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EXPERIMENTAL STUDY ON METAKAOLIN AND GGBS BASED GEOPOLYMER CONCRETE

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ABSTRACT

This study investigation the performance of concrete incorporating Ground Granulated Blast Furnace Slag (GGBS) and Metakaolin as supplementary cementitious materials (SCMs). The objective is to evaluate the impact of these SCMs on mechanical properties, durability, and environmental performance. Geopolymer concrete mixes were prepared with varying dosages of GGBS and Metakaolin. The geopolymer concrete specimens are cast and tested for different types of strengths for 7 and 28 days of curing. Key performance indicators including compressive strength, tensile strength, were assessed. The combination of MK and GGBS significantly improves the mechanical properties and reduces the environmental impact of concrete, making it a viable alternative to conventional cement-based concrete. Results indicate that the addition of GGBS and Metakaolin significantly enhances the mechanical properties and durability of concrete. The SCMs contribute to improved strength, sulfate resistance, and chloride penetration resistance, while reducing carbon emissions compared to traditional Portland cement-based concrete This study helps in gaining knowledge about the morphological composition of concrete which might result in path-breaking trends in the construction industry.

Keywords: Geopolymer concrete, Supplementary cementitious materials (SCMs), Ground Granulated Blast Furnace Slag (GGBS), Metakaolin (MK), Compressive strength, Durability, Sulfate resistance, Chloride penetration resistance.

1. INTRODUCTION

The construction industry, a major contributor to global carbon emissions, is under increasing pressure to adopt sustainable practices [1]. One promising approach involves the utilization of supplementary cementitious materials (SCMs), like Ground Granulated Blast Furnace Slag (GGBS) and Metakaolin (MK) in concrete production. Ground Granulated Blast Furnace Slag (GGBS) is byproduct of the iron-making process [2] [3], possessing excellent pozzolanic properties [4]. It reacts with calcium hydroxide in the presence of moisture to form hydration products, contributing to the development of strength and durability in concrete. Metakaolin, derived from the calcination of kaolin clay, is a highly pozzolan. It reacts with calcium hydroxide to C-S-H gel, a key component of the hardened cement pate. By incorporating GGBS and MK into concrete mixes [5], it is possible to reduce the consumption of Portland cement, a significant source of greenhouse gas emissions. Additionally, these SCMs can enhance the mechanical properties, durability, and sustainability of concrete [6].

Geopolymer concrete is an innovative material that employs a binder system based on alumino-silicate materials and alkali activators, instead of ordinary Portland cement [7]. This type of concrete has gained attention due to its potential to reduce CO_2 emissions and its favorable mechanical and durability properties [8]. Geopolymer concrete can be produced using various industrial by-products like fly ash, Ground Granulated Blast Furnace Slag (GGBS), and Metakaolin (MK), which are rich in silica (SiO_2) and alumina (Al_2O_3). These materials, when activated by an alkaline solution (commonly sodium hydroxide or sodium silicate), undergo a chemical reaction that forms a binding gel, which imparts the material with concrete-like properties.

2. EXPERIMENTAL INVESTIGATION

The Quality of concrete can be achieved by the selection of suitable materials, cementitious materials, admixtures, the choice of mix proportion, water cement ratio and use of proper methods of mixing, placing and curing. All these aspects depends upon the selection of materials and admixtures.

Ground Granulated Blast furnace slag (GGBS) is a by-product for manufacture of pig iron and obtained through rapid cooling by water or quenching molten slag. Here the molten slag is produced which is instantaneously tapped and quenched by water. This rapid quenching of molten slag facilitates formation of “Granulated slag”. Ground Granulated Blast Furnace Slag (GGBS) is processed from Granulated slag. If slag is properly processed then it develops hydraulic property and it can be effectively used as a pozzolanic material. However, if slag is slowly air cooled then it is hydraulically inert and such crystallized slag cannot be used as pozzolanic material. Though the use of Ground Granulated Blast furnace slag (GGBS) in the form of Portland slag cement is not a common in India, experience of using Ground Granulated Blast furnace slag (GGBS) as partial replacement of cement in concrete in India is very less quantity. Ground Granulated Blast furnace slag (GGBS) essentially consists of silicates and alumino silicates of calcium and other bases that is developed in a molten condition simultaneously with iron in a blast furnace. The chemical compositions of oxides in ground granulated blast furnace slag (GGBS) are similar to that of Portland cement but the proportions may vary.

Figure 1: Metakaolin.

Metakaolin is a dehydroxylated form of the clay mineral kaolinite. Stone that are rich in kaolinite are known as china clay or kaolin, traditionally used in the manufacture of porcelain. The particle size of metakaolin is smaller than cement particles, but not as fine as silica fume.

Figure 2: GGBS

1.1 Fine Aggregate

Fine aggregates are materials passing through an IS sieve that is less than 4.75mm gauge. Simply the aggregates which are passing 4.75mm sieve are called as Fine Aggregates. The most important function of the fine aggregate is to provide workability and Uniformity in the mixture. The fine aggregate also helps the cement paste to hold the coarse aggregate particle in suspension.

Table 1. Physical properties of fine aggregate

S. No.	Property	Value
1	Specific Gravity	2.5
2	Fineness Modulus	2.36
3	Grading	Zone –II

Table 2. Sieve analysis of fine aggregate

S. L N o	IS Sieve Size	Weight Retained (Kg)	Cumulative weight retained	Cumulative % weight retained (Kg)	Cumulative % Passing
1	4.75 mm	0	0	0	0
2	2.36 mm	0.042	4.2	4.2	95.8
3	1.18 mm	0.150	15	19.2	80.8
4	600 mm	0.250	25	44.2	55.8
5	300 mm	0.295	29.5	73.7	26.3
6	150 mm	0.218	21.8	95.5	4.5

1.2 Coarse aggregate

Coarse aggregates are materials which retains on an IS sieve 4.75mm gauge. Simply the aggregates which are retaining on 4.75mm IS sieve are called as Coarse Aggregates. The coarse aggregate used here with having maximum size of 20mm. We used the IS 383:1970 to find out the proportion of mix of coarse aggregate, with 60% 20mm size and 40% 10mm.

Table 3. Physical properties of coarse aggregate

Properties	Results Obtained
Specific gravity	2.87
Fineness Modulus	7.8

Table 4. Sieve analysis of coarse aggregate

S. L N o	Is ieve Size	Weight retained(g)	Cumulative weight retained	Cumulative % weight retained (g)	Cumulative % passing
1	37.5 mm	0	0	0	0
2	20 mm	1220	24.4	24.4	75.6
3	16 mm	2320	46.4	70.8	29.2
4	12.5 mm	1190	23.8	94.6	5.4
5	10 mm	260	5.2	99.8	0.2

1.3 Water

General water has been used in this experimental program for mixing and curing.

1.4 Super plasticizer

The super plasticizer used in this experiment is DR. FIXIT Pidiproof LW+.

Super Plasticizers are new class of generic materials which when added to the concrete causes increase in the workability. They consist mainly of naphthalene or melamine sulphonates, usually condensed in the presence of formaldehyde.

2. RESULTS AND DISCUSSION

2.1 Compressive strength results

The results of compressive strength of M40 concrete is tested after 7 days & 28 days curing and are tabulated from table 4.5 to 4.10. The results of split tensile strength of M40 concrete is tested after 7 days & 28 days curing.

Fineness modulus of Coarse aggregate =

$\Sigma g/100$

=289.6/100+(5)

=7.8

Table 5. Details of Concrete Mix Proportions for M40

Material Used	Cementous Material	Fine Aggregate	Coarse Aggregate	Sodium hydroxide	Sodium silicate
Quantity	406	616	1248	53	133

2.2 Tabulation

Table 6. 7- days Compressive Strength for ratio 70:30

Sl. No.	Area of Cubes mm^2	Load N	Compressive Strength, N/mm^2	Avg. Compressive Strength, N/mm^2
1.	22500	400×10^3	17.78	18.67
2.	22500	440×10^3	19.55	
3.	22500	420×10^3	18.67	

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Table 7. 7- days Compressive Strength for ratio 80:20

Sl.No.	Area of Cubes mm^2	Load N	Compressive Strength, N/ mm^2	Avg. Compressive Strength, N/mm^2
1.	22500	530×10^3	23.56	23.78
2.	22500	545×10^3	24.22	
3.	22500	555×10^3	24.67	

Table 8. 28- days Compressive Strength for ratio 70:30

Sl. No.	Area of Cubes mm^2	Load N	Compressive Strength, N/ mm^2	Avg. Compressive Strength, N/mm^2
1.	22500	850×10^3	37.78	38.88
2.	22500	875×10^3	38.88	
3.	22500	900×10^3	40	

Table 9. 28- days Compressive Strength for ratio 80:20

Sl.No.	Area of Cubes mm^2	Load N	Compressive Strength, N/mm^2	Avg. Compressive Strength, N/mm^2
1.	22500	1000×10^3	44.44	45.33
2.	22500	1015×10^3	45.11	
3.	22500	1045×10^3	46.44	

2.3 Split Tensile Strength Test

TABULATION

Table 10. 7- days Tensile Strength for ratio 80:20

Sl. No.	Dia. of the Specimen	Length of the Specimen	Breaking Load(N)	Splitting Strength (N/mm^2)
1.	150	300	130×10^3	1.84
2.	150	300	146×10^3	2.06
3.	150	300	160×10^3	2.26

Table 11. Split Tensile strength for different mixes.

Sl. No.	Dia. of the Specimen	Length of the Specimen	Breaking Load(N)	Splitting Strength (N/mm^2)
1.	150	300	320×10^3	4.50
2.	150	300	300×10^3	4.24
3.	150	300	340×10^3	4.80

3. RESULTS

i) 7- days Compressive Strength for ratio 70:30

Average Compressive Strength **=** **18.67** N/mm^2.

ii) 7- days Compressive Strength for ratio 80:20

Average Compressive Strength = **23.78** N/mm^2.

iii) 28- days Compressive Strength for ratio 70:30

Average Compressive Strength **=** **38.88** N/mm^2.

iv) 28- days Compressive Strength for ratio 80:20

Average Compressive Strength = **45.33** N/mm^2.

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4.1 SPLIT TENSILE STRENGTH TEST

CALCULATION

FORMULA:

Tensile Strength = $\frac{2P}{\pi dl}$

4. RESULTS AND DISCUSSION

i) 7- days Tensile Strength for ratio 80:20

Split Tensile Strength = **2.05** N/mm^2

ii) 28- days Tensile Strength for ratio 80:20

Split Tensile Strength = **4.51** N/mm^2.

The tensile strength ranges from 7 to 11% of the compressive strength and usual levels average 10% of the compressive strength.

5. CONCLUSION

From above results it is apparent that Geopolymer concrete based on GGBS and Metakaolin has got more compressive strength then conventional concrete. Workability of geopolymer concrete decreased as the metakaolin content increases with GGBS. But increase in GGBS does not affect the workability. Mechanical properties such as compressive strength, split tensile strength and flexural strength shows increasing trend with the decrease of metakaolin. Mix with 20% of metakaolin and 80% of GGBs and seems to have good compressive, split strengths, this may be due to increase in alkaline reaction between GGBS particles and calcium in Metakaolin. Nearly 50% of total strength of GPC is achieved within the age of 7 days.

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