International Journal of Disaster Recovery and Business Continuity
Vol. 12, No. 1, (2021), pp. 668-673

# An Investigation On Geopolymer Concrete: A Review

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**Abstract**

*In the world of concrete, where cement is the main constituent, there is a new development named as Geopolymer concrete (GPC). In Geopolymer concrete, the cement is totally replaced by pozzolanic materials like fly ash or ground granulated blast furnace slag. The Geopolymer concrete uses highly alkaline activators to act as binder for the concrete. An experimental investigation has been carried out in order to find the suitable ingredients of the Geopolymer concrete and mix design procedure is proposed to achieve the desired strength at required workability. The fly ash, being waste is disposed and hence poses an environment threat. Also for reducing the cement consumption, effective promotion of Geopolymer concrete is required. And hence, mix design procedure for production of Geopolymer concrete is essential. Therefore, efforts have been made in order to develop a mix design methodology for Geopolymer concrete with the main objective on achieving better compressive strength in an economical way. Fly ash of Class F is used as a binder material for this study, which was brought from local sources. Based on the investigation carried out, sodium hydroxide and sodium silicate are taken as alkaline activator solutions. To achieve the compressive strength in an economical way, correlation between alkaline activator solution molarity and 28 days compressive strength has been investigated for the advancement of conceptual mix design method for Geopolymer concrete. The proposition of mix design includes various molarities of alkaline activator solution ranging from 12 to 16 M and the 28 day compressive strength has been calculated. The proposed design methodology has been given step wise and its verification is given with the help of example in this research. Geopolymer concrete consists of broader range of constituents and therefore for obtaining the best strength of Geopolymer mix, numerous trial mixes are required. In this research, strength criterion mix design is proposed in an economical way, considering all primary constituents and their proportions. The tests for workability, compressive strength and durability are included in this research.*

## 1. INRODUCTION:

### 1.1 Background:

It is well known fact that concrete is one of the many widely used materials in the world [1]. The requirement of housing and infrastructure is directly proportional to the ever increasing population. The global demand of building material is being fed upon by the above mentioned increased demand of housing [3]. The primary binder used to produce concrete is Ordinary Portland Cement (OPC) [1]. In the current scenario OPC based concrete is the leading construction material with 4.0 billion tons of cement usage per annum and having a growth rate of 4% per annum [2]. The manufacturing process of OPC generates carbon dioxide in the range of 0.6 to 0.8 kg for every kilogram of cement, which further results in 5 to 7% of carbon dioxide emissions worldwide [3].Also OPC production consumes significant amount of natural resources [1]. Simultaneously, industrial wastes such as fly ash, ground granulated blast furnace slag, mine waste, red mud etc. are being disposed in large areas of useful



ISSN: 2005-4289 IJDRBC

land, impacting the environment [2]. This level damage of pollution to the atmosphere is unsustainable and hence motivated the research for environmentally friendly concrete. Geopolymer concrete is one such concrete which reduces the CO2 emission up to 26 to 45% [3].

### 1.2 Geopolymer Concrete Development:

Due to the growing demand of OPC and limited reserves of limestone, the concrete industry faces a lot many challenges before itself including the slow manufacturing growth and the increasing carbon taxes on production of Ordinary Portland Cement (OPC) [6]. People's attention to depleting natural resources and environment harm caused by OPC has led to the lookout for alternatives to accustomed construction materials [2]. 100% replacement of the amount of OPC in the concrete with a byproduct material such as Fly ash is such alternative, termed as Geopolymer concrete(GPC), the environmentally friendly product [1]. The commercial name of alkaline activated concrete (AAC), Geopolymer concrete(GPC) results from the aluminosilicate waste materials and alkaline activators [4] The development of aluminosilicate polymer, Geopolymer, is synthesized from materials of geological origin being rich in silicon and aluminium such as fly ash. The source material of GPC, Fly ash is abundantly available worldwide and to date its utilization is limited [1]. Other GPC binders can be produced from various natural and industrial by products such as metakaolin, fly ash, ground granulated blast furnace slag, red mud, mine waste etc. [2] Early compressive strength, low permeability, good chemical resistance and excellent fire resistant behavior are the various characteristics of GPC [6] Effective evaluation of the waste source materials, poor workability due to sticky mortar and cost concentrated alkali silicate as activator are the various issues faced during the practical use of GPC. Despite these many GPCs perform even better than Portland Cement Concrete (PCC) for chemical resistance, high temperature strength, resistance to chloride penetration and freeze thaw cycle [5].

Low calcium class F fly ash is used. The alkaline activators typically provided for the geopolymeric reaction are sodium hydroxide (NaOH) in combination with sodium silicate (Na2SiO3) [2]. The silica and alumina oxides contained in the fly ash react under highly alkaline environment to produce an amorphous three-dimensional network of silicon and aluminium atoms linked by oxygen atom [3]. The study of Geopolymer is done extensively and the research is shifting from chemistry domain to engineering applications [7].

### 1.3 Significance of Research:

In the paper presented, the factors influencing the strength of GPC are studied and the corresponding outcomes of the research are discussed. GPC has not been studied in detail in India. Also India is facing major problems of depletion of natural resources such as limestone. Hence detailed study of GPC is a much need of the time [1]. It has been noticed that the mixing sequence of fly ash, alkaline activators and aggregates have an effect on geopolymerization process and on the compressive strength attained. Also the molarity oh sodium hydroxide solution affects the leaching behavior of aluminates and silicates of fly ash. The otherfactors which affect the compressive strength of GPC are Na2SiO3 to NaOH ratios, effect of curing temperature and time of curing, activator solutions to fly ash ratios, water to geopolymer solids ratios by mass and fineness of fly ash [2]. Researches published till date on fly ash based GPC had the chemical and physical properties of precursor fly ash as a main subject of focus. However, for the development of a standard mix design for GPC, limited study has been done [3]. Hence an attempt has been made in the present investigation for the mix design procedure of geopolymer concrete. The research in the presented paper aims to deliver a comprehensive review on the design methodology of Geopolymer concrete. In order to enhance the overall performance of GPC the various parameters affecting its compressive strength have been



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investigated such as ratio of alkaline liquid to fly ash, concentration of sodium hydroxide, ratio of sodium silicate to sodium hydroxide, curing time, and curing temperature in the Geopolymer concrete mixes [1].

## 1.4 OUTCOMES OF LITERATURE REVIEW:

M. I Abdul and P.D. Arumeiraj in their paper “Geopolymer Concrete – A Review” conclude that, ' User-friendly geopolymer concrete can be used in place of conventional concrete in same conditions. Geopolymer have high early strength so it can effective in precast industries. The problem in concrete world like shortage, breakage and transportation can be minimized Geopolymer concrete also useful in reinforcement structure. Due to use of fly-ash landfills problem reduced.[15] Chau-Khun Ma, Abdullah Zawawi Awang and Wahid Omar in their paper “Structural and material performance of geopolymer concrete: A review”, perform experiment on concrete using different types of waste product which have cementious properties for the replacement of cement in concrete. The paper gives the idea of performance of geopolymer concrete on material basis and structure basis. On the basis of alumina Silicate source author categories Geopolymer concrete in six group. They are FA (Fly Ash)-based, MK(Metakaolin)-based, SG(Slag)-based, RHA (Rice Husk Ash)-based, HCWA (High Calcium Wood Ash)-based and combination of either two of the earlier mentioned alumino-silicates. From the above types Fly-Ash based Geopolymer concrete gives best results.[16] Shahikant and Prince Arulraj G in their paper “A Research Article on Geopolymer Concrete” made a detailed review of geopolymer concrete and reported that fly-ash is the most widely used material for geopolymer concrete, optimum time of curing to be 20 to 24 hours. Sodium Hydroxide (NaOH) of concentration of range 8M to 16 M widely used. Author reported that 20% replacement of fly-ash withordinary Portland cement gives higher compressive strength than geopolymer concrete. The authors coins the term “Semi Geo-polymer Concrete” which means partial replacement of fly ash by cement.[17] Prakash R. Vora and Urmil V Dave in there paper they researched on ' Parametric studies on compressive strength of geopolymer concrete'.[1] They studied various parameters such as alkaline liquid to fly ash ratio,effect of sodium silicate solution to sodium hydroxide solution on compressive strength and effect of curing period.They get the result that optimum value of compressive strength gains at AAS to fly ash ratio of 0.35.Also compressive strength of geopolymer concrete at sodium silicate to sodium hydroxide ratio of 2.5 is lesser than ratio at 2.Also they researched that as curing temperature and curing time increases compressive strength increases.[12] DjwantoroHardjito, Steenie E Wallah in their paper they studied 'On the development of fly ash based Geopolymer concrete'[2].They researched effect of curing temperature,curing period,effect of creep and shrinkage,effect of percentages of superplasticizers on Geopolymer concrete. They found that as curing temperature increases, compressive strength increases. Also, they found when superplasticizers are used 1 to 2% by mass of fly ash, compressive strength increases. They also reported that as water to geopolymer solid ratio increases, compressive strength decreases. Also geopolymer concrete undergo little creep and very less drying shrinkage.[13] Supriya Kulkarni in her paper she study on 'Geopolymer concrete' compared various parameters of geopolymer concrete and conventional concrete. She also concluded that GPC is more resistant to fire and corrosion.Also when GPC is steam cured ,it gains 10% more strength.[14]

## 2. PARAMETER CONSIDER FOR GEOPOLYMER CONCRETE:

### 2.1 Fly Ash:



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Fly ash is a fine particular solid product of coal combustion. The composition of which varies according to the components and source of the coal being burned. Although all fly ash has silicon di oxide, aluminium oxide, and calcium oxide in a considerable substantial amounts.There are mainly two types of fly ash defined by ASTM C618, class C fly ash and Class F fly ash. Both Class F and Class C fly ash can be used in concrete works but Class F fly ash shows more better performance than Class C fly ash when it gets cured at high temperature.

**Class F:**

Class F fly ash produces after the burning of anthracite and bituminous coal. This fly ash contains less than 7% lime. Its nature is pozzolanic.

**Class C:**

Class C fly ash produces after the burning of sub-bituminous coal. It offers self-cementing properties. This fly ash contains more than 20% lime, Class C fly ash contains alkali and sulfate in higher amount.

### 2.2 Solution:

Sodium or potassium based soluble alkalis are mainly used as the alkaline activator. The commonly used alkaline activators are sodium hydroxide in combination with sodium silicate. These two solutions are added in the proportion of 1:1.5 will get better results. Depending upon the molarities of solution compressive strength of geopolymer concrete also varies. Solution having 16M molarity shows highest compressive strength, above which it becomes uneconomical.

### 2.3 Solution to fly ash ratio (AAS/ FA):

Joseph Davidov it's found that fly ash reacted with alkaline activator solution and formed a binding material. Hardijito & Rangan observed that higher concentration of sodium hydroxide (molar) results higher compressive strength and higher the ratio of sodium silicate to sodium hydroxide, gives higher compressive strength of geopolymer concrete.[10] Solution to fly ash ratio ranges from 0.3 to 0.8 and in order to verify the mix design procedure, a sample design of GPC with AAS/FA ratio of 0.35 is considered.It is observed that as we increased the AAS/ FA ratio from 0.3 to 0.8, compressive strength of concrete decreases and slump value increases.

### 2.4 Water to Geopolymer Binder Ratio:

**D. Bondaretal** indicated that the strength of geopolymer concrete decreased as the ratio of water to geopolymer solids by mass increased.[11]

**Ferdous M.W. et al. (2013)** proposed a method for selecting the mix proportions of fly ash based geopolymer concrete and their experimental results showed that the compressive strength of the fly ash based geopolymer concrete decreased linearly with increase in the water to geopolymer binder ratio.[7]

**Sudhakar reddy K et al (2018)** reported that at 6% of replacement of cement in fly ash of geopolymer concrete yields the betterresults in flexural strength of beams. They also reported that higher replacement of fly ash in geopolymer concrete increases the strength of concrete.[8]

**Fan F et al. (2017)** carried out an experimental investigation on the thermo-mechanical properties of geopolymers prepared using a class F fly ash, KOH and $Na2SiO3$ solution. They reported that the compressive strength of the geopolymer with the water/ash ratio of 0.25 and 0.3 are very close, and the residual strength of the geopolymer matrix after 500C heating with the water/ash ratio of 0.3 is higher than that for the water/ash ratio of 0.25, which shows that the water/ash ratio of 0.3 might be the optimal mixture ratio. [9]



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### 2.5 Degree of Heating:

Increases compressive strength when temperature is in the range of 30 to 90 ℃ and longer curing time increased the compressive strength. Researchers work with the geopolymer concrete up to120 minutes without any sign of setting and without any reduction in the compressive strength, result in very little drying shrinkage and low creep.Curing at a range of 65℃ to 80℃ in a furnace gives good results but oven curing gives better results. Oven curing provides twice the strength provided by furnace.[10]

### 2.6 Curing Conditions:

Several attempts have been made to study the effect of different curing conditions on the properties of geopolymer pastes. The curing temperatures were reported in the range between 40 ℃ and 85 ℃ for complete geopolymerization reactions. Palomo et al studied curing of alkali activated fly ash (0.25 and 0.30 liquid/solid ratio) at 65 ℃ and 85 ℃. They indicated that the compressive strength of geopolymers (8–12 M) cured at 85℃ for 24 h was much higher than those cured at 65 ℃. Curing after 24hr gives much smaller rise in strength. Perera et al studied the curing of metakaolin-based geopolymers under ambient (21–23 ℃) and heat conditions (40– 60 ℃) with a controlled relative humidity (RH) for 24 h and found that curing at 30% RH was preferable to that at 70% RH. Heah et al concluded that the curing of metakaolin-based geopolymers at ambient temperature was not feasible while increase in temperature (40 ℃, 60 ℃, 80 ℃, 100 ℃) favored the strength gain after 1–3 days. However, curing at higher temperature for a longer period of time caused failure of samples at a later age due to the thermolysis of –Si–O–Al–O– bond. Rovnanik reported that curing of metakaolin based geopolymer at elevated temperature (40 – 80℃) accelerated the strength development but in 28 days, the mechanical properties deteriorated in comparison with results obtained for an ambient or slightly low temperature. Ebrahim and Ali prepared three mixes with different formulations and cured hydrothermally at different temperatures (45, 65, 85 ℃) and time (5–20 hr) after 1 and 7 days of procuring. Resting longer at room temperature, before curing is beneficial for higher strength development. In general, adequate curing of geopolymeric materials is required to achieve optimal mechanical and durability performance to maintain their structural integrity.

## 3. ADVANTAGES OF GEOPOLYMER CONCRETE:

1. High initial strength.
2. Environment friendly.
3. Reduction in pollution by using waste materials like fly ash and slag.
4. Produce less emission of carbon dioxide than cement.
5. Gives high strength and durability.

## 4. DISADVANTAGES OF GEOPOLYMER CONCRETE:

1. No standard mix design.
2. Requires a specific curing conditions for fly ash based geopolymer concrete.
3. Concentrated chemicalsare used, which require skilled labors.



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## 5. CONCLUSION:

Conventionally, geopolymer binders require heat curing, high pH and also have difficulty in field handling. Hence efforts are required to develop room temperature cured geopolymer system using solid activators in place of alkaline solutions.

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ISSN: 2005-4289 IJDRBC

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ISSN: 2005-4289 IJDRBC