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EXPERIMENTAL STUDIES ON GGBS BASED GEOPOLYMER CONCRETE: A REVIEW

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Abstract
Geopolymer concrete is a type of concrete that does not use cement as a binder but instead uses industrial by-products such as ground granulated blast furnace slag (GGBS) that are activated by alkaline solutions. Geopolymer concrete has many advantages over conventional concrete, such as lower carbon footprint, higher strength, durability, and resistance to chemical attack. Geopolymer concrete can be made with different proportions of fly ash and GGBS, as well as different concentrations and ratios of alkaline activators. The optimal mix design of geopolymer concrete depends on various factors, such as the properties of the raw materials, the curing conditions, and the desired performance of the concrete. Some researchers have also explored the use of polypropylene fibres to improve the workability and toughness of geopolymer concrete.

Keywords: GGBS, Geopolymer Concrete, Alkaline Liquid, Sodium Silicate, Sodium Hydroxide.

I. Introduction

Geopolymer concrete is a type of concrete that does not use cement as a binder but instead uses industrial by-products such as Ground granulated blast furnace slag (GGBS) that are activated by alkaline solutions. This introduction will provide an overview of the history, composition, properties, advantages, and applications of geopolymer concrete.

The term geopolymer was coined by French chemist Joseph Davidovits in 1978 to describe materials that are formed by the reaction of aluminosilicate minerals with alkaline solutions. He also proposed that ancient civilizations, such as the Egyptians, used geopolymer technology to build some of their monuments. However, this hypothesis is controversial and not widely accepted by archaeologists.
The first modern geopolymer concrete was developed in the 1980s by researchers at the University of Melbourne, Australia. They used fly ash, a waste product from coal-fired power plants, and sodium hydroxide and sodium silicate solutions as the alkaline activators. They found that geopolymer concrete had higher compressive strength, lower shrinkage, and better resistance to sulfate attack than conventional concrete.

Since then, many researchers have experimented with different types of geopolymer concrete using various sources of aluminosilicate materials, such as metakaolin, rice husk ash, blast furnace slag, and red mud. They have also investigated the effects of different parameters, such as the ratio of fly ash to GGBS, the concentration and ratio of sodium hydroxide to sodium silicate, the curing temperature and time, and the addition of fiber’s or admixtures on the properties and performance of geopolymer concrete.

Geopolymer concrete has many advantages over conventional concrete, such as lower carbon footprint, higher strength, durability, and resistance to chemical attack. Geopolymer concrete can reduce the greenhouse gas emissions from cement production, which accounts for about 8% of global CO2 emissions. Geopolymer concrete can also utilize industrial wastes that would otherwise pose environmental problems. Geopolymer concrete can achieve higher compressive strength than conventional concrete in a shorter curing time. Geopolymer concrete can also withstand high temperatures, acids, salts, and alkalis better than conventional concrete.

Geopolymer concrete has been used for various applications in the construction industry, such as pavements, bridges, buildings, dams, and pipes. Some examples of geopolymer concrete projects are the Brisbane West Wellcamp Airport in Australia, the Main Street Bridge in Ohio, USA, and the Mahatma Gandhi Flyover in Nashik, India. Geopolymer concrete is also being explored for potential applications in other fields, such as nuclear waste immobilization, fire-resistant coatings, and lunar construction.

Ground-Granulated Blast-Furnace Slag (GGBS)
GGBS is a principal byproduct produced by steel and iron productions. The furnace is typically run at a temperature of 1500 degrees Celsius. The blast furnace is supplied with a carefully regulated combination of limestone, iron ore and coke. When limestone, iron ore and coke are melted together in a blast furnace, iron and slag are created in the molten state. When the slag from the blast furnace is molten, it is swiftly cooled with strong water jets, which transform it into GGBS, a fine, granular and glassy substance. depicts the GGBS manufacturing process.

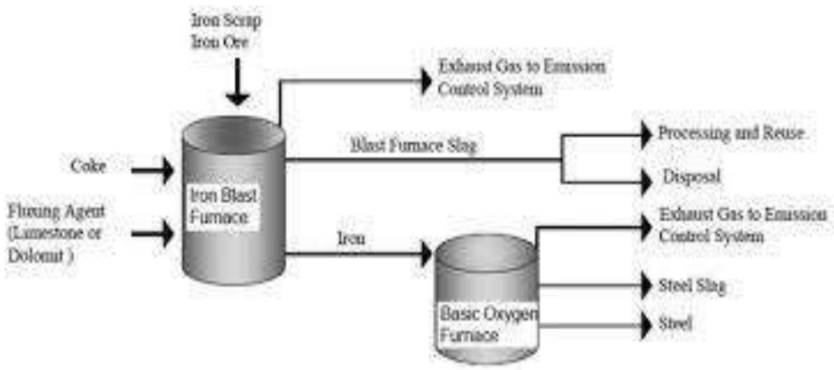

Figure 1.1 - Manufacturing Process of GGBS

II. Literature

Anubhav Rai et al. (2023) studied about the environmentally responsible building materials which are now being researched and produced all over the world to reduce the generation of greenhouse gases and the worrisome rate at which natural resources are diminishing. Geopolymer serves a crucial role in this regard, and various researchers have looked into the many aspects of its suitability as a binding substance. Fly ash-based geopolymer concrete (abbreviated as GPC) has been made using ground granulated blast furnace slag (abbreviated as GGBS) to modify the geopolymerization reaction of fly ash. To ascertain how the amount of Alkaline Activated Solution (AAS) in the mixture of GPC affects the compressive strength of the GPC under ambient temperature, this paper examines the influence of various proportions of GGBS (100%) on fly-based GPC. From the results of the experiments, it was determined that the sodium silicate solution, in which the concentration of sodium hydroxide in the aqueous solution is fixed at a constant value of 10M, increases the compressive strength of the GPC both with an increase in the percentage of GGBS and also with an increase in the amount. Even though there was a small quantity of sodium hydroxide in the solution remained the same. [9]

Md Adil Ahmed (2021) reported that the partial replacement of fly ash in geopolymer concrete with lime and silica fumes up to 7.5 and 2%, respectively, enhanced its compressive strength. Also, properties like setting time and workability were reduced with the use of lime and increased with the use of silica fume. The value of compressive strength of the geopolymer concrete was reported to be the highest at 28 days when the ratio of alkaline activator to binder was 0.4 and 0.35 for 14M and 12M NaOH concentration, respectively, in the alkaline activator solution. The use of 10% also fine by weight of fly ash in geopolymer concrete was observed to give a compressive strength of up to 43 MPa. The use of only one activating solution (10M NaOH) in an ambient cured geopolymer concrete with 100% GGBS produced a higher compressive strength. It was reported that the compressive strength of fly ash-based geopolymer concrete, blended with different proportions of GGBS, increased with the increase of the slag content for all ages up to 180 days. However, a reduction of activator liquid and the addition of water to improve workability decreased the compressive strength. For every 10% increment of the slag content, the 28-day compressive strength increased by about 10 MPa. Compressive strength also increased by increasing the Si/Al ratio in the constituents of the mixtures. In contrast, with the increase in alkaline liquid, a reduction of strength occurred while the setting time and workability increased. Geopolymers produced using three precursors, consisting of Ground Glass Fiber (GGF), glass powder and fly ash were compared, and it was observed that while the addition of soluble Si (i.e., increase in SiO_2/Na_2O) to mixtures has improved the compressive strength of glass-powder and fly ash-based geopolymers, it had decreased the compressive strength of GGF geopolymer samples. Samples that had larger Si content showed high early-age strengths and no significant improvement in later ages. It was also observed that GGF samples had the highest compressive strength for all levels of activator dosage compared with glass-powder-based geopolymer and fly ash samples. Incorporating 10% arccosine (low calcium silicate slag) while preparing fly ash-based geopolymer concrete, 12M of NaOH solution was found to be of the molarity which was optimal to make the GPC more economical (8). It was reported that the geopolymer concrete with ground granulated blast furnace slag (GGBFS) as an aluminosilicate source having a binder content of 450 kg/m^3, SS/SH ratio of 2.5, SH concentration of 14 M and Alkaline to Binder ratio of 0.35 achieved the highest 7-day compressive strength (60.4 MPa) at ambient curing conditions. [10]

Raghda O. Abd and Alftah et al. (2020) studied the effect of Ground Granulated Blast Furnace Slag (GGBS) and concentration of sodium hydroxide (NaOH) solution on the mechanical properties of the Geopolymer Concrete (GPC) with fly ash binder. Strength study of Geopolymer Concrete Incorporating fly ash and GGBS with 10M Alkali Activator Solution. Geopolymer concrete is set up by utilizing a soluble arrangement of sodium silicate and sodium hydroxide. This settled proportion is 2.5 and the concentration of sodium hydroxide is 10M. A summary of the extensive studies conducted on fly ash-based geopolymer concrete is presented. Test data are used to identify the effects of salient factors that influence the properties of the geopolymer concrete and to propose a simple method for the design of geopolymer concrete mixtures. Test data of various short-term properties of the geopolymer concrete and the results of the tests conducted on large-scale reinforced geopolymer concrete members show that geopolymer concrete is well-suited to manufacture precast concrete products that can be used in infrastructure developments. An experimental study on the strength properties of geopolymer concrete prepared using the ground granulated blast furnace slag and fly ash is presented in the paper. The geopolymer concrete was initially prepared with ground-granulated blast furnace slag as the primary binder instead of cement and was replaced with fly ash and blast furnace slag. The addition of more than 20 % of fly ash in geopolymer concrete retards the strength development, although such strength values are still above the target strength of 10 % and 5 % replacement levels. [7]

G. Srinivasa Rao and B. Sarath Chandra Kumar (2019) reported that the researchers are currently focused on various materials to replace and reduce the usage of cement. In this study, Geopolymer concrete is prepared with Ground Granulated Blast furnace Slag (GGBS) with the addition of steel fibers. GGBS is the by-product produced by the steel industry. Steel fibers are added to increase the tensile strength of concrete. In this experimental investigation geopolymer concrete containing GGBS and steel fiber (0.5%) with 8 Molar and 10 Molar alkaline activators are used. The ratio of these alkali activators is 1:2.5. The results showed that fiber can significantly enhance the Mechanical properties. The enhancement also increases with the increasing fiber volume fraction. [1, 25 - 33]

Padmanaban M S and Sree Rambabu J (2018) reported that Geo-polymer concrete is such a one and in the present study, to produce the geo-polymer concrete the Portland cement is fully replaced with GGBS (Ground granulated blast furnace slag) and alkaline liquids are used for the binding of materials. The alkaline liquids used in this study for the polymerization are the solutions of Sodium-hydroxide (NaOH) and sodium silicate (Na_2Sio_3). This study investigates the use of GGBFS (ground granulated blast furnace slag) in 100% replacements by mass in cement. Harden concrete properties like compressive strength, Spilt tensile, and flexural strength of concrete are determined for Geopolymer concrete and Normal concrete. Finally, the test results were compared from the test results, it has been observed that the geo-polymer concrete possess better result than the normal concrete. [8]

P. Guru Chaitanya and K. Bhanu Prakash Reddy (2018) explain that manufacturing of Ordinary Portland cement contributes an average of 5-7% of total greenhouse gases, such as Carbon dioxide emission. A huge number of natural resources are consumed in the production of OPC. Geopolymer concrete (GPC) is one of the processes that reduces cement usage and increases the usage of industrial by-products in concrete. In the present study, OPC is fully replaced by pozzolanic materials and alkaline liquids such as Sodium hydroxide (NaOH) and Sodium silicate (Na2Sio3) to produce the Geopolymer concrete. In this experiment, the effect of pozzolanic materials and concentration of NaOH on concrete is studied. [2]

Anusha and Dheekshith K. (2017) elaborated the study of the effect concrete using cement alone as a binder requires high paste volume, which often leads to excessive shrinkage and large evolution of heat of hydration, besides increased cost. With this view, we have attempted to replace cement with a mineral admixture, (i.e.), ground granulated blast furnace slag (GGBS) in concrete mixes to overcome these problems. This paper presents the workability study of concrete with GGBS as a replacement material for cement without the addition of a Superplasticizer. Concrete grades of M25 have been taken for the work. The mixes were designed using the IS Code method. GGBS replacement adopted was 0% to 25% in steps of 5%. A slump test is conducted to check its workability. The effect of the replacement of cement by GGBS at various percentages on its strength is compared with conventional concrete. [3]

Mr. Gidd M. M. and Birajdar B.V. (2017) explained the process of material is usually based on fly ash as source material and is termed geopolymer or alkali-activated fly ash cement. The mortar and concrete made from this geopolymer possess similar strength and appearance to those from ordinary Portland cement. Geopolymers exhibit many excellent properties such as high compressive strength, low creep, good acid resistance, low shrinkage, fire resistance and other mechanical properties. The work on geopolymer has been based on the normally used low-calcium fly ash. Low calcium fly ash has been successfully used to manufacture geopolymer concrete when the silicon and aluminium oxides constituted about 80% by mass, with a Si-to-Al ratio of about 2. It is also known that high calcium fly ash contains a reasonable amount of silica and alumina. This high calcium fly ash could also be suitable for use as a base material for making geopolymer. [4]

Annapurna Sivakumar and Ravande Kishore (2017) identified that Fly ash (FA), Silica fume, and Ground granulated Blast furnace slag(GGBS), are recognized as a low emission alternative binders for concrete. Recent studies have shown that the properties of Geopolymers are mostly similar to those of the OPC binder that is traditionally used for concrete. Geopolymer has limitations of slow setting at ambient temperature which can be eliminated by using GGBS. In the present study, an attempt is made to study the mechanical properties of Geopolymer concrete (GPC) containing GGBS as an additional ingredient. Five mix cases having varying GGBS dosages have been considered to study the mechanical properties. Standard cubes (150 mm), cylinders (150 mm dia. x 300mm. Length) and prisms (100 x 100 x 500 mm) were moulded to evaluate the mechanical properties of Fly Ash and GGBS-based Geopolymer concrete. The results of the investigations indicate that all the mechanical properties of Fly ash and GGBS-based Geopolymer concrete are in good agreement with conventional concrete properties. [5]

Baljot Kaur (2019) concluded that the use of cement has been rising at its peak in the last few decades due to the enormous demand for the construction of megastructures all around the globe. In addition to that cement is the only material whose demand is increasing day by day to meet the needs of mankind. Subsequently, the price of cement is also increasing as its demand is increasing profoundly and it is available only. Manufacturing of cement results in the emission of CO_2 and other gases which contribute to global warming and which further contribute to climate change and thus it is one of the most complicated materials. Its use cannot be stopped but can be limited by using various materials. [6]

III. Methodology

3.1 Source Materials

The materials used for making geopolymer concrete specimens are alkaline liquids, aggregates, water, and low-calcium fly ash.

3.1.1 Alkaline Liquid: Generally alkaline liquids were prepared by mixing the sodium hydroxide solution and sodium silicate at room temperature. When the solution is mixed both solutions start to react, it is recommended to use it in the next 36 hours.

3.1.2 Sodium Silicate: The advantages of sodium silicate adhesives include their ability to expand and make contact; a controllable index adjustment across broad ranges; and the formation of a rigid layer that is a strong, permanent seal resistant to tearing, bugs (i.e., pests) and moderately resistant to heat and water. They are used for paper, wood, metal, sheet metal and other materials, except plastic.

3.1.3 Sodium Hydroxide: The sodium hydroxide used was in the flakes form with 99% purity.

Table3.1: Chemical ingredients of sodium hydroxide

Chemical ingredients	Per cent
Carbonate	2%
Chloride	0.01%
Sulfate	0.05%
Potassium	0.1%
Silicate	0.05%
Zinc	0.02%
Iron	0.002%

3.1.4 Aggregates: For this Project work, locally available aggregates, comprising 20 mm and 14 mm coarse aggregates, in dry surface conditions were used. Locally available river sand was used as fine aggregates.

3.1.5 Water: The water used for the preparation of the solutions was mineral water. Water was used only for the preparation of sodium hydroxide solution.

3.1.6 GGBS: The GGBS was obtained from quenching molten iron slag from a blast furnace in water or stream, to produce a glassy, granular product that is then dried and ground into a fine powder.

3.2 Mixture Proportion: The development and manufacture of geopolymer concrete took place at Curtin University when the present work was undertaken. Some results of that study which had already been published by several authors were referred. Based on that study, mixture proportions were formulated. For preparing the following mixture proportion IS 456 was used.

3.3 Curing :

Curing of concrete must begin as soon as possible after placement and finishing and must continue for a reasonable period as per the relevant standards, for the concrete to achieve its desired strength and durability. Uniform temperature should also be maintained throughout the concrete depth to avoid thermal shrinkage cracks. Also, protective measures to control moisture loss from the concrete surface are essential to prevent plastic shrinkage cracks.

Table No. 3.2 Mixture Proportion for 8 Molarity of NaOH for one Specimen

Materials	Quantity per 1 Cube
GGBS	1.5 kg
Fine Aggregate (Sand)	2.25kg
Coarse aggregate	4.5 kg
Sodium silicate solution	450 ml
Sodium Hydroxide Solution	167 ml
Potable water (Excess)	520 ml

IV. Conclusions

1. GGBS geopolymer concrete is a sustainable alternative to traditional Portland cement concrete, as it utilizes industrial by-products and reduces carbon emissions.
2. GGBS geopolymer concrete often exhibits comparable or superior strength and durability properties compared to conventional concrete.
3. Geopolymer concrete can be more resistant to chemical corrosion and alkali-silica reactions, making it suitable for harsh environments.
4. The use of GGBS and geopolymer technology reduces greenhouse gas emissions and contributes to environmentally friendly construction practices.
5. The cost-effectiveness of GGBS geopolymer concrete compared to traditional concrete can be a key factor for adoption.

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