PARAMETRIC STUDY ON GGBS BASED GEOPOLYMER CONCRETE

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Abstract: Concrete is the most consumable material after water in the world. Geopolymer concrete is emerging as a promising alternative to conventional concrete. Inadditiontothatcementistheonly material 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 limited only. The manufacturing of Ordinary Portland cement contributes an average of 5-7 % of total greenhouse gases, such as Carbon dioxide emissions. Geopolymer concrete is such one and in the present study, to produce the geopolymer 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 GGBS 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 and it is found that the geopolymer concrete possessed better results than the normal concrete.

KEYWORDS: GGBS, Geopolymer Concrete, Alkaline Liquid, Compressive Strength. Spilt Tensile, Flexural Strength.

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 sulphate 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 the concentration and ratio of sodium hydroxide to sodium silicate, the curing temperature and time on the properties and performance of geopolymer concrete [1 - 5]

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 CO_2emissions. 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.[6 - 7] 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 Well camp 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. GGBS is a principal byproduct produced by steel and iron production. 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.

Origin of term

‘Geopolymer’ The term ‘‘Geopolymer’’ was first introduced to the world by Davidovits of France resulting in a new field of research and technology. Geopolymer also known as 'inorganic polymer' has emerged as a 'green' binder with wide potential for manufacturing sustainable materials for environmental, refractory and construction applications [8].

1. Materials

Ground Granulated Blast Furnace Slag (GGBS)

GGBS is a by-product of steel production commonly used as a cementitious material as it improves strength and reduces penetrability by increasing the boundary with the aggregate. In addition to providing financial and environmental advantages in power and supply reductions, employing GGBS as a binding ingredient in concrete manufacturing may also result in significant cost savings. For more than a century, GGBS was the primary supplemental cementing material used in the construction industry. Cementitious and pozzolanic characteristics may be found in GGBS material. Various research has been performed on the impact of GGBS on the performance of various kinds of concrete and mortars. The substitution of OPC decreases the discharge of harmful gases and the use of superfluous electricity. In addition to its cost-effectiveness and being eco-friendly, its strength and durability characteristics are equivalent to those of cement.

Fine Aggregate

The most widely regarded as fine aggregate is a 4.75 mm. The main ingredient is a strong construction material made from natural sand or broken stone. The aggregate which used in geopolymer concrete. The fine aggregate is clean, inert and free from organic matter, silt and clay.

Coarse Aggregate

The unit maintained in IS Sieve at 4.75 mm is known as the coarse unit. The rough aggregate's job is to serve as the key load-carrying factor in the cement. Aggregates are the world's most polluted content. Aggregates are parts of construction materials such as concrete and asphalt concrete, and the resulting construction material is reinforced by the aggregate. Grow aggregates of more than 0.19 inch are particles with a diameter varying from 0.375 to 1.5 inches. The crushed granite of size20 mm was locally available for the cement mix used in this experimental work [9 – 11]

Water

The pH value is as perfect for the water as it is used in concrete construction. PH Value Indian Standard 456-2000 [6] less than 6.0 water used for mixing and healing shall be clean and free from unhealthy amounts of oils, acids, alkalis, salts, sugar, organic materials or other substances which may be hazardous to concrete or steel.

Alkaline Activator

The second-most portion in geopolymer concrete was the alkaline activator. This activator's main purpose is to react with the GGBS and make it a binder, in which GGBS cannot act as binders without this activator solution. The source materials such as slag, fly ash, metakaolin etc. contain a rich quantity of silicon and aluminium and now the alkaline solution can react with silicon and aluminium to form a binder. The alkaline activator solutions have typically been based mainly on potassium or sodium. The widely used alkaline activators in geo polymerization are potassium hydroxide or sodium hydroxide, and potassium silicate or sodium silicate. For this analysis, sodium silicate and sodium hydroxide were mixed into the alkaline activator solution. Distilled water was used to dilute the flakes for the preparation of the sodium hydroxide solution. And one day before casting, this alkaline activator solution was prepared, since the NaOH solution emits a lot of heat when diluting sodium hydroxide flakes.

2. Methodology

Preparation of Alkaline Solutions

The strength of geopolymer concrete is Studied for the mixes of 8 molarity of sodium hydroxide. The molecular weight of sodium hydroxide is 40. To prepare 8 molarity of solution 320 g of sodium hydroxide flakes are weighed and they can be diluted into distilled water to form 1 litre solution. A measuring flask of 1000 gram capacity is taken, and sodium hydroxide flakes are added slowly to distilled water to prepare 1000-gram solution. The alkali activator solution has to be prepared 24 hours in advance before use.

Figure-1: SodiumHydroxideandSodiumSilicate

Mix Design

The Ratio of Sodium Hydroxide to Sodium silicate is 1:2.5 and the concentration of NaOH was taken as 10 M, 12 M and 14 M. In the case study M40 grade concrete was used. Similar grades of geopolymer concrete were designed and optimized by trial-and-error method.

Mixing and casting

The fine aggregate, coarse aggregate and GGBS were mixed in dry condition for 2 to 3 minutes and then the alkaline solution which is an assemblage of sodium hydroxide solution and sodium silicate solution was added to the dry mix. The mixing is done for about 8 to 10 minutes for proper Mixing of all the materials. After the mixing is done, specimens are cast by giving proper compaction in three layers.Forthecuring, the geopolymer specimens are demoulded after 1 day of casting and they are placed at room temperature (Ambient curing) and the normal concrete specimens are cured under water.[11 – 24]

Testing of Specimens

The specimens were tested at the age of 7,14 and 28 days of curing for each mix proportion three numbers of cubes were tested at the age of 7,14 and 28 days. For each mix proportion, three numbers of cylinders were tested at age of 7, 14 and 28 days. For each mix proportion three numbers of prisms tested at the age of 7,14 and 28 days.

Table1: Details of specimen

Name of Test	Sizeofspecimen(mm)	Numberofspecimens
CompressiveStrengthTest	Cube(150x150x150)	9
SplitTensileTest	Cylinder(150x300)	9
FlexuralTest	Prism(100x100x500)	9

3. RESULTS AND DISCUSSION

Compressive Strength

The compressive strength of geopolymer concrete and ordinary Portland cement concrete cubes were tested in the compressive testing machine to determine their compressive strength for 7, 14 and 28 Days. The specimens are tested for compressive strength using a compression testing machine of 2000 KN capacity. The average compressive strength of concrete specimens is calculated by using the following equation.

Figure-2: Compressive Strength Testing

Table2: Mix ID

Mix ID	M1	M2	M3
Grade of Concrete	30	8M	10M

Table3: Test Results of Average Compressive Strength for 3, 7 and 28days

Mix ID	3Days (MPa)	7Days (MPa)	28Days (MPa)
M1	19.78	24.65	30.00
M2	21.33	29.56	34.21
M3	36.10	39.60	41.67

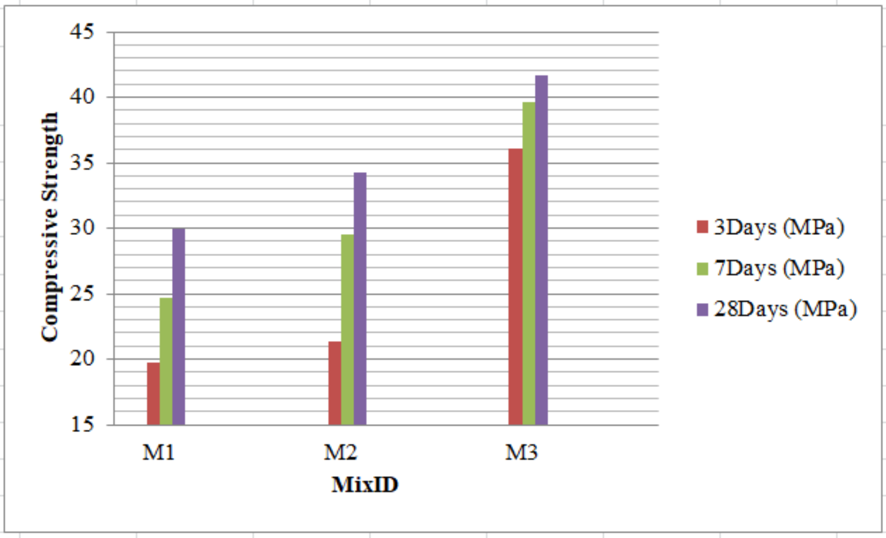

Figure-3: Compressive Strength for GPC for 3,7,28 days

Here is the figure 3 showing the compressive strength of the three concrete mixes (M1, M2, and M3) over different curing times (3 days, 7 days, and 28 days). Each mix's strength increases over time, with M3 consistently having the highest strength and M1 the lowest.

Spilt Tensile Strength

It is finding a concrete strength to subject into the cylinder of a lateral compressive force. There was no direct method for knowing the Concrete tensile strength, for determining the tensile strength of geopolymer cylinders. The test specimens in a horizontal direction they were placed in the compressive force machine. In the size of 15cm diameter and 30cm large cylinders were cast with the same molarity (i.e., 12 Molarity, 14 Molarity, 16 Molarity). After 1440 mins the cylinder specimens are demoulding and subjected to ambient curing. After 3,7,28 days the specimens are ambient curing, and allow the waterless and test machine to place the specimen horizontally. The load was applied gradually until the cylinder splits into two parts. The test was performed as per IS 5816: 1999.

Table4: TestResultsofAverageSplitTensileStrengthfor3, 7 and 28days

MixID	3 Days (MPa)	7 Days (MPa)	28 Days(MPa)
M1	2.90	3.05	3.62
M2	3.83	3.95	4.52
M3	3.94	4.6	4.65

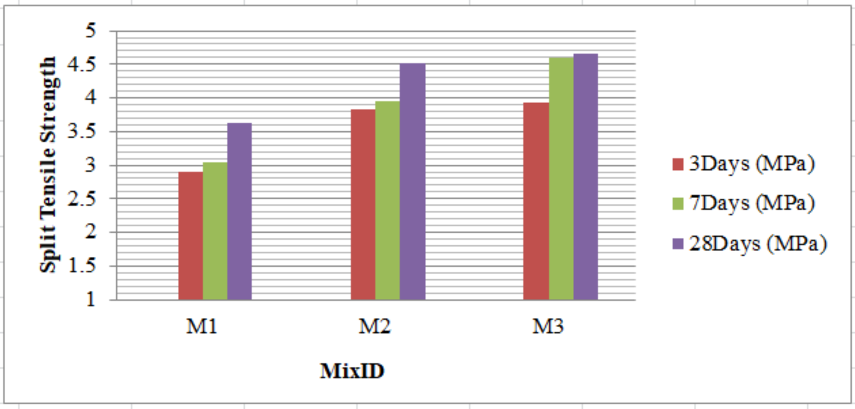

Figure-4: AverageSpiltTensileStrengthforGPCfor3,7 and 28days

Flexural Strength Test

It is finding a concrete strength to subject into the prism beam of a lateral compressive force. The size of 15cm X 15cm X 70cm was cast with the same molarity. After 3, 7, and 28 days the specimens are ambient curing is taken and allow the water less and the test machine to place the specimen horizontally.

Table5: Test Results of Average Flexural Strength for 3,7,28day

MixID	3Days (MPa)	7Days (MPa)	28Days(MPa)
M1	3.30	3.65	4.48
M2	5.22	5.65	6.32
M3	5.27	5.73	6.45

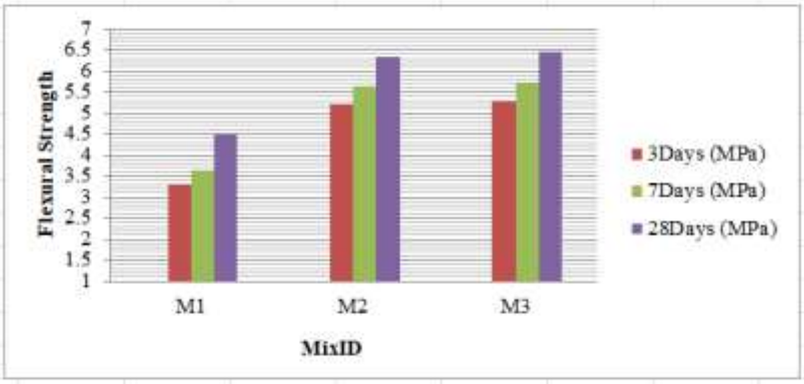

Figure-5: Average Flexural Strength for GPC for 3, 7 and 28days

4. Conclusions

The following conclusions are drawn from the result obtained from the test conducted on GGBS-based geopolymer concrete and plain cement concrete.

1. Mix M3 (M10) exhibits the highest compressive strength at all curing times, making it the most suitable for applications requiring high early and ultimate compressive strength.
2. Mix M2 (M8) shows moderate strength, performing better than M1 but not as high as M3. It is a good balance between strength and cost.
3. Mix M1 (M30) has the lowest compressive strength across all curing times, suitable for applications where lower strength is adequate or where cost savings are a priority.
4. Mix M3 (M10) exhibits the highest split tensile strength at all curing times, making it the best option for applications requiring high early and ultimate tensile strength.
5. Mix M2 (M8) shows moderate tensile strength, performing better than M1 but not as high as M3.
6. Mix M1 (M30) has the lowest split tensile strength across all curing times, suggesting it is suitable for applications where lower tensile strength is sufficient or where cost savings are prioritized.
7. Mix M3 (M10) exhibits the highest flexural strength at all curing times, making it the most suitable for applications requiring high early and ultimate flexural strength.
8. Mix M2 (M8) shows moderate flexural strength, performing better than M1 but not as high as M3.
9. Mix M1 (M30) has the lowest flexural strength across all curing times, suggesting it is suitable

for applications where lower flexural strength is sufficient or where cost savings are prioritized.

10. Mix M3 (M10) is the best-performing mix across all strength tests (compressive, split tensile, and flexural) at all curing times, making it ideal for applications requiring high strength and durability.
11. Mix M2 (M8) is a good intermediate option, providing decent strength in all tests, and suitable for a balance between cost and performance.
12. Mix M1 (M30), while the weakest in terms of strength, may still be suitable for less demanding applications where cost is a more significant concern than the highest possible strength.

In summary, a comprehensive evaluation of compressive strength, split tensile strength, and flexural strength data allows for informed decisions regarding concrete mix selection, ensuring structural integrity and durability in construction projects.

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