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EXPERIMENTAL ANALYSIS ON THE MECHANICAL PROPERTIES AND DURABILITY OF GEOPOLYMER CONCRETE

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ABSTRACT

Recent interest in geopolymer concrete, a cutting-edge substitute for conventional Portland cement-based concrete, has increased because of its promising mechanical qualities and environmental sustainability. This study investigates the mechanical characteristics of geopolymer concrete made with fly ash, GGBS, & alkali activator solution as the only precursor materials. Three different mix calculations—one using fly ash, one using ground granulated blast furnace slag (GGBS), and one combining fly ash & GGBS—have been assessed. The combinations were maintained at a Na_2SiO_3/NaOH ratio of 2.0 & 3.0 after being activated with a 12M molarity NaOH solution. To ascertain their mechanical performance, concrete samples were created and evaluated for durability & compressive strength after 28 days. This study contributes to ongoing research and development efforts in sustainable building materials by examining the characteristics of geopolymer concrete and presenting test results based on our findings.

Keywords

Geopolymer concrete, Fly ash, GGBS, Alkali activators, Industrial by-products.

INTRODUCTION

One of the sectors with the fastest rate of growth in the world today is construction. Global infrastructure development is increasing, which has led to a significant growth in the demand for cement concrete and, consequently, cement output. In the end, it has caused the natural supply of limestone to be rapidly depleted. Environmental contamination is yet another important aspect. Ordinary portland cement (OPC) manufacturing accounts for 1.35 billion tons of greenhouse gas emissions annually worldwide and around 7% of all greenhouse gas emissions in the earth's atmosphere[1]. Even though they were intended to endure more than 50 years, it is also observed that many concrete structures that have employed OPC begin to disintegrate after 25 years, particularly those that are situated in corrosive environments[2]. Therefore, in order to minimize greenhouse gas emissions, various efforts are needed to apply new eco-friendly sustainable construction materials, also known as green construction materials. In the 1970s, a French scientist by the name of Prof. Joseph Davidovits coined the term "geopolymer" to describe a class of materials that are produced when a basic solution reacts with alumina-silicate, low-calcium fly ash (ASTM C 618 Class F), a production by-product rich in silicon & aluminum. In geopolymer concrete, this reaction is chemically triggered with a high-alkaline solution to form a compound with tensile and compressive properties that serves as a reinforcing agent in the cementitious material[4]. By using readily accessible natural resources and other industrial by-products helps to produce environmentally friendly concrete in order to reduce total carbon dioxide emissions. By reducing the pace of material consumption, the primary objective of maximizing the impacts of an undesired by-product of industries might be accomplished[3]. The production of various industrial byproducts is rising quickly, particularly in China and India. At the end of 2010, it was estimated that the aforementioned nations produced around 780 million tons of fly ash yearly. Thermal power plants generate a lot of fly ash (FA), which leads to a number of disposal-related issues[5]. Research on GPC has revealed that it possesses comparable or superior characteristics than OPC concrete. GPC has superior compressive strength relative to OPC concrete, along with enhanced fire resistance and improved resistance to sulfate and salt[6-8]. Geopolymers, like to zeolites, undergo a series of distinct reaction stages from initial pozzolanic activation to the ultimate development of pore structure. The geopolymerisation process and the pace of final strength development in GPC are influenced by several parameters, including the chemical makeup of the source material, the alkaline activator solution, & the curing conditions. An alkali-activated alumina-silicate material can serve as the adhesive in Geopolymer paste, replacing ordinary cement. In Geopolymer paste, the conventional cement-based adhesive is substituted with an alkali-activated amorphous binder. The primary function involves a combination of an alumina-silicate source, such as fly ash in geopolymer concrete, and an alkaline solution, which facilitates the solidification of the matrix by eliminating excess moisture and expanding an inorganic solvent. Prior study indicates that the transformations of recognized pozzolanic materials are the paramount factor in the geopolymerization process, resulting in a mechanically robust adhesive.

The aim of the research is to identify the ideal component combination for geopolymer concrete, comprising alkali activators, fly ash, & ground granulated blast furnace slag (GGBS). The study aims to investigate different combinations of mix designs, activator concentrations, and proportions to assess their effects on the workability, durability, & compressive strength of concrete. The research is to assess the performance of geopolymer concrete in comparison to traditional Portland cement concrete.

This research aims to enhance the comprehension of geopolymer concrete technology and its practical applications, with its contribution focused on optimizing mix designs, assessing performance, & advocating for sustainability in building materials.

LITERATURE REVIEW

Geopolymer concrete has emerged as a potential alternative to traditional Portland cement-based concrete due to its advantageous properties & sustainability attributes[9].

Geopolymer concrete is produced by activating aluminosilicate materials such as fly ash or slag with alkali activators. This generates a binder with outstanding mechanical strength, durability, and resistance to adverse environments[10].

One of the primary advantages of geopolymer concrete is its reduced environmental effect compared to Portland cement-based concrete. Utilizing fly ash and slag, two industrial wastes, as precursors, geopolymer concrete diminishes carbon emissions and minimizes the reliance on natural resources[11-12].

Investigations in geopolymer concrete have concentrated on refining mix formulations, comprehending material characteristics, and examining novel applications. Research has examined the impact of many characteristics, such as activator types, curing settings, and extra ingredients, on the efficacy of geopolymer concrete[13].

Recent advancements in fiber-reinforced geopolymer composites can enhance the mechanical properties and ductility of geopolymer concrete, hence creating new structural application possibilities for the material[14]. Moreover, innovative techniques have been explored to improve the properties of geopolymer concrete and expand its utilization in construction, including the incorporation of diverse supplementary cementitious materials[15]. Recent study has shown the potential of geopolymer concrete as an eco-friendly and efficient building material. Continuous efforts in this field are essential for enhancing understanding of geopolymer technology and realizing its full potential in practical applications.

MATERIALS AND METHODS

1. Sample Collection

The materials for this experiment were collected from Chhattisgarh, India& are as follows:

- Fly Ash: Sourced from a local power plant in Bhilai.
- GGBS: Sourced from a steel manufacturing plant in Bhilai.
- Alkali Activators: Sodium hydroxide (NaOH) in the form of pallets and sodium silicate (Na_2SiO_3) in solution, were procured from a chemical supplier in Raipur.

2. Experimental Procedure

Step 1: Preparation of Alkali Activator Solution

- NaOH Solution Preparation:

  In order to create solutions with molarities 12M as needed by various mix designs, NaOH pellets were dissolved in drinking water.

- Na_2SiO_3 Solution:

  Sodium silicate solution was prepared according to the required Na_2SiO_3 to NaOH ratio for each mix design.

  The number of moles of solute (in this example, NaOH or Na2SiO3) dissolved in a certain volume of water is used to determine the molarity of a solution. The quantity of solute in moles per liter of solution is known as molarity (M).

Calculate the molarity for solutions of NaOH and Na2SiO3:

For NaOH (Sodium Hydroxide):

1) Calculate the Number of Moles of NaOH:
   - Dissolve a certain amount of NaOH pellets in a known volume of water to prepare the solution.

Moles=mass (g) molar/mass (g/mol)

For 1 mole, dissolve 40 grams of NaOH pellets (molar mass of NaOH = 40 g/mol) in enough water to make a 1 liter solution, you would have 1 mole of NaOH.

2) Calculate the Molarity (M):
   - Molarity (M) = moles of solute/volume of solution (in liters)
   - Dissolve 40 grams of NaOH pellets in 1 liter of water, the molarity would be 1 M.

For Na2SiO3 (Sodium Silicate):

1) Calculate the Number of Moles of Na2SiO3:
   - Similar to NaOH, dissolve a certain amount of Na2SiO3 in a known volume of water.

Moles=mass (g) molar/mass (g/mol)

2) Calculate the Molarity (M):
   - Molarity (M) = moles of solute/volume of solution (in liters)

For 4M, dissolve 160 grams of NaOH pellets in enough water to make a 4 liter solution:

- Moles of NaOH = 160 g/40 g/mol=4 moles
- Molarity (M) = 4 moles/4 L=1 M

Similarly, 12M solutions, adjust the mass of solute accordingly to achieve the desired molarity.

Step 2: Mix Design Preparation

Three categories of mix designs were prepared: Fly Ash-based, GGBS-based, and Combined (Fly Ash + GGBS). Each category included three different mixes with varying alkali activator concentrations.

1) Fly Ash-based Mixes:
- FA1: 100% Fly Ash, 12M NaOH, 2.0 Na_2SiO_3/NaOH ratio
- FA2: 100% Fly Ash, 12M NaOH, 3.0 Na_2SiO_3/NaOH ratio

2) GGBS-based Mixes:
- GB1: 100% GGBS, 12M NaOH, 2.0 Na_2SiO_3/NaOH ratio
- GB2: 100% GGBS, 12M NaOH, 3.0 Na_2SiO_3/NaOH ratio

3) Combined Mixes (Fly Ash + GGBS):
- C1: 50% Fly Ash, 50% GGBS, 12M NaOH, 2.0 Na_2SiO_3/NaOH ratio
- C2: 50% Fly Ash, 50% GGBS, 12M NaOH, 3.0 Na_2SiO_3/NaOH ratio

This represents the ratio of sodium silicate (Na_2SiO_3) to sodium hydroxide (NaOH) in the mix. In this case, the ratio is 2.0, 3.0, meaning that for every mole of NaOH, there are

2.0, 3.0 mole of Na_2SiO_3 present in the mix. This ratio affects the chemical composition and properties of the resulting geopolymer binder, influencing factors such as setting time, strength development, and durability of the concrete.

Step 3: Mixing and Casting

1) Mixing:
- The dry materials (fly ash or GGBS) were first mixed thoroughly. Next, in order to ensure a consistent consistency, the alkali activator solution was progressively added to the dry mix while being stirred constantly.

2) Casting:
- The concrete mix was poured into standard square molds (150mm/6 inches).
- The molds were compacted to remove any air bubbles and ensure proper compaction.

3) Curing:
- The cast specimens were let to settle for a full day at room temperature.
- To speed up the geopolymerization process, the specimens were cured in an oven for 24 hours at 60°C after being unmolded.

Step 4: Testing

The concrete samples were tested for compressive strength, workability, and durability at 28 days.

1) Compressive Strength Test:
Compression testing equipment was used to determine the square specimens' compressive strength in accordance with ASTM C39 guidelines.

2) Workability Test:
In accordance with ASTM C143 requirements, the workability of new concrete mixtures was evaluated by the slump test.

3) Durability Tests:
- Sulfate Resistance Test: • Following a 28-day immersion in a sulfate solution, specimens' weight loss was assessed.
- Acid Resistance Test: After being submerged in an acidic solution for 28 days, the specimens' weight loss was calculated.

RESULTS AND DISCUSSION

An overview of the results at 28 days for each mix design is shown in Table 1. It makes it possible to compare various blends and shows how strength changes over time. Mixtures with greater molar concentrations of NaOH and higher percentages of GGBS often have higher compressive strengths. When it comes to strength development, mix C3 (50% fly ash, 50% GGBS, 12M NaOH, and 3.0 Na_2SiO_3/NaOH ratio) regularly outperforms the other mixes.

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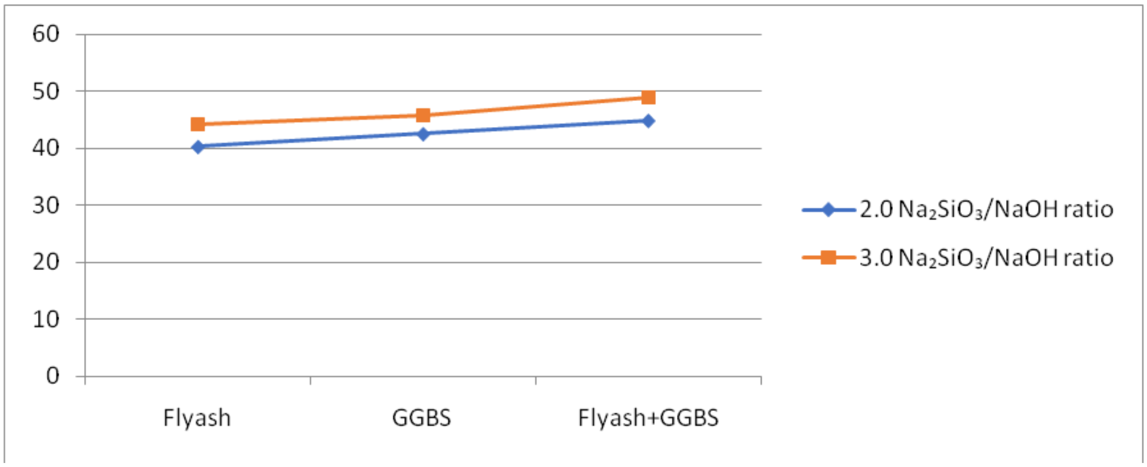
Table 1 Compressive strength at 28 days

Material	2.0 Na_2SiO_3/NaOH ratio	3.0 Na_2SiO_3/NaOH ratio
Flyash	40.3	44.2
GGBS	42.5	45.7
Flyash+GGBS	44.8	48.9



Graph 1 Comparative results of compressive strength at 28days

The slump test results for each mix design are shown in Table 2, which also shows how easy it is to handle and lay new concrete. Better workability is indicated by higher slump levels. Because they enable better fluidity, mixes with lower molar concentrations of NaOH typically have superior workability. Despite the greater concentration of NaOH, Mix C2 exhibits positive findings once more, suggesting strong workability.

Table 2 Slump test results

Mix ID	Slump (mm)
FA1	73
FA2	80
GB1	69
GB2	75
C1	79
C2	85

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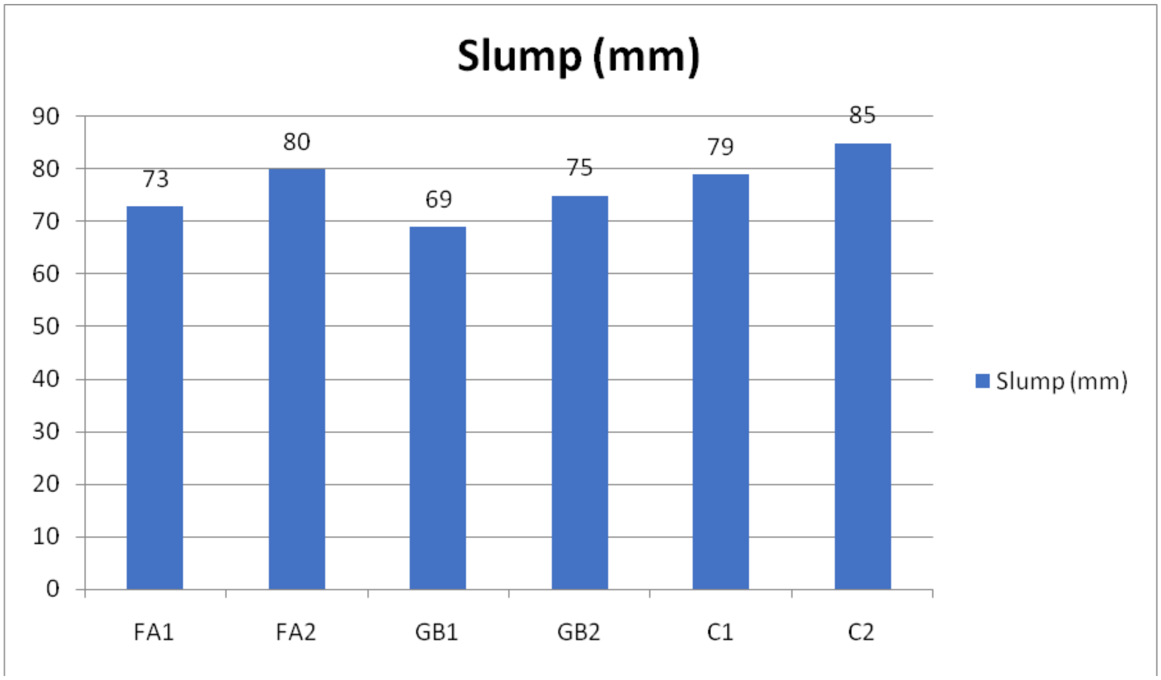

Graph 2 Comparative results of Slump of different mixes

Table 3 displays the results of the acid and sulfate resistance testing for each mix design. Lower percentage weight loss values indicate better resistance to sulfate and acid attack. Because Mix C2 is very resilient to both sulfate and acid conditions, it offers promise for use in challenging circumstances.

Table 3 Durability test results

Mix ID	**Sulfate Resistance (% weight loss)**	**Acid Resistance (% weight loss)**
FA1	1.8	2.2
FA2	1.2	1.8
GB1	1.6	2.0
GB2	1.0	1.6
C1	1.5	2.1
C2	1.0	1.5

For geopolymer concrete that utilizes fly ash, GGBS, or a combination of the two, this comprehensive experimental study provides an in-depth analysis of the procedures and results involved in selecting the optimal mix design.

CONCLUSION

The experimental findings demonstrate how crucial it is to optimize mix designs for geopolymer concrete. With 50% fly ash, 50% GGBS, 12M NaOH, and a 3.0 Na_2SiO_3/NaOH ratio, Mix C2 was the best-performing mix in terms of durability, workability, & strength under compression. Geopolymer concrete has a lot of promise for environmentally friendly building, but issues with standardization, mix design optimization, and resource availability require more study and development. However, it is a viable substitute for conventional Portland cement concrete due to its higher performance qualities & environmental advantages. Geopolymer technology may become more widely used in building methods as a result of more research and development, supporting the concrete industry's sustainability initiatives.

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