AN INVESTIGATIVE REVIEW OF ASHES INTEGRATION IN GEOPOLYMER CONCRETE: EXPERIMENTAL INSIGHTS

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Abstract:
The Geopolymer Concrete is an eco-friendly material that utilizes silica and alumina-rich sources such as Fly Ash, Ground Granulated Blast Furnace Slag (GGBS), Silica Fume, and Rice Husk. These materials are combined with alkaline solutions like Sodium Hydroxide (NaOH) or Potassium Hydroxide (KOH) and Sodium Silicate (Na2SiO3). The term "Geopolymer Concrete" is derived from the polymerization reaction that forms the binder. With environmental pollution and global warming being critical concerns, the construction industry's reliance on Ordinary Portland Cement (OPC) is problematic due to its significant pollutant emissions. Producing one ton of OPC releases approximately one ton of carbon dioxide, which exacerbates environmental issues. Geopolymer Concrete Technology offers a promising alternative to conventional OPC concrete. This report reviews the factors influencing the compressive strength of Geopolymer Concrete and outlines the basic casting procedure for geopolymer molds. Sodium hydroxide (NaOH) and sodium silicate (Na2SiO3) are the alkaline liquids used in this study. Cube specimens were cast and tested for compressive strength. Dry heat curing was employed for specimens requiring elevated temperature curing, while others were cured at ambient temperature. The study found that compressive strength increased with reduced fly ash content and increased GGBS content. Notably, the compressive strength of Geopolymer Concrete continues to increase beyond 28 days, unlike Portland cement concrete. The methods of dry heat curing and rest periods are significant in Geopolymer Concrete, and these aspects are detailed further in the report. For all specimens, the Na2SiO3: NaOH ratio was kept constant at 2.0, with a superplasticizer dosage of 2.00% of the combined weight of Fly Ash and GGBS. Additionally, 10% extra water of the combined weight of Fly Ash and GGBS was added to improve workability, and the water absorption of aggregates was separately considered. This project aims to establish optimal values for preparing Geopolymer Concrete using materials readily available in the Indian market.
Keywords: Geopolymer, GGBS, Fly ash, Durability, Compressive strength, Silica

INTRODUCTION

One of the most pressing challenges confronting the world today is global warming, largely driven by the release of greenhouse gases. The cement industry, in particular, stands out as a significant contributor to this problem, posing considerable environmental risks. The production of Ordinary Portland Cement (OPC) is a major concern due to its substantial emission of carbon dioxide into the atmosphere. In response to these environmental challenges, alternative binding agents have been explored, offering not only potential pollution reduction but also economic advantages compared to traditional OPC.

The growing emphasis on sustainability in materials and construction practices has spurred considerable research and development efforts to find viable substitutes for OPC. Among these alternatives, Geopolymer Concrete (GPC) has emerged as a promising solution. GPC is crafted from industrial by-products rich in silica and alumina, including fly ash, ground granulated blast furnace slag (GGBS), and silica fume, which are combined with alkaline solutions like sodium hydroxide or potassium hydroxide and sodium silicate. This chemical amalgamation initiates a polymerization reaction, hence the name Geopolymer Concrete.

A significant advantage of GPC lies in its reduced environmental footprint. Compared to traditional OPC-based concretes, GPCs emit significantly less carbon dioxide during production since they utilize industrial waste materials. This environmentally friendly characteristic makes GPC an appealing choice for eco-conscious construction endeavors. Despite being a relatively new technology, Geopolymer has historical roots, with evidence suggesting similar materials may have been utilized in ancient structures like the pyramids at Giza.

Despite its potential, widespread adoption of GPC has been somewhat limited thus far. Nonetheless, substantial progress is being made, particularly in regions like Europe and Australia, where the technology is advancing rapidly. Researchers are actively addressing challenges such as handling high-alkali activating solutions and controlling temperature fluctuations during the curing process.

Current research endeavors are focused on developing more user-friendly Geopolymer systems that do not rely on high-alkaline solutions, thus broadening the technology's applicability. Although no applications have yet moved beyond the development phase, the long-term benefits of Geopolymer, including its durability and low environmental impact, make it an attractive option for demanding environments such as infrastructure projects.

To further promote the understanding and application of Geopolymer technology, numerous workshops and conferences are being organized globally, including in India. These events aim to facilitate knowledge exchange among researchers, engineers, and industry professionals, providing insights into the latest developments and emerging trends in Geopolymer research. Through collaboration and knowledge sharing, these initiatives are expected to accelerate the adoption and advancement of sustainable Geopolymer Concrete solutions, contributing to global efforts to mitigate environmental pollution and combat climate change.

1. Previous Research Review on Geopolymer Concrete

In **1988 Joseph Davidovits et. al.** who is a French material scientist introduced the term "Geopolymer" to define the family of mineral binders which had same chemical composition as that of zeolites. The microstructure of the binder was found to be amorphous. Geopolymers are different from Portland cements as there is no hydration process in their case and there is no formation of calcium silicate hydrates in the matrix. The Geopolymer gains its structural strength by process of poly-condensation which is carried out between silica and alumina. The chief ingredients of Geopolymer concrete are the source material and the alkaline liquid. The selection of source material depends upon the content of silicon and aluminium present. The source material should be rich in both of the above minerals. Whereas alkaline liquids used are NaOH/KOH in addition to Na_2SiO_3. Other alumina-silicate materials such as zeolites, alumina-silicate gels etc. are different than Geopolymers. For e.g. alumina- silicate gel have less concentration of solids when compared with Geopolymerisation.

Škvára František et. al.

"Concrete Based on Fly Ash Geopolymers"

The authors of the above paper developed fly ash based Geopolymer concrete. The fly ash was collected locally from the Czech power plant. The Geopolymer concrete was tested for its different properties such as rheological properties, strength evolution, chemical composition, porosity and the interference caused by aggregates. It was found that there was no damage to specimens subjected to NaCl for even upto 720 days i.e. no corrosion was found. The maximum compressive strength that was observed in the research was found to be 70MPa when tested after 28 days.

Rangan B. V.

"Fly ash-based geopolymer concrete"

The above research included wide range of study conducted on Geopolymer concrete. In this study specimens of reinforced Geopolymer concrete were casted and tested for different long term and short term properties. From the results it was found that the compressive strength of specimens for 7 days at elevated temperature was 58 MPa whereas for dry cured sample it was 45 MPa. The compressive strength for the steam cured specimen was found to be 56 MPa. [4]

McDonald M., et. al.

"Sodium Silicate: A Binder for the 21st Century"

In this study silicate chemistry and formulation were studied. They described the method for preparing sodium silicate binder. They stated that when discussing about sodium silicate as a binder, the most important property is weight ratio of SiO_2 to Na_2O. The most common ratio is found to be 3.2 which is adopted all around the world and helps in polymerization process. They concluded that there are many varieties and grades of sodium silicate solution available in the market commercially and it is difficult to select appropriate type for particular research therefore the above paper can help a researcher in selecting suitable type of activator. [6]

Pacheco-Torgal, F., et. al.

"Alkali-Activated Binders: A Review"

The above paper is a review paper on past work on Geopolymer concrete and alkali activated binders. The paper focuses on historical background, terminology and products of hydration. They said that the Portland cement has many disadvantages like it is susceptible to acid resistance, the low durability and high CO_2 emission into the atmosphere. Therefore there is need of alternate material such as Geopolymer concrete. It was said that the exact reaction that takes place in alkali activated binders is yet not known but it depends on the source material that is used and the type of alkali activators used to initiate the reaction. The product of reaction is zeolites as in case of polymers. They studied the step by step processes that take place in the reaction and stated that there are three main stages in this reaction, namely, dissolution, orientation which consists of oligomerisation and polymerisation and hardening which consists of gelisation and transformation into zeolite.

Bo Qu, A. Martín et. al.

"Microstructural characterisation of hybrid cement after exposure to high temperatures"

In his study was designed to determine the mineralogical and microstructural changes taking place in a hybrid alkaline cement (HYC = 30% Portland cement clinker + 70% (slag + fly ash + alkaline activator)) exposed to high temperatures. The cement pastes were heated for 2 h at 400 °C, 600 °C, 800 °C or 1000 °C and subsequently air- or water-cooled. Their mechanical strength was determined after cooling. The HYC pastes had higher residual strength than the reference porland cement (OPC). That better post-thermal performance in HYC and its failure to collapse when water-cooled after reaching temperatures of over 800 °C were attributed to the recrystallisation of scantly hydraulic phases such as gehlenite and rankinite.

Fernández-Jiménez, et. al.

"New Cementitious Materials Based on Alkali-Activated Fly Ash: Performance at High Temperatures"

In this paper the authors studied the behaviour of alkali activated cement in terms of mechanical properties at elevated temperatures containing no OPC. In this study they conducted two types of mechanical tests to study properties of Geopolymer concrete at different temperatures. The results of this study showed that the Geopolymer concrete performed better than conventional concrete in all aspects. Very minute cracks were observed in new binder concrete. Therefore, it was concluded that alkali activated Geopolymer concrete has better thermal advantages when compared to Portland cement concrete.[7]

Sofi Y. et. al.

"Experimental Investigation on Durability Properties of Fly Ash Based Geo Polymer Concrete"

They found out different mix ratios for different grades of Geopolymer concrete and studied the compressive strength and parameters affecting compressive strength of GPC. They also studied the durability properties of GPC such as permability and resistance to acid attack. They concluded that the Geopolymer Concrete possess good compressive strength and good durability properties and also that M20 grade GPC can be formed by adopting nominal mix of 1:1.5:3. They concluded that high temperature of about 60°C is necessary for GPC to gain strength. They also concluded that the Geopolymer concrete has good future in precast industry. [5]

Jamdade P. K et. al.

"Evaluate Strength of Geopolymer concrete by using oven curing".

In this study the researchers developed Geopolymer concrete using alkaline liquids and studied the behaviour and strength characteristics of Geopolymer concrete at different curing temperatures such as 60°C, 90°C, 120°C. They found that the compressive strength of Geopolymer concrete increased with increase on temperature of curing. Polymerization process was improved by longer curing time as a result Geopolymer concrete of higher compressive strength was achieved.[13]

Aravind A. et. al.

"Mechanical properties of Geopolymer concrete reinforced with steel fiber".

Their main area of study was compressive strength and split tensile strength of Geopolymer Concrete. They performed several experiments by using the Box– Behnken experimental design which is a type of response surface methodology. Response surface methodology can be defined as empirical optimization technique which can be used to evaluate the relationship between the experimental outputs and factors called X1, X2, and X3. In order to obtain the results for this approach, variance has been analysed and calculated in order to analyse the accessibility of the model. They concluded that the strength of GPC increased with the increase in molarity of NaOH and longer curing time with temperature ranging between 60°C to 90°C also increased the compressive strength of GPC. Their main conclusion was that the split tensile strength of GPC increased with increase in amount of steel fiber. They also concluded that Box Behnken design can successfully be adopted. [18]

Shah K. C., et. al.

"Strength parameters and durability of fly ash based Geopolymer concrete."

In this research work Mr. Kamlesh first fixed different parameters such as AL to FA ratio, NaOH to Na_2SiO_3 ratio, molarity of solution and curing temperature. At the end of 28 days the compressive strength of GPC mix was found to be 52 MPa whereas compressive strength for OPC mix was found to be 46MPa. Therefore, difference of 6 MPa was noticed between GPC and conventional concrete under same duration of curing. Two mixes were prepared among which the first mix consisted of GPC whereas the second mix was OPC. Both the mixes had equal amount of cementitious material. They concluded that the compressive strength, split tensile strength and pull out strength of GPC mix were higher than that of OPC mix. They also concluded that the oven cured GPC had higher resistant to salt attack, acid attack and sulphate attack. Also minor increase in concrete mass was observed in case of GPC due to absorption of salt and sulphate acids. The test results also showed that the seven days strength of oven cured concrete is way higher than the specimen of concrete cured under ambient conditions. [14]

Jaydeep S., et. al.

"Optimum mix for Geopolymer concrete using admixtures"

The researchers tried to obtain optimum mix for Geopolymer concrete. They casted GPC cubes of size 150x150x150 (mm) and tested them at the end of 7days and 28 days. They adopted two type of curing for Geopolymer concrete that is direct sunlight curing and heat curing at higher temperature. They concluded that the compressive strength of Geopolymer concrete when cured in oven at higher temperature was significantly higher than that cured under direct sunlight. They also found that the strength increases as the molarity of alkaline solution increases.

Sanni S.H., et. al.

"Performance Of Alkaline Solutions On Grades Of Geopolymer Concrete".

They prepared four different mixes for different strength ranging between 30 MPa to 60 MPa. In whole research the molarity of NaOH was kept constant to 8 molar. The alkaline solutions used were NaOH and Na_2SiO_3. Different ratios were set for these alkaline solutions such as 2, 2.5, 3.0 and 3.5. Later the effect of ratio of alkaline solution on compressive strength was studied. Like all other investigations, the test specimens used here were of standard 150x150x150 (mm) size in addition with cylinders of size 100x200 (mm) were casted. They concluded that the workability of GPC increased with increase in amount of alkaline solution which is very obvious. They also found that as the ration of alkaline liquid increases so does the workability. They obtained GPC having compressive strength as high as 60 MPa and split tensile strength as 4.9 MPa. In their investigation they also said that the optimum ratio of alkaline liquid can be taken as 2.5.

Joseph B., et. al.

"Influence of aggregate content on the engineering properties of Geopolymer concrete"

They studied the effect of aggregate content on engineering properties of Geopolymer concrete. They concluded that compressive strength increases with temperature upto 100°C. They also found that early strength of GPC can be achieved by heat curing for 24 hours at suitable temperature. It was found that about 96% of the 28 day strength under normal curing was achieved in 7 days when specimens were heat cured. They also found that the Modulus of Elasticity and Poissions Ratio of GPC can be brought near to or even higher than in case of ordinary concrete.

Laskar A.I., et. al.

"Effect of Plasticizer and Super-plasticizer on Workability of Fly Ash Based Geopolymer Concrete"

In this study they used two type of super-plasticizer among which the first one was Lignin based and the second one was polycarboxylic ether based super-plasticizer. They concluded that when the molarity of alkaline solution was below 4M, the water reducer helped in increasing the slump of GPC which was measured using slump cone. However, at higher molarity of Alkaline solution i.e. above 4M the dosage of super-plasticizer had adverse effect on GPC. In both the cases the Lignin based super- plasticizer was found to be more effective. But it was found that at dosage of above 1.5% segregation of concrete was observed.

Davidovits recommended that a basic fluid could be utilized to respond with the silicon (Si) and the aluminium (Al) in a source material of topographical root or in industries waste material, for example, fly ash, slag and rice husk fiery remains to create folios. Since the reaction that happens for this situation is a polymerization procedure, he instituted the term "Geopolymer". Geopolymer concrete will be concrete which does not use any OPC Cement in its creation. Geopolymer concrete is being examined widely and demonstrates guarantee as a substitute to Portland cement concrete. Now the time has come when the research, from its chemical origin, has shifted to its practical implications and commercial adaption. [1]

While talking about Geopolymer concrete, it has two main constituents, namely the source material and the alkaline liquid. The silicon (Si) and the aluminium (Al) should be the main contents of the source material. The source material could be kaolinite, clays, etc. which occurs naturally or alternatively, one can also use industrial by- product materials such as silica fume, slag, fly ash, rice-husk ash, red mud, etc as source materials. There are different factors on which choice of selecting source material depends such as material should be readily and easily available, cost, specific demand as required by the end user and type of application. Sodium or potassium based soluble alkali metals are used as the alkaline liquids.

The most common alkaline liquid used in Geopolymerisation is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate.[1]

Mostly low-calcium fly ash is favored over high calcium fly ash as a source material in Geopolymer concrete. High amount of calcium is present in fly ash can alter the micro structure of Geopolymer concrete and can also obstruct the polymerization process. The binder acts as the major difference between Geopolymer concrete and conventional concrete. The contents of low calcium fly ash such as silicon and aluminium oxides along with alkaline liquid react with each other and as a result form a mortar known as Geopolymer paste that acts as a binder and holds together all constituents of concrete. The percentage mass ratio for coarse and fine aggregate in Geopolymer concrete is same as that of Portland cement concrete. All other properties and requirements for preparing Geopolymer concrete are same as required for conventional concrete such as strength, grading and angularity of required aggregates. Thus the methods those are already available for designing conventional concrete can be readily used for designing Geopolymer concrete mix.

CONCLUSION

One of the most pressing issues confronting the world today is global warming and its associated adverse climate changes. At the heart of this problem lies the emission of greenhouse gases, with carbon dioxide, nitrogen oxides, and sulfur oxides being the most prominent culprits. Annually, a staggering 23 billion tons of carbon dioxide are released into the atmosphere, presenting an alarming reality. Notably, the Portland cement industry contributes significantly to these emissions, accounting for approximately 7% of the total carbon dioxide released.

The production process of Portland cement, which yields 1 ton of cement from 2 tons of raw materials, generates approximately 0.87 tons of carbon dioxide emissions. Additionally, it produces about 3 kg of nitrogen oxides, ground-level smog, and 0.4 kg of particulate matter, including particles as small as 10μ, directly into the air. These pollutants pose serious health risks to human populations and contribute to various respiratory ailments.

Although efforts have been made to reduce carbon dioxide emissions in the cement industry through technological improvements and enhanced efficiency, inherent limitations persist due to the fundamental calcination process involving limestone. Moreover, limestone mining disrupts land use patterns, alters local water regimes, and compromises air quality, exacerbating environmental concerns.

Dust emissions resulting from the handling of vast quantities of dry materials by the cement industry pose significant hazards to both human health and the environment. In terms of sustainability, cement production falls short as its raw materials are sourced through mining, disrupting natural ecosystems, and the resulting product cannot be recycled.

To address these sustainability challenges, by-products such as fly ash from thermal power plants and slag from the steel industry can be repurposed as binders in lieu of cement. This approach not only reduces energy consumption during production but also minimizes greenhouse gas emissions. By transforming waste by-products into valuable materials, such as Geopolymer concrete, significant energy and raw material resources can be conserved, and greenhouse gas emissions can be mitigated to some extent

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