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EXPERIMENTAL STUDIES 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. In addition to that cement is the only material whose demand is increasing day by day in order to meet the needs of mankind. Subsequently, the price of cement is also increasing as its demand is increasing profoundly and also it available limited only. The manufacturing of Ordinary Portland cement contributes an average of 5-7% of total greenhouse gases, such as Carbon dioxide emission. Geopolymer concrete is such a 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 from that the geopolymer concrete possess better result than the normal concrete.

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

1. 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 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 fibres' or admixtures 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_2 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.[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 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.

1.1 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 potentials for manufacturing sustainable materials for environmental, refractory and construction applications [8].

2. 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.

2.1 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.

2.2 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 0.19inch are particles with a diameter varying from 0.375 to 1.5inches. The crushed granite of size 20 mm was locally available for the cement mix used in this experimental work [9 – 11]

2.3 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.

2.4 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 as 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

3. Methodology

3.1 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: Sodium Hydroxide and Sodium Silicate

3.2 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 were used. Similar grade of geopolymer concrete were designed and optimized by trial-and-error method.

3.3 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 a 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. For the curing, 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]

3.4 Testing of Specimens

The specimens are 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.

Table 1: Details of specimen

Name of Test	Size of specimen(mm)	Number of specimens
Compressive Strength Test	Cube(150x150x150)	9
Split Tensile Test	Cylinder(150x300)	9
Flexural Test	Prism(100x100x500)	9

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4. RESULTS AND DISCUSSION

4.1 Compressive Strength

Compressive strength of geopolymer concrete and ordinary Portland cement concrete cubes were tested in compressive testing machine to determine its compressive strength for 7, 14 and 28 Days. The specimens are tested for compressive strength using 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

Table 2: Test Results of Average Compressive Strength for 3, 7, 28days

Mix ID	Grade/Molarity	3 Days (MPa)	7 Days (MPa)	28 Days (MPa)
M1	M40	26.65	32.56	38.21
M2	12M	34.12	36.70	68.34
M3	14M	38.60	40.30	70.20
M4	16M	40.80	42.78	73.82

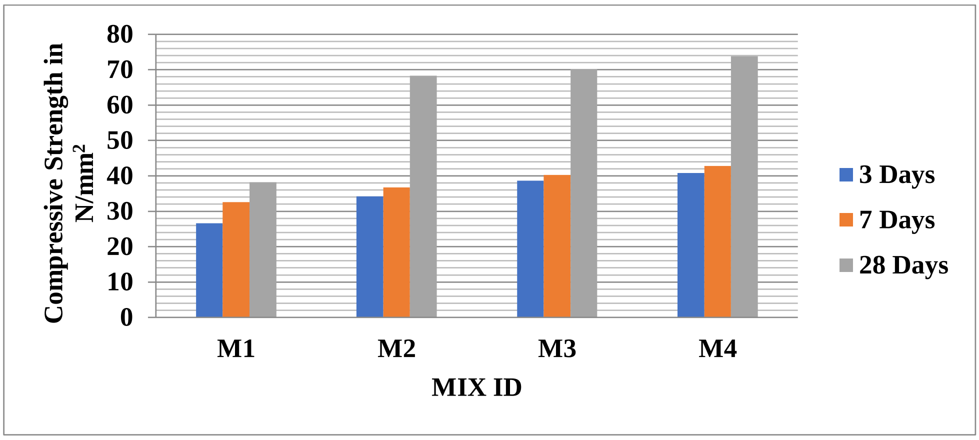

Figure-3: Compressive Strength for GPC for 3, 7, 28 days

4.2 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 cylinder 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 is taken and allow the waterless and test machine to place the specimen horizontal. The load was applied gradually until cylinder splits into two parts. The test was performed as per IS 5816: 1999.

Table 3: Test Results of Average Split Tensile Strength for 3, 7, 28days

Mix ID	Grade/Molarity	3 Days (MPa)	7 Days (MPa)	28 Days (MPa)
M1	M40	2.90	3.05	3.62
M2	12M	3.83	3.95	4.52
M3	14M	3.94	4.6	4.65
M4	16M	4.20	4.12	5.02

4.3 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 (i.e., 12 Molarity, 14Molarity and 16Molarity). After 3,7,28 days the specimens are ambient curing is taken and allow the waterless and test machine to place the specimen horizontal.

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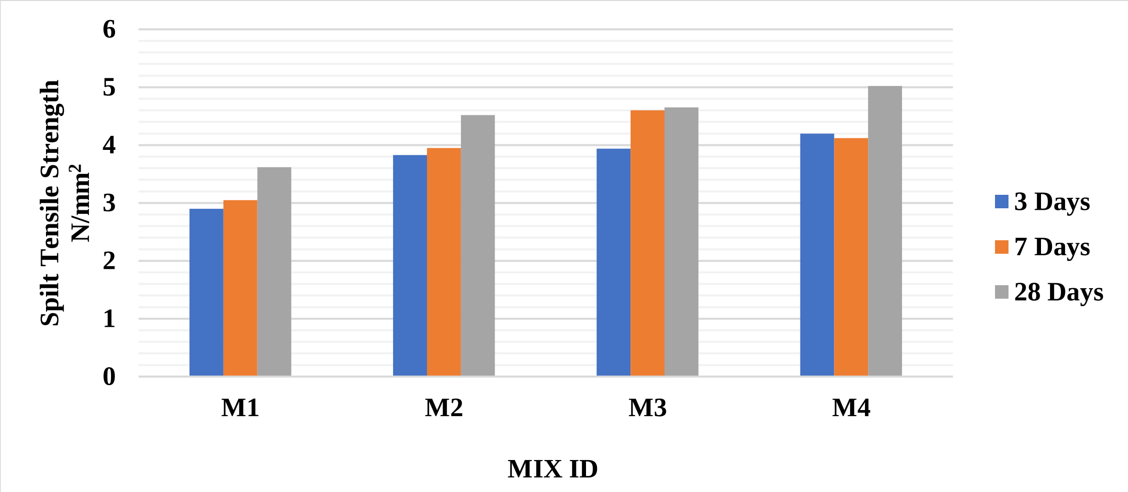

Figure-4: Average Spilt Tensile Strength for GPC for 3, 7, 28 days

In the test machine, a specimen cube was positioned so that it was centrally located on the bottom of the test machine and the moving part was modified to reach the top surface of the cube. The charge applied without any application of shock until the sample failed, the value is reported. After 1440 mins the beam specimens are demoulding and subjected to ambient curing.

Table 4: Test Results of Average Flexural Strength for 3, 7, 28 days

Mix ID	Grade/Molarity	3 Days (MPa)	7 Days (MPa)	28 Days (MPa)
M1	M40	3.30	3.65	4.48
M2	12M	5.22	5.65	6.32
M3	14M	5.27	5.73	6.45
M4	16M	5.73	5.88	6.54

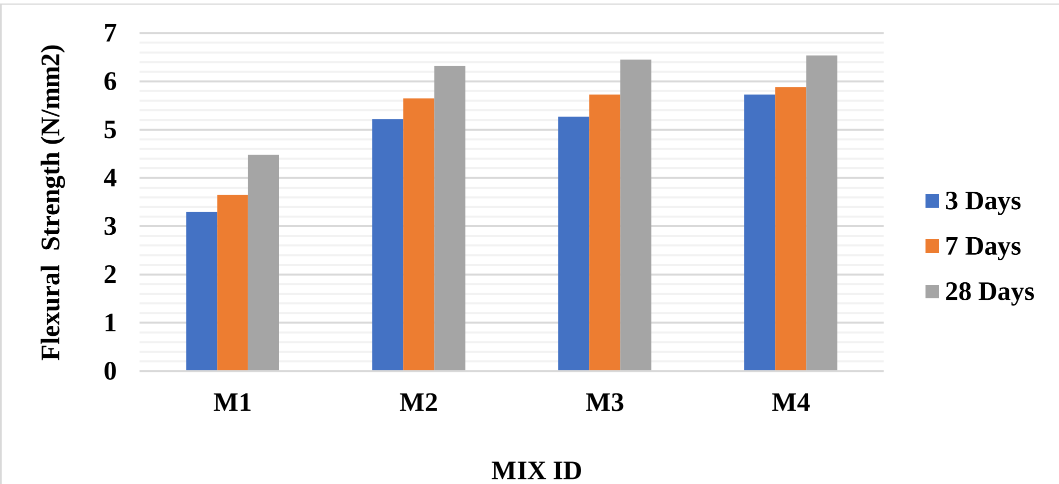

Figure-5: Average Flexural Strength for GPC for 3, 7 and 28 days

5. Conclusions

The following conclusions are drawn for the result obtained from the test conducted on

GGBS based geopolymer concrete and plain cement concrete.

1. Mix M1 has the lowest slump, indicating it may be less fluid and may require more effort to place and compact compared to mixes with higher slump values (M2, M3, and M4). However, the differences in slump values among the mixes are relatively small.
2. Mix M1 has a slightly higher density compared to mixes M2, M3, and M4. This could suggest differences in the composition or proportions of materials used in each mix, potentially affecting their mechanical properties such as strength and durability.
3. There is a clear trend of increasing compressive strength with increasing curing time for all mixes, which is typical for concrete. This indicates that the concrete continues to gain strength as it matures.
4. Mixes M3 (14M) and M4 (16M) demonstrate the highest compressive strengths across all ages, indicating that they are likely the most durable and suitable for structural applications requiring high strength.
5. Mixes M3 and M4 also exhibit relatively high compressive strengths at early ages (3 and 7 days), which can be advantageous for projects requiring early formwork removal or rapid construction progress.
6. Mix M4 (16M) shows the highest compressive strength at 28 days, suggesting that it continues to gain strength over time and may be particularly suitable for long-term durability requirements.
7. There is an increase in split tensile strength as the concrete matures. This is evident in the data for all mixes, where the split tensile strength tends to increase from 3 days to 7 days and further to 28 days.
8. Mixes M3 (14M) and M4 (16M) consistently demonstrate higher split tensile strength values across all ages compared to mixes M1 (M40) and M2 (12M). This suggests that mixes with higher grades or molarities (14M and 16M) have superior tensile strength properties, making them potentially more suitable for applications where tensile stresses are significant.
9. Mix M4 (16M) shows relatively high split tensile strength even at early ages (3 days), indicating its potential for applications requiring early strength development and resistance to cracking.
10. Mix M4 (16M) maintains the highest split tensile strength at 28 days, indicating its potential for long-term durability and resistance to tensile stresses.

11. The split tensile strength data provides valuable insights into the tensile behavior of the concrete mixes over time. Mixes with higher grades or molarities exhibit superior tensile strength properties, with Mix M4 (16M) demonstrating particularly favorable performance.
12. Similar to compressive and split tensile strength, there is a general increase in flexural strength as the concrete ages. This indicates that the concrete continues to gain strength and stiffness over time.
13. Mix M4 (16M) maintains the highest flexural strength at 28 days, suggesting its potential for long-term durability and resistance to bending stresses.
14. Mix M4 (16M) stands out as the top performer across all three strength parameters, demonstrating superior compressive strength, split tensile strength, and flexural strength.
15. Mixes M3 (14M) and M2 (12M) also show competitive strength characteristics, particularly in terms of split tensile and flexural strength.
16. The selection of mix design, grade, and molarity significantly influences the mechanical properties of concrete, and proper consideration of these factors is essential for achieving the desired performance in various structural applications.

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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