajjiwala and H S Patil 2011).
- Flexural strength test as conducted by T V Srinivas Murthy et al. 2014 shows about 6.7% average increase in flexural strength of GPC over OPC concrete (M50).

OTHER USEFUL PROPERTIES OF GEOPOLYMER CONCRETE

Shrinkage and Creep

In addition to high strength, drying shrinkage strains are extremely small in order of 100 micro strains after one year by GPC as compared with the range of values of 500 to 800 micro strains by OPC concrete (Hardjito and Rangan 2005; Olivia and Nikraz 2012; Wallah and Rangan 2006).

Fire Resistance

When concrete members are subjected to high temperatures, they start spalling and this drastically reduces their capacities. When compared with OPC concrete GPC

is considered as fire resistant. At early part of the curing cycle, high temperature improves the compressive strength of GPC (Satpute et al. 2012). Mane and Jadhav (2012) observed that even when exposed to high temperature of 500°C geopolymer specimen show less reduction (29%) in the capacity than that for OPC (36%). In general GPC has good fire resistance compared to OPC when exposed to more than 800°C (Zhao and Sanjayan 2011).

Chemical Resistance

Durability of concrete structures is very important property which affects service life of structures. Penetration of aggressive substances may damage concrete and corrode reinforcement inside it. GPC has been tested under many aggressive environments, and has proved to have excellent resistance against chemicals like Sulphates, chlorides, and acids.

GPC can be used to build structures exposed to marine conditions (Reddy et al. 2011). Wallah and Rangan (2006) studied the effect of immersing low calcium fly ash GPC in 5% sodium sulphate solution for different time durations up to 1 year and the sulfate resistance was evaluated based on visual appearance, change in length, change in mass, and change in compressive strength. On visual appearance it was observed that there was no sign of surface erosion, cracking or spalling of specimen, change in length was extremely small and less than 0.015%, and there was a slight increase (1.5%) in the mass of specimens due to the absorption of the exposed liquid after one year. Sanni and Khadiranaiker (2012) showed that GPC lost only 15% of its compressive strength on an average compared with 25% for OPC.

Acid resistance of fly ash-based geopolymer concrete has been studied by soaking concrete in various concentrations of sulfuric acid solution up to one year, and by evaluating the behaviour in terms of visual appearance, change in mass and change in compressive strength after exposure (Wallah and Rangan 2006). It was seen that specimens exposed to sulfuric acid undergoes erosion of the surface. The damage to the surface of the specimens increased as the concentration of the acid solution increased. The compressive strength decreased about 20% after one year exposure, concentration and time of exposure influenced it. By exposing to 5% sulfuric acid and hydrochloric acid, Davidovits (1994) reported that geopolymeric cements remained stable in acidic environment with mass loss in the range of 5-8%, compared to 30 to 60% mass loss of calcium-aluminate cement.

BOND STRENGTH

Even though GPC has higher tensile strength compared with OPC, its structural performance still depends on the bonding between concrete and steel bars. Bonding strength between the reinforcement and surrounding concrete is an essential factor to examine the structural performance of the material. D B Rajjiwal and H S Patil (2011) concluded that In Pull Out test, GPC increases over controlled concrete by 1.5 times. GPC shows higher bond strength to the reinforcement because of its higher tensile strength (Sarker2010; Sarker 2011).

ECONOMIC BENEFITS OF USING GPC

Use of fly ash, slag, rice husk ash, and GGBS which are by-products of industries enhances economic benefits of GPC.

- This makes GPC cheaper than Portland cement in terms of the materials cost. After allowing for the price of alkaline liquids needed to make the geopolymer concrete it is 10 – 25% cheaper than that of portland cement concrete.
- Nearly 1 ton fly ash is utilized for 2.5 m³ of GPC thus cutting the world's carbon.
- 1 ton fly ash or GGBS earns one carbon-credit and hence earn monetary benefits through carbon-credit trade.
- Hectares of land which would otherwise be required for dumping of industrial wastes can be saved now.

In addition to the lower price of the production of GPC, its superior properties in shrinkage, creep, resistance to fire and chemical yield in excellent durability and long lifetime for the structure. As a result, fewer damages and less rehabilitation costs will be incurred, which is beneficial for the economic growth of a country.

DEVELOPMENTS AND APPLICATIONS OF GEOPOLYMER CONCRETE IN RECENT SCENARIO

Geopolymer concrete has potential for use in civil engineering applications. High-early strength gain is a characteristic of geopolymer concrete when dry-heat or steam cured, although ambient temperature curing is possible for geopolymer concrete. It has been used to produce **precast railway sleepers, sewer pipes**, and other prestressed concrete building components. Recently, geopolymer concrete has been tried in the production of **precast box culverts** with successful production in a commercial precast yard with steam curing (Gurley J T and Johnson 2005). The products included sewer pipes, railway sleepers, floor beams and wall panels. Reinforced geopolymer concrete sewer pipes with diameters in the range from 375 mm to 1800 mm have been manufactured using the facilities currently available to make similar pipes using Portland cement concrete (N A Lloyd and B V Rangan 2010).

HySSIL is a light weight precast geopolymer concrete product. **HySSIL (High Strength Structural Insulated Light weight)** products has developed a range of cellular Geopolymer precast panels which are half the weight of conventional concrete precast panels, with similar durability and strength and up to five times more insulative than conventional concrete.

Geopolymer concrete bricks produced on an industrial scale are found to meet the minimum compressive strength requirement with low water absorption (Dr. S Ramchandra Murthy 2014).

Another class of geopolymer concrete is fibre reinforced geopolymer units which are gaining attraction due to their high tension capacities.

GPC is becoming popular in Marine structures construction also due to its high resistance against chemical attacks and Due to low permeability values it is being used in Waste containments and mining waste encapsulations.

CONCLUSION

Geopolymer concrete offers environmental protection by means of up cycling low-calcium fly ash and blast furnace slag, waste/by-products from the industries, into a high value construction material needed for infrastructure developments. The document presented brief details of GPC, its properties, relevant comparisons with conventional concrete, economic benefits to the society, and its applications. Following conclusions can be arrived at about GPC

1. Geopolymer concrete has many superior properties compared with its counterpart OPC concrete and GPC is an environmentally friendly sustainable construction material which is becoming increasingly popular.
2. The reduced CO₂ emissions of Geo-polymer concrete make it a good alternative to Ordinary Portland Concrete.
3. Geo-polymer concrete shows significant potential to be a material for the future because it is not only environmentally friendly but also possesses excellent mechanical properties.
4. It is possible to utilize various waste products from different industries (FA, GGBS, Red mud, Copper ash, RHA etc.) through geo-polymer technology for the development of eco- friendly construction material.
5. Recommendations on use of geo-polymer concrete technology in practical applications such as precast concrete products and waste encapsulation need to be developed.

REFERENCES

1. Davidovits, J 1999, 'Chemistry of geopolymeric systems, terminology', in Proceedings of Second International Conference on Geopolymer: Proceedings of Second International Conference on Geopolymer pp. 9 40.
2. N A Lloyd and B V Rangan 2010, 'Geopolymer Concrete with Fly Ash' Curtin University of Technology , Perth australia. (June 2010)
3. M. F. Nuruddin, A. kusbiantoro, S. Qazi, M.S. Darmawan, and N.A. Husin 2011, 'Development of geopolymer concrete with different curing conditions', The Journal for Technology and Science', vol. 22, No. 1.
4. Prof. M.A.Bhosale, Prof. N.N.Shinde july-august 2012, 'Geopolymer concrete by using fly ash in construction', IOSR Journal of Mechanical and Civil engineering vol. 1, Issue 3, pp 25-30.
5. Shankar H Sanni, Dr.R.B.Khadiranaikar 2013,' Performance Of Geopolymer Concrete Under Various Curing Conditions' International Journal of Scientific Research, vol 2 Issue 3, March 2013.
6. Sourav Kr. Das, Amarendra Kr. Mohapatra, A. K. Rath 2014, 'Geopolymer concrete-Green concrete for the future-A review', International Journal of Civil engineering Research, vol. 5, No. 1, pp. 21-28.
7. Yasir Sofi, Iftakar Gull 2015, 'Study of properties of fly ash based geopolymer concrete', International Journal of Engineering Research vol. 3, Issue 1, 2015.

8. L Krishnan, S karthikeyan, S. Nathiya, K.suganya 2014, 'Geo-Polymer concrete –an eco friendly construction material', International Journal of Research in Engineering and Technology, 3(23 ,)pp 164–167.
9. T .V. Srinivas Murthy, Dr. Ajeet Kumar Rai 2014 "Geopolymer concrete, an earth friendly concrete, very promising in the industry', International Journal of Civil Engineering and Technology vol. 5, Issue 7, July 2014).
10. A. R. Krishnaraja, N. P. Sathishkumar, T. Sathish Kumar, P. Dinesh Kumar 2014, 'Mechanical Behaviour of Geopolymer Concrete under Ambient Curing', International Journal of Scientific Engineering and Technology vol 3, issue 2, Feb 2014.
11. R. Anuradha, V. Sreevidya, R. Venkatasubramani, and B.V. Rangan 2011, 'Modified guidelines for geopolymer concrete mix design using Indian standard', sid.ir.
12. Indian standard code of practice, Guidelines for concrete mix design, IS 10262:2009, BIS New Delhi, India.
13. Davidovits, J 2002, 'Personal communication on process of making geopolymer concrete'.
14. B V Rangan 2008, 'Studies on fly ash based geopolymer concrete', Malaysian Construction research Journal, vol. 3, No. 2.
15. Hardjito, D & Rangan, BV 2005, 'Development and properties of low-calcium fly ash-based geopolymer concrete', Research Report, Perth, Australia: Curtin University of Technology.
16. G Manjunath, Giridhar C 2011, 'Compressive strength development in ambient cured geopolymer mortar', International Journal of Earth Sciences and Engineering vol. 4, No. 6 pp. 830-834.
17. Nasvi, M, Gamage, RP & Jay, S 2012, 'Geopolymer as well cement and the variation of its mechanical behavior with curing temperature', Greenhouse Gases: Science and Technology, vol. 2, no. 1, pp.46-58.
18. M R Nagral, Tejas Ostwal, Manoj Kumar V Chitawadagi 2014, 'Effect of curing temperature and curing hours on the properties of geopolymer concrete', International Journal of Computational Engineering Resesarch' vol. 4 Issue 9.
19. Dr. R. Malathy " Fresh and hardened properties of Geopolymer concrete and mortar"(2009) Kongu Engg. College , India.
20. B Rajini, A V Narasimha Rao 2014, 'Mechanical properties of geopolymer concrete with fly ash and GGBS as source materials', International Journal of Innovative Research in Science, Engineering and Technology vol. 3 Issue 9.
21. Majid Muttashar, Weena Lokuge, Warna Karunasena 2014, 'Geopolymer Concrete: The green alternative with suitable structural properties', 23rd Australasian Conference on the Mechanics of Structures and Materials, Australia, December 2014
22. Olivia, M., and Nikraz, H. 2012. Properties of Fly Ash Geopolymer Concrete Designed by Taguchi Method. Elsevier/Materials and Design, Vol 36.
23. Raijiwala D B, H S Patil 2011, 'Geopolymer concrete : A concrete of next decade'. Journal of Engineering Research and Studies. Vol. 2, Issue 1, March 2011.
24. Satpute M B, Wakchaure M R & Patankar S V 2012, 'Effect of Duration and Temperature of Curing on Compressive Strength of Geopolymer Concrete', International Journal of Engineering and Innovative Technology vol. 1, no. 5, pp. 152-155.
25. Sweta Mane , H S Jadhav 2012 "Investigation of Geopolymer Mortar and Concrete Under High Temperature" International Journal of Emerging Technology and Advanced Engineering Volume 2, Issue 12, December 2012)
26. Zhao, R & Sanjayan, J 2011, 'Geopolymer and Portland cement concretes in simulated fire', Magazine of Concrete Research, vol. 63, no. 3, pp. 163-73.
27. Reddy, D, Edouard, J, Sobhan, K & Rajpathak, S 2011, 'Durability of reinforced fly ash- based geopolymer concrete in the marine environment', 36th Conference on Our World in Concrete & Structures, pp. 14-6.
28. Wallah, S & Rangan, B 2006, 'Low-calcium fly ash-based geopolymer concrete: Long-term properties', Res. Report-GC2, Curtin University, Australia. pp. pp. 76-80.
29. Sarker, PK 2011, 'Bond strength of reinforcing steel embedded in fly ash-based geopolymer concrete', Materials and structures, vol. 44, no. 5, pp. 1021-30.
30. D. L. Y. Kong and J. G. Sanjayan, (2010), 'Effect of elevated temperatures geopolymer paste, mortar and Concrete, Cement Concrete', 40 , 334-339.
31. Hardjito, D, Wallah, SE, Sumajouw, DM & Rangan, BV 2005, 'Fly ash-based geopolymer concrete', Australian Journal of Structural Engineering, vol. 6, no. 1, pp. 77-84.
32. B.Vijaya rangan "Geo- polymer concrete for Environmental protection" , special Issue – future concrete.,, December 2010 Proceedings of the International Workshop on Geopolymer Cement and Concrete, Allied Publishers Private Limited Mumbai, India
33. D S Ramchandra Murhty "Fly Ash based GPC bricks for building construction" ICI Journal Oct-Dec 2014
34. Gourley, J.T. and Johnson, G.B 2005, "Developments in Geopolymer Precast Concrete", Proceedings of the International Workshop on Geopolymers and Geopolymer Concrete, Perth, Australia, 2005.