



GEPOLYMER CONCRETE: AN ECO-FRIENDLY CONCRETE OF MODERN DAYS

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ABSTRACT

Concrete is a mix made up with fine aggregate, coarse aggregate, binding material as cement and water, which is used as a construction material. Concrete is used in almost all type of construction and cement is a very important ingredient to be added in concrete. Ordinary Portland Cement (OPC) is a common type of cement which is used. But OPC generates a huge amount of CO₂ in the environment and thus increasing the pollution level. Geopolymer concrete is such a type of special concrete where geopolymer like fly ash, ground granulated blast furnace slags (GGBS), etc. are used instead of cement and thus making the concrete an eco-friendly concrete. In this paper, a general overview on geopolymer concrete has been discussed. This paper also focuses on the history and advancements of geopolymer concrete along with its advantages, disadvantages, and applications in India. This paper also made a study of about various research works about the mentioned topic across the globe.

Keywords- CO₂, Fly ash, GGBS, Geopolmer Concrete, Sodium Silicate

INTRODUCTION

Geopolymer concrete is a special kind of concrete where different types of geopolymers are used in place of cement. Geopolymers are inorganic, ceramic materials that form long-range, covalently bonded, non-crystalline networks. In Geopolymer concrete, the concrete is made by reacting aluminate and silicate bearing materials like fly ash, blast furnace slags, etc. with a caustic activators like sodium hydroxide, sodium silicate, etc.

Fly ash which is rich with silica and alumina activated with alkaline activators form aluminosilicate gel that act as the binding material for the concrete [1]. Some research works and studies about the geopolymer concrete is discussed herewith. Kulkarni, S [1] made a paper based on various studies of geopolymer concrete. Author also showed the compressive strength variation between conventional concrete, geopolymer concrete with water curing and geopolymer concrete with steam curing collected from different papers. Das, S.K. et al [2] made a paper involving different studies on the properties of fresh and hardened concrete i.e. setting time and workability, compressive strength and durability and finally concluded that geopolymer concrete is better than OPC based concrete. Shashikant, Prince Arulraj G [3] presented a research article about geopolymer concrete and its various limitations and other features. Author mentioned that as presence of OPC in concrete is the reason for the emission of 5% of total global CO₂ hence it is high time to consider geopolymers as an alternative to cement. Author also highlighted from his study that replacement of fly-ash with 20% of ordinary

Portland cement gives higher compressive strength than geopolymer concrete. Rajamane.N.Pet.al[4] presented a paper on the geopolymer cement concrete from the data collected from CSIR-SERC, SJCE, and SRMU. Author highlighted that the data obtained from stress-strain curves, bond strengths, corrosion and sulphate resistances, thermal conductivity, etc. that geopolymer concrete will have satisfactory structural and durability performances with low carbon foot print. Rajamane.N.P et.al [5] conducted a research experiment over geopolymer concrete and concluded that geopolymer concrete were found to resist sulphate attack unlike OPC where decalcification of C-S-H gel takes place due to exposure to high concentration of $MgSO_4$ and forms Magnesium Silicate Hydrate (M-S-H). Author also examined the Eco-friendliness of geopolymer concrete with various parameters like Embodied Energy, Embodied Carbon, etc. and found that geopolymer concrete was superior. Vahini M. et. al [6] presented a paper to study the effect of naphthalene based superplasticizer on geopolymer concrete blended with GGBS and discussed its result based on workability, strength properties, etc. Boopalan.C and Rajamane.N.P[7] studied and investigated the bond strength with the reinforcing bars and geopolymer concrete so that this can be even used in RCC field and concluded that the bond strength for the geopolymer concrete were higher than conventional concretes. Chithambar and Muthukannan[8] did a review research paper to focus on the influence of different variables like M-sand, alkali activators, curing period and time etc. on geopolymer concrete and the progress of research in the field of geopolymer concrete. Singh. H.V and Maanik.V[9] in their project paper did a mechanical and durability analysis of geopolymer concrete with a practical experiment by using sodium hydroxide and sodium silicate as fluid and fly ash and GGBS as geopolymers. Sabitha.D et.al [10] did a research work between the potassium and sodium activated fly ash based geopolymer concrete and concluded that potassium activators lowers the initial setting time, enhances the reactivity of the components and thus improves the compressive strength, and even sucrose can be used to enhance the workability but will reduce down the strength. Lateef. N. Assi et.al [11] did a research work globally to understand the availability of raw materials for the geopolymers. Author in the study said that more researches are required to reduce the use of sodium hydroxide to improve availability and reduce the cost of geopolymer concrete. Author also added that only 7% replacement of OPC with geopolymer concrete is feasible due to limitations in sodium hydroxide supply whereas 25% replacement is desirable. Rajamane.N.Pet. al[12] did a study of the comparison between PPC concrete and geopolymer concrete against sulphate attack and reported that on exposure to 2% and 10% sulphuric acid, loss of strength, weight and thickness in geopolymer concrete is much lesser than PPC concrete due to absence of free lime in geopolymer concrete.

HISTORICAL BACKGROUND OF GEOPOLYMER CONCRETE

The concept of Geopolymer concrete was first introduced by a french scientist and archeologist Prof. Joseph Davidovits. He was honored with Chevalier de l'Ordre National du Mérite, one of the two highest award of France for his works and is worldwide famous for his works on geopolymers.



Fig No.:1 Prof. Joseph Davidovits (Ref:Geopolymer Chemistry and Applications, 5th edition) [13]

From the book written by Davidovits himself, "Geopolymer Chemistry and Applications, 5th edition"[13] author mentioned that from the first industrial research efforts in 1972 at the Cordi-Géopolymère private research laboratory, France which was founded by the author himself, until the end of 2019, thousands of papers and patents were published dealing with geopolymer science and technology. In the year 2005, the Geopolymer Institute announced that (www.geopolymer.org): "Since 1997, 80000 papers have been downloaded by 15000 scientists around the world at the geopolymer.org website".

Davidovits[13] in his book described geopolymers as ceramic like inorganic polymers produced at low temperature below 1000°C. They consist of chains or networks of mineral molecules linked with covalent bonds. The raw materials for geopolymer includes rock-forming minerals, alumino-silicates, amorphous silica and industrial by-products like coal fly ashes, blast furnace slag. This raw materials will react with acidic medium and alkaline medium with sodium and potassium hydroxides and soluble alkali silicates.

Davidovits[13] also mentioned that Hardening, or setting, or geopolymerization will occur at low temperature, below 100°C, or at room temperature. The nature of the hardened geopolymer is either X-ray amorphous at ambient and medium temperatures, or X-ray crystalline at temperatures above 500°C for Na-based, and above 1000°C for K-based species respectively and this new material can be used for coatings and adhesives, new binders for fiber composites, waste encapsulation and cement for concrete. The CO₂ emission rate for Kaolin based geopolymeric cement is six times that of Portland cement and for fly ash based geopolymeric cement the CO₂ emission rate falls up to nine times that of Portland cement hence making it an eco-friendly material.

Davidovits[14] in a paper wrote that 1 ton of Portland cement generates 0.95 ton of CO₂. An article published in the magazine New Scientist in 1997 stated that "Davidovits calculated the world cement production of 1.4 billion tonnes a year produces 7% of current CO₂ emission". But in 2012, the situation got more critical when CO₂ emission from Portland cement reached approx. 3 billion tonnes a year.

From the above report present in the research paper of J Davidovits himself, it is clear the importance of geopolymer cement in the present days. Davidovits[14] also classified geopolymer cement into:

- a. Slag based geopolymer cement.
- b. Rock based geopolymer cement.
- c. Fly ash based geopolymer cement.
- d. Ferro-Sialate based geopolymer cement.

EXPERIMENTAL STUDY ON GEOPOLYMER CONCRETE

From Davidovits[13] it has been found that thousands of papers and patents have been published on Geopolymer Concrete till 2019. Likewise many experimental studies have been also performed by different researchers across the globe. Some of the experimental studies have been discussed herewith. Dawczyński.S .et.al [14] conducted an experimental study by considering two different type of geopolymers and carrying out their strength test in the laboratory. The materials used were tungsten mine waste and minced glass in one sample and tungsten mine waste and metakaolin in another sample and sodium silicate and sodium hydroxide as chemical activator and author concluded that both the set of samples showed promising results but required more additional research. Aziz I.K et.al [15] did a detailed experimental study on the strength development on GGBS geopolymer with combinations of various solid/liquid and alkaline activator ratios. Author also performed the micro-structure analysis using Scanning electron microscopy, Fourier-transform infrared spectroscopy and X-ray powder diffraction which is a very advanced nondestructive test using micro X-ray

fluorescence. From results obtained, author concluded that GGBFS with 3.0 solid/liquid ratio and 2.5 alkaline activator ratio results in high compressive strength than other combinations after 28 days of curing. Results obtained from the X-ray powder diffraction test also showed that calcium concentration was higher at silica and alumina regions of the sample. Vora and Dave [16] conducted an experimental study to evaluate the effect of various parameters like ratio of alkaline liquid to fly ash, dosage of superplasticiser, ratio of sodium silicate to sodium hydroxide, etc. affecting the compressive strength and thus to enhance it. Author conducted the test over 20 samples of geopolymer concrete. From the test result, author concluded that compressive strength increases with increase in the curing time and temperature, workability increases with addition of superplasticiser up to 4% of fly ash by mass but decreases with increase in the ratio of water to geopolymer solids by mass. Author also marked that naphthalene based superplasticiser also helps to improve the workability of fresh geopolymer concrete. Sharma A and Singh K [17] presented an experimental study by adding Polyethylene terephthalate (PET) fiber with different percentages in the geopolymer concrete containing fly ash and GGBS and the mechanical and durability properties were studied. Samples were tested after 7 and 28 days and cured by oven curing and ambient curing under controlled laboratory conditions. Author concluded that the tensile and flexural strength showed relatively high strength results with addition of PET fibers which actually acts as a crack arrester during the loading. Rajini B et. al [18] did an experimental research work to study the effect of Fly Ash (FA) class and GGBS of FA0-GGBS100, FA25-GGBS75, etc. on the micro properties of geopolymer concrete at different replacement levels. From the result obtained, author concluded that the mechanical property decreases with the increase in the FA content at the ambient room temperature. Author also did a cost comparison which resulted that initial material cost of GPC (FA0-GGBS100) was about 32% higher than that of M45 grade cement concrete. Rajamane.N.P et.al [5] also in his research work conducted an experiment in which specimen of geopolymer concrete and PPC based concrete were submerged in 5 percent Na_2SO_4 and 5 percent MgSO_4 solutions for 90 days and observed that there was significant changes in strength between geopolymer concrete and PPC based concrete depending on the time and nature of sulphate. Author finally from the test result concluded that geopolymer concrete was better than PPC based concrete against resistant to sulphate attack. Vahini M. et. al [6] did an experimental research work to study the effect of naphthalene based superplasticizer on geopolymer concrete. In the experiment, author replaced the fly ash with GGBS at 20% increment level with a constant dosage of naphthalene based superplasticizer at 3% and studied the changes in the workability and strength properties where workability increases and strength decreases up to 40% for 40% replacement of fly ash with GGBS in presence of superplasticizer.

ADVANCEMENT IN GEOPOLYMER CONCRETE

With the increases in demand of the eco-friendly concrete, use of geopolymer concrete has increased a lot. Day by day various experiments and researches are going on with geopolymer concrete as a result of which various new advancement in the field of geopolymer concrete has been developed. Suksiripattanapong C et. al [19] presented a study where author used the ash obtained from Mae Moh electrical power plant and produced a geopolymer cellular lightweight mortar blocks with certain definite mix proportions and definite alkaline activator ratios. In the experiment author also set out the foam content at 0, 1, 2 and 3% by total solid weight. The result obtained from the experiment showed that unit weight of the cellular lightweight bottom ash based geopolymer (CLBAG) mortar mainly depended on the foam content and lowest unit weight was obtained at foam content of 3% with other certain parameters. Some of the other results which author highlighted were compressive strength increases with the increase in binder and NS content but decreases with the increase in

foam content, thermal conductivity decreases proportionally with the increase in porosity. Author also marked the certain proportions which will produce an optimum CLBAG mortar mix in terms of economy. Revathi T et. al[20] in the study used Cetyltrimethylammoniumbromide (CTAB) and Acetylenicglycol (AG) admixture on a fly ash based geopolymer mix with activator solution of sodium silicate and sodium hydroxide. From the output result, author concluded that workability of geopolymer concrete improved while addition of AG from 0.5 to 2% when the compressive strength was maintained to 30Mpa and also it will help to find out the time available for placing, compaction and transport of geopolymer during large scale preparation. Author also performed the micro-structure analysis. Boopalan.C and Rajamane.N.P[7] in the study used the geopolymer concrete for reinforced structural members, and studied the bond behavior of 12mm and 16mm dia. bars embedded in the geopolymer concrete. Specimens of conventional PPC based concrete and reinforcement embedded geopolymer concrete was considered and pull out test was performed to observe the bond stress and its corresponding slips and observed that bond stress increases with the increase in compressive strength and the peak value of bond stress was observed to be 4.3times more than the design bond stress as per BIS codal provision for reinforcement embedded geopolymer concrete and 3.6times for PPC based concrete. Author finally concluded that the reinforcement embedded geopolymer concrete possessed higher bond strength than that of PPC based conventional concrete. Jeyalakshmi. R et. al [21] did a research work on the effect of heat treatment on fly ash based geopolymer mortar containing fly ash (Class F –Low lime) and alkaline binary activator of sodium silicate and sodium hydroxide when heated at an elevated temperature (200°C, 400°C, 600°C and 800°C) for the sustained period of 2hrs to check the fire related temperature resistance of the sample. From the result obtained, author concluded that the thermal stability of the geopolymer mortar was found to be high. Addition of Zirconium di oxide (ZrO₂) improved the thermal resistance of the sample and no cracks were visible with or without ZrO₂. Prasad B.V and Arumairaj P.D [22] did a review work to study the short term and long term characteristics using class F and class C fly ash based geopolymer concrete and development of hybrid geopolymer concrete by partial replacement of fly ash with cement and slag. Prakash S.A and Kumar S. G[23] did a research work on geopolymer concrete using steel fibres also known as fibre reinforced geopolymer concrete (FRGPC) to determine the mechanical properties such as compressive strength, split tensile strength and flexural strength. From the test result author concluded that compressive strength and split tensile strength corresponding to 1% steel fibres increase up to 5% strength. Keerthi. M et. al[24] did a review research work on the replacement of river sand with various materials like fine bone China ceramic, recycled fine aggregate, waste marble aggregate, iron tallings etc. in the geopolymer concrete. From the study, author concluded that replacement of natural river sand with the above mentioned aggregates enhances the strength parameters.

ADVANTAGES OF GEOPOLYMER CONCRETE

From the various studies and researches made by different researchers, it is very clear that geopolymer concrete is advantageous than normal conventional OPC based concrete. It has been found that production of every 1 metric tonne of cement generates 1 metric tonne of CO₂. Cement industry is one of the worst source of atmospheric pollution than any other industry. Thus the necessity for an alternative material was required and soon geopolymer emerged as an alternative material which is eco-friendly with reduced carbon dioxide emissions [25] Fly ash which comes out from the thermal power plants are very difficult to dispose and hence those fly ash nowadays are used for different purposes and geopolymer concrete is one such thing where those fly ash are used. With the recent advancements in the field of geopolymers, wide range of applications and benefits of geopolymers have come up. Neupane K et.al [26] made a study on the advantages and challenges of

high-strength geopolymer concrete. The study was based on the experimental result and author concluded that high strength geopolymer concrete showed higher tensile and flexural strength, higher durability and lower shrinkage. It also eliminated the problem of high heat of hydration in early age in high-strength concrete.



Fig. No. 2 Advantages of geopolymer concrete (Ref: NMB&CW [25])

Geopolymer concrete is much more long lasting than standard concrete and requires little repair, thus saves huge amounts of money. Apart from these, many researches have proved that fibre reinforced geopolymer concrete, reinforced geopolymer concrete, etc. will impart more mechanical strength and properties than conventional concretes. Rajamane.N.P et.al [5] in his research work showed that geopolymer concrete are also sulphate resistant in nature. Vahini M. et. al[6] in research work showed that use of admixture in geopolymer concrete also enhances its various properties.

DISADVANTAGES OF GEOPOLYMER CONCRETE

Although there are many advantages of geopolymer concrete, but still now geopolymer concrete is not used in most of the cases because of some of its major disadvantages. Some of its advantages are listed below:

- A. Expert and skilled labors who can easily work with geopolymer concrete are not commonly available.
- B. Geopolymer concrete requires high temperature curing which sometimes is not possible on the field site.
- C. For large volume of geopolymer concrete, high amount of sodium silicate as an alkaline activator is required which is difficult to produce.
- D. Sometimes initial cost gets increase.
- E. Though it is accepted that geopolymer concrete is a powerful alternative material and as a sustainable concrete, its application to structural members has not yet gained wide acceptance because of lack of proper structural design standards and codes.²⁵
- F. More research is required for the long term behavior and durability of geopolymer concrete in the long run.

APPLICATIONS OF GEOPOLYMER CONCRETE FOR VARIOUS PROJECTS

Geopolymer concrete has its application in various fields like building up pavements, retaining walls, water tanks as well as precast concrete products like bridge decks, railway sleepers, electric power poles, parking tiles,

etc. Geopolymers are also used for in marine structures for their capacity of resisting sulphate attacks.[27] Recently world's first building with geopolymer concrete has been constructed at, the University of Queensland's Global Change Institute (GCI). It is a four storey high building. 33% panels used in the GCI's floor plates are made of GPCNMB&CW [25].



Fig. No.: 3 University of Queensland's Global Change Institute (Ref: NMB&CW [25])

Other significant present day application includes Brisbane West Wellcamp airport which is the world's largest geopolymer concrete project and was built with about 40,000 m³ (100,000 tonnes) of geopolymer concrete and saved 6,600 tonnes of carbon emissions in the construction of airport. Another major project was the turning node, apron and taxiway aircraft pavements which welcomes a heavy 747 cargo for regular air traffic between Toowoomba-Wellcamp BWWA airport and Hong Kong NMB&CW [25].

In India geopolymer concrete has been used in the Delhi Metro Project. Bhavin B et.al [27]. NTPC-NETRA (NTPC Energy Technology Research Alliance) and CSIR-Central Building Research Institute, Roorkee have developed high strength fly ash based geopolymer concrete for construction of road as per IRC specifications with road stretch of 50 m length and 3 m width and 40 MPa concrete strength, successfully laid at CSIR-CBRI, Roorkee using NTPC Dadri fly ash which is first of its kind in India and this road will not require water curing NTPC [28].

CONCLUSION

As global warming is a major concern nowadays, hence steps have to be taken to reduce the cause of global warming to a large extent. Cement industry can be considered as one of the worst source of global warming due to generation of large amount of CO₂. Hence production of cement have to be reduced. Geopolymer concrete can be a good alternative of conventional cement based concrete from all respect. But still because of various limitations, this concrete is not used for large number of projects. Countries like India where generation of large amount of fly ash is a huge matter of concern as fly ash cannot be disposed easily, hence one can consider geopolymer concrete as a good choice where fly ash can be utilized. Although many experiments and researches are happening worldwide still more intensive research works need to be carried out to overcome the limitations and different constructional organizations have to take steps to increase the use of geopolymer

concrete. Concept of geopolymer concrete have to be included in the syllabus more vastly. More we are familiar with this concept of concrete, more construction projects will take place using this geopolymer concrete, and hence it will be better for the environment also.

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