

# A Review on Strength and Durability Studies on Geopolymer Concrete

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**ABSTRACT:** Concrete using Ordinary Portland Cement (OPC) is the most versatile, durable and reliable construction material in the world. While compared with water, OPC concrete is the second most used material. The production of OPC requires large amount of energy consumption, also leading to an enormous emission of carbon di-oxide to the atmosphere, which is being a great challenge to the sustainable development. Efforts are needed to develop an environmental friendly civil engineering construction material for minimizing emission of green-house gases to the atmosphere. A review summary of the extensive literature survey conducted to know about one such environmental friendly concrete namely geopolymer concrete is presented in this paper. In geopolymer concrete, the inorganic alumino-silicate polymer gel synthesised from source materials rich in silicon and aluminium, such as low calcium (class F) fly ash, which binds the loose aggregates, and other un-reacted materials in the produced geo-polymer mix. It is found to be an excellent alternative construction material to the concrete produced using OPC, as the production of this concrete will not utilize ordinary Portland cement. This paper briefly reviews the constituents of geopolymer concrete, its strength and potential applications. The test results demonstrate the excellent potential of geopolymer concrete to be a material of choice for the future.

**KEYWORDS:** Geo-polymer, Fly Ash, Alkaline Activator, Molarity, Durability, Elevated temperature.

## I. INTRODUCTION

Construction is one of the fast growing fields worldwide. As per the present world statistics, annual global production of Ordinary Portland Cement (OPC) is over 4.1 Billion Metric tons. This quantity will be increased by more than 25% within a next 10 years. The main source material for the production of ordinary Portland cement is Lime stone, and there is an acute shortage for the same, availability of which might end within next 40 years. It's a well known fact that production of one ton of OPC, utilizes a huge quantity of energy, with approximately one ton of carbon dioxide emission to the atmosphere as a by-product, which is a major challenge for the sustainable development. Hence it is most essential to find an alternative binder. The output of industrial waste materials which can be suitably used as cement replacement materials (Fly Ash, Slags, Rice Husk Ash etc.) is more than double this amount of OPC annual production. By producing Geopolymer Concrete (GPC) all the above mentioned issues shall be solved by rearranging them. Since Geopolymer concrete doesn't use any OPC, the production of cement shall be reduced and hence the pollution of atmosphere by the emission of carbon dioxide shall also be minimized, also utilizing the Industrial wastes. GPC is being studied extensively and shows promise as a substitute to Portland cement concrete. Research is shifting from the chemistry domain to engineering applications and commercial production of geopolymer concrete.

A French Professor Davidovits [Geopolymer Institute 2010] proposed that an alkaline activating liquid could be used to react with the silicon (Si) and the aluminium (Al) in a source material of earth origin or in by-product materials such as fly ash and rice husk ash to produce binders. Because the chemical reaction that takes place in this case is a polymerization process, he used the term "Geopolymer" in the year 1978 to represent these binders.

These geopolymers depend on thermally activated natural materials like Meta kaolinite or industrial by products like fly ash or slag to provide a source of silicon (Si) and aluminium (Al). Professor B. Vijaya Rangan (2008) said that, the ultimate structure of the geopolymer depends largely on the ratio of Si to Al (Si:Al), with the materials most often considered for use in transportation infrastructure typically having an Si : Al between 2 and 3.5. The reaction of Fly

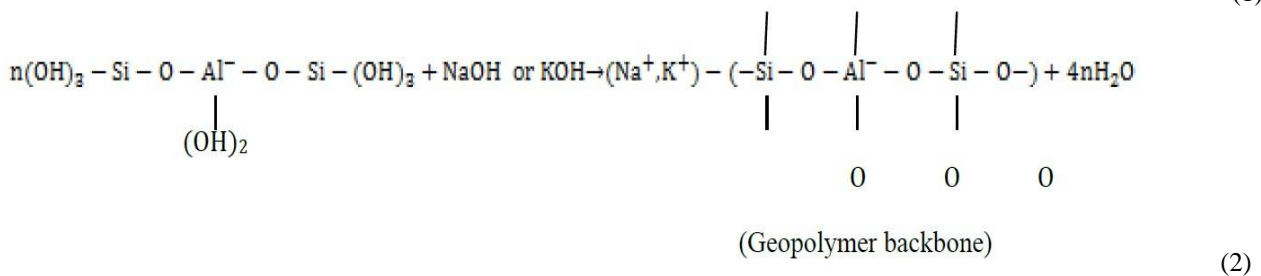
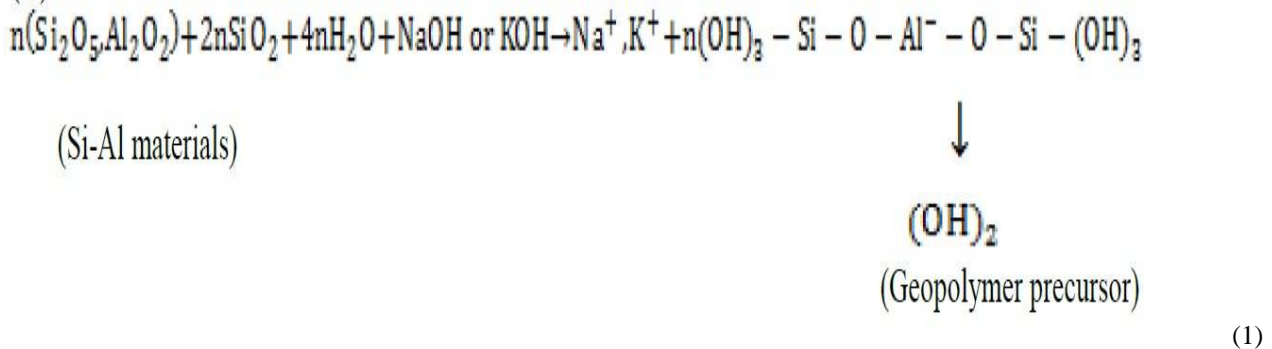
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Ash with an aqueous solution containing Sodium or Potassium Hydroxide and Sodium Silicate in their mass ratio, results in a material with three dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds.

The schematic formation of geopolymer material can be shown in Equations 1 and 2:



During the hydration process in OPC, when the water is mixed to produce concrete, it leads to the production of calcium hydroxide and calcium silicate hydrate during its curing process, but this action is not true in the case of strength gaining action of GPC. The water is not involved in the chemical reaction of Geopolymer concrete and instead water is expelled during curing and subsequent drying. This change has a great impact on the mechanical and chemical features of the final hardened geopolymer concrete element, and also renders it more resistant to heat, water ingress, alkali-aggregate reactivity, and other types of chemical attack.

In the case of GPC produced using fly ash, the role of calcium is very important, because its presence can result in flash setting and thus it must be carefully controlled. The source material is mixed with an activating solution that provides the alkalinity (sodium hydroxide or potassium hydroxide, Sodium hydroxide is often used) needed to liberate the Si and Al and possibly with an additional source of silica (sodium silicate is most commonly used).

Physically Sodium Hydroxide looks like flakes or pellets which is almost white in colour. In normal market it is available with different purity content. It cost also vary with the purity of the substance. Since the geo-polymer concrete is homogeneous in nature and the material is also homogeneous and its main work is to activate the sodium silicate, so it is recommended to use a purity level of 94% to 96% i.e. a low cost sodium hydroxide. Physically Sodium Silicate looks like a gel like liquid, which is also known as water glass or liquid glass. It's the main constituent in the alkali solution required to produce GPC. Because of different % of Na<sub>2</sub>O the strength of geo-polymer concrete varies. With 8% Na<sub>2</sub>O in sodium silicate gives a much more good result with a curing temperature of 45°C.

The temperature during curing is very important, and depending upon the source materials and activating solution, heat often must be applied to facilitate polymerization, although some systems have been developed that are designed to be cured at room temperature. In this paper, an attempt is made to discuss the need, Constituent materials, Fresh and hardened Properties of the Geo-polymer concrete in brief.

## II. CONSTITUENT MATERIALS TO PRODUCE GEOPOLYMER CONCRETE

Geo-polymer concrete is generally a mix of binder and alkali solution with fine aggregate and coarse aggregate, where the role of binder plays by mainly Fly-ash, but with a replacement of some percentage of fly-ash with Ground Granulated Blast Furnes Slag (GGBS) shows a good result. The alkali solution is the mixture of Sodium Hydroxide (or

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Potassium Hydroxide) and Sodium Silicate (or Potassium Silicate) to a different ratio. In addition to above mentioned major ingredients, some of the researchers also suggested to use admixtures such as Naphthalene Based Super Plasticizer, and glass powder (Mithanthaya et. al 2015) to improve the fresh and hardened properties of GPC.

### III. MIX PROPORTIONING AND PROPERTIES OF GEO-POLYMER CONCRETE

There is no standard mix design approaches are yet available for GPCs. Djwantoro Hardjito, et al (2004), showed that the geopolymer paste binds the coarse aggregates, fine aggregates and other un-reacted materials together to form the GPC, and usual concrete mixing methods to produce GPC mixes can be often employed. Mixture proportions are characterized by an alkaline liquid to fly ash by mass of 0.35 and aggregate to total mass proportion of approximately 75% with the nominal strengths. Same as in the OPC concrete, the aggregates occupy the largest volume, (about 75-80 % by mass) in GPCs. The silicon and the aluminium in the fly ash are activated by a combination of sodium hydroxide and sodium silicate. The influence of aggregates, such as grading, angularity and strength, are considered to be the same as in the case of Portland cement concrete [Lloyd and Rangan, 2009]. Thus the geopolymer concrete mix design can be obtained using the tools currently available for OPC concrete or from the available standard literature.

A lot of studies have been carried out on fly ash-based geopolymer concrete. The compressive strength and the workability of geopolymer concrete are influenced by the proportions and properties of the constituent materials that make the geopolymer paste. Research results [Hardjito and Rangan, 2005] have shown the following:

- Higher concentration (in terms of molar) of sodium hydroxide solution results in higher compressive strength of geopolymer concrete.
- Higher ratio of sodium silicate solution-to-sodium hydroxide solution ratio by mass, results in higher compressive strength of geopolymer concrete.
- The slump value of the fresh geopolymer concrete increases when the water content of the mixture increases. Superplasticizers may assist in improving workability.
- As the  $H_2O$ -to- $Na_2O$  molar ratio increases, the compressive strength of geopolymer concrete decreases.

The main interesting characteristics of geopolymer concrete according to Prof. B.V.Rangan and Hardjito are summarized as follows:

- It can set at room temperature without any elevated temperature.
- It's highly resistant to chemical action, its non-toxic and bleeding free.
- It has a higher compressive strength of about 1.5 times than a normal OPC concrete mix.
- It's impermeable like normal OPC concrete.
- It shows a higher resistance to sulphate attack after full immersion for 15 weeks in different % of magnesium sulphate solution.
- Geo-polymer mortar shows a higher resistance to sulphuric acid solution.

### IV. FACTORS AFFECTING STRENGTH OF GEOPOLYMERS

The major factors affecting the fresh and hardened properties of GPC are briefly discussed below [Hardjito and Rangan, 2005]:

- *Molarity*: The Molarity of Alkali (NaOH solution) plays an important role in the strength of GPC with a higher concentration of NaOH solution a higher compressive strength can be achieved, A satisfactory result was obtained from 8M to 16M, which has shown an increase in the Compressive strength results for all the produced GPC mix.
- *Sodium silicate to Sodium hydroxide ratio*: The GPC mix produced by maintaining the ratio as 2.5 gives a higher compressive strength. For producing optimum results, a ratio of 1.5 has been suggested.
- *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 binding materials, the mass of sodium hydroxide solids used to make the sodium hydroxide

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solution and the mass of solids in the sodium silicate solution i.e. the mass of  $\text{Na}_2\text{O}$  &  $\text{SiO}_2$ . It has suggested using a ratio of 0.17 to 0.18 to get good strength while designing GPC mix.

- *Fly ash and alkaline activator ratio:* Higher fly ash content with a higher alkaline activator content gives a high compressive strength and vice versa, geopolymer with a ratio of 1.4 to 2.3 provides a high compressive strength.
- *Rest Period:* Rest period is time between casting and curing and is of 3 hour to 2 days, inclusion of a 24 hour period before curing, or rest day, increased the compressive strength of geopolymer concrete.

## V. WORKABILITY OF FRESH GEOPOLYMER

Water also play important role in geopolymer concrete, similar to normal concrete produced using OPC. The amount of water used in geopolymer concrete is to improve the workability, but it will increase the porosity in concrete due to the evaporation of water during curing process at elevated temperature (Kong and Sanjayan, 2008).

Chindaprasirt et al. (2007) discovered an increase in sodium hydroxide and sodium silicate concentration will reduce the flow of mortar. The workable flow of geopolymer mortar was in the range of  $110 \pm 5$  to  $135 \pm 5\%$ . To improve the workability of mortar, super-plasticiser or extra water can be added.

## VI. CASTING AND CURING OF GEO-POLYMER SPECIMEN

Casting of GPC specimens are very much similar to that of OPC concrete specimens in laboratory. Generally the mix design is achieved from the available literature. Then, exact amount of fine aggregates, coarse aggregates and fly ash are weighed to the required quantities and then they are mixed in dry condition in a mixer for 2-3 minutes and then the alkaline solutions prepared (combination of sodium hydroxide and sodium silicate) are to be taken to required quantity in addition to the superplasticizer (if needed) and this solution is added to the dry mix. This mixing is done for 5-7 minutes in the mixer for proper bonding of all the materials. After the mixing is done the mix is filled in the moulds in 3 layers with required compaction and the specimens are kept on a vibrating table so that to minimize amount of voids.

Heat-curing of low-calcium fly ash-based geopolymer concrete is generally recommended. Heat-curing substantially assists the chemical reaction that occurs in the geopolymer paste. Both curing time and curing temperature influence the compressive strength of geopolymer concrete. Heat-curing can be achieved by either steam-curing or dry-curing. Test data show that the compressive strength of dry-cured geopolymer concrete is approximately 15% larger than that of steam-cured geopolymer concrete [Hardjito and Rangan, 2005]. It shows a good strength with continuous heating for the period of general period of heat curing i.e. 24 hours. Till date in most of the cases of geo-polymer it is seen that the geo-polymer concrete is cured by heat curing with a temperature ranging between  $60^\circ\text{C}$  to  $90^\circ\text{C}$  but some results are also obtained with a highly elevated temperature ranging from  $100^\circ\text{C}$  to  $1000^\circ\text{C}$  also.

## VII. MAJOR HARDENED PROPERTIES OF GEO-POLYMER CONCRETE

### COMPRESSIVE STRENGTH OF GPC

Compressive strength is an essential property for all concrete where it also depends on curing time and curing temperature. When the curing time and temperature increase, the compressive strength also increases, due to a fact that at high temperature the rate of polymerization increases and hence a high strength is observed. In addition, the compressive strength of geopolymers also mainly depended on the content of fly ash fine particles (smaller than  $43 \mu\text{m}$ ). It has also observed that, as the fineness of fly ash increases, compressive strength also increases. For different fineness of fly-ash different test results are noted from which it is seen that the maximum strength is generated for that kind of flyash which fineness is  $542\text{m}^2/\text{kg}$ . With the addition of slag the curing temperature of geo-polymer concrete get reduce and it can be cured at room temperature also to get good strength.

### REINFORCED GPCS

The major parameters that effect structural geopolymer concrete are similar to that of ordinary concrete and therefore IS 456:2000 can be applied conservatively. Load carrying capacity of geopolymer beams and slabs are slightly higher

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than normal concrete at similar concrete strengths and the behaviour of geopolymer flexural members are similar as well. The load capacity and behaviour of geopolymer columns are similar to the conventional concrete. The bond strength of GBS is observed to be significantly higher than that of conventional OPC concrete.

## **DURABILITY and LONG TERM PROPERTIES of GPC**

The creep and shrinkage of geopolymers are substantially lower than conventional Portland concrete. Drying shrinkage strains of fly ash-based Geopolymer concretes were found to be insignificant. The ratio of creep strain to- elastic strain (called creep factor) reached a value of 0.30 in approximately 6 weeks after loading on the 7<sup>th</sup> day with a sustained stress of 40% of the compressive strength. The GPC specimens also show a higher resistance to sulphate attack after full immersion for 15 weeks in different % of magnesium sulphate solution in terms of weight loss and compressive strength as compared with conventional concrete. The performance of geopolymer materials when exposed to acid solutions was superior to ordinary Portland cement concrete.

The studies on the effect of corrosion resistance, utilizing activated flyash mortars in construction industry performed well and also indicated reduced corrosion of reinforcing steel. Also, Geopolymer materials do not generate any dangerous alkali aggregate reaction, even in the presence of high alkali content.

## VIII. BEHAVIOUR OF GEOPOLYMER AT ELEVATED TEMPERATURE

Fire resistance of concrete was other properties that are always considered due to the safety of user. Kong and Sanjayan (2008) said that the ratio of fly ash to alkaline solution influence the general strength and fire resistance of geopolymer. It was found that the fly ash-based geopolymer displayed increase in strength after temperature exposure.

Kong and Sanjayan (2010) observed the behaviour of geopolymer concrete under elevated temperature affected by the size of aggregates. The aggregate with smaller sized (<10 mm) could lead to spalling and also extensive cracking of geopolymer but the larger aggregate (>10 mm) were more stable. In addition, the thermal incompatibility between the geopolymer matrix and its aggregate components was the most likely cause of strength loss in geopolymer concrete specimens at elevated temperatures. It can be proved by comparison between geopolymer concretes made two different aggregates with distinctly different thermal expansion characteristics. The geopolymer concrete with greater incompatibility led to higher strength loss during elevated temperature. Thus, the expansion of aggregate with respect to temperature was a factor that controls the performance of geopolymer.

## IX. CONCLUDING REMARKS

From the Literature review on the various research articles in the field of geopolymer concrete, it had shown a significant potential as a good engineering material for the future research, as the GPC is not only environmental friendly but also it possesses excellent mechanical properties, both in short term and long term. Further research is needed to understand the science behind geopolymer technology like microstructure, rheology of fresh concrete etc. The economic benefits and contributions of geopolymer concrete to sustainable development are evident.

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