PERFORMANCE ASSESSMENT OF GGBS CONCRETE WITH SILICA FUME, METAKAOLIN AND CALCIUM FORMATE

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Abstract— Concrete is the most widely used construction material; however, the excessive use of cement leads to significant environmental concerns, including high energy consumption, excessive heat of hydration, and increased CO_2 emissions. To mitigate these issues, partial replacement of cement with Ground Granulated Blast Furnace Slag (GGBS) has been widely adopted due to its sustainability benefits. Nevertheless, a major limitation of GGBS concrete is its slow early-age strength development. To overcome this drawback, calcium formate is incorporated as an accelerator to enhance early-age strength gain. Additionally, the combined use of metakaolin and silica fume as supplementary pozzolanic materials is investigated to improve particle packing density and pozzolanic reactivity, thereby enhancing the overall performance of GGBS-based concrete.

In this study, an M30 grade concrete mix is designed with cement partially replaced by GGBS (30–50%), metakaolin (5%), and silica fume (7.5%), along with calcium formate (0–2%) as a chemical admixture. The strength performance of concrete is evaluated through compressive strength tests conducted at1,3,7 and 28 days of curing.

Keywords- Ground Granulated Blast Furnace Slag (GGBS), metakaolin, silica fume, Calcium formate, compressive strengths

Introduction

Concrete is the most widely used construction material in the world due to its versatility, durability, and cost-effectiveness. However, the extensive use of Ordinary Portland Cement (OPC) in concrete production has led to serious environmental concerns. Cement manufacturing is an energy-intensive process and contributes significantly to global carbon dioxide (CO_2) emissions, accounting for nearly 7–8% of total anthropogenic CO_2 emissions. In addition, the hydration of cement releases a large amount of heat, which can cause thermal cracking in mass concrete structures and adversely affect long-term durability. To mitigate these environmental and technical challenges, the partial replacement of cement with supplementary cementitious materials (SCMs) has gained considerable attention in recent years. Among various SCMs, Ground Granulated Blast Furnace Slag (GGBS), a by-product of the iron and steel industry, has emerged as a sustainable and eco- friendly alternative. GGBS enhances the long-term strength, durability, and resistance to chemical attack of concrete while significantly reducing CO_2 emissions and energy consumption.

Despite these advantages, GGBS-based concrete exhibits slow early-age strength development, which restricts its application in fast-track construction, pavement works, precast elements, and highway projects where early strength gain is critical. The delayed hydration of GGBS results in extended setting time and reduced early compressive strength, particularly under normal curing conditions.

To overcome this limitation, chemical accelerators are commonly incorporated into GGBS concrete. Calcium formate is one such accelerator that has shown promising results in enhancing early-age hydration by accelerating the formation of calcium silicate hydrate (C–S–H) gel. Calcium formate improves early strength without significantly compromising long-term performance, making it a suitable accelerator for GGBS-based systems.

In addition to chemical accelerators, the use of highly reactive pozzolanic materials such as metakaolin (MK) and silica fume (SF) has proven effective in improving the mechanical and microstructural properties of concrete. Metakaolin refines the pore structure and enhances early strength due to its high alumina content, while silica fume contributes to dense packing and increased compressive strength. The combined use of GGBS, calcium formate, metakaolin, and silica fume represents an innovative approach to developing a sustainable, high-performance concrete that achieves both environmental benefits and improved early-age strength. This project aims to investigate the synergistic effects of these materials on the fresh and hardened properties of concrete, with special emphasis on early-age strength development.

GGBS in the range of 30–50% significantly improves long-term strength while reducing heat of hydration. However, most researchers observed a reduction in early compressive strength, especially at 1, 3, and 7 days. This drawback has been consistently highlighted as the main limitation of GGBS concrete. Metakaolin improves early-age strength and reduces porosity due to its high pozzolanic reactivity. Silica fume, on the other hand, enhances compressive strength and durability by improving particle packing.

I. PROPERTIES OF FINE AGGREGATE

S. No.	Properties	Fine aggregates values
1	Specific Gravity (%)	2.00
2	Bulk Density (loose) (gm/cm³)	1.44
3	Bulk Density (compacted) (gm/cm³)	1.6
4	Water absorption (%)	0.9

TABLE-1- **PROPERTIES OF FINE AGGREGATE**

II. PHYSICAL PROPERTIES OF GGBS

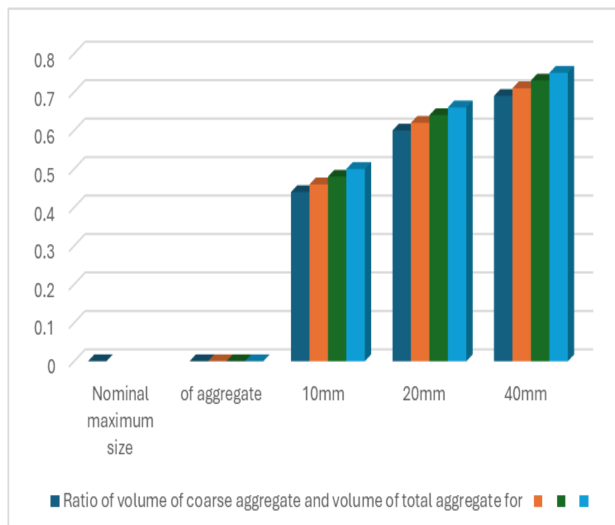
S. No.	Property	Test Value
1	Specific gravity	2.5
2	Blaine's Fineness, m²/kg	322
3	Retained on 45 micron in Wet Sieving, %	6.6
4	Lime reactivity, N/mm²	16.2

TABLE-2- **PHYSICAL PROPERTIES OF GGBS**

III. AGGREGATE RATIO FOR DIFFERENT ZONES

Nominal maximum size of aggregate	Ratio of volume of coarse aggregate and volume of total aggregate for different zones of fine aggregate			
	Zone – 1	Zone – 2	Zone – 3	Zone – 4
10mm	0.44	0.46	0.48	0.50
20mm	0.6	0.6	0.6	0.26
40mm	0.9	0.1	0.7	0.7

TABLE-3- **AGGREGATE RATIO FOR DIFFERENT ZONES**



GRAPH-1- **AGGREGATE RATIO FOR DIFFERENT ZONES**

IV. EXPERIMENTAL DESIGN

Run	GGBS %	SF %	MK %	CF %	SP %	W/B		Age days	Slump mm	Compressive Strength MPa
	0	0	0	0	0	0.		1		13.45

1						42			104	
	0	0	0	0	0	0.42		3		21.5
	0	0	0	0	0	0.42		7		29.16
	0	0	0	0	0	0.42		28		39.45
2	30	7.5	5	0	1	0.42		1	80	15.44
	30	7.5	5	0	1	0.42		3		23
	30	7.5	5	0	1	0.42		7		27.78
	30	7.5	5	0	1	0.42		28		37.99
3	30	7.5	5	1	1	0.42		1	106	17.11
	30	7.5	5	1	1	0.42		3		19.22
	30	7.5	5	1	1	0.42		7		26.45
	30	7.5	5	1	1	0.42		28		38.66
4	30	7.5	5	2	1	0.42		1	105	16.89
	30	7.5	5	2	1	0.42		3		17.11
	30	7.5	5	2	1	0.42		7		32.78
	30	7.5	5	2	1	0.42		28		43.88
5	40	7.5	5	0	1	0.42		1	100	14.45
	40	7.5	5	0	1	0.42		3		19.35
	40	7.5	5	0	1	0.42		7		23.33
	40	7.5	5	0	1	0.42		28		35.44
6	40	7.5	5	1	1	0.42		1	114	13.33
	40	7.5	5	1	1	0.42		3		22.22
	40	7.5	5	1	1	0.42		7		24.89
	40	7.5	5	1	1	0.42		28		38.83
7	40	7.5	5	2	1	0.42		1	95	13.45
	40	7.5	5	2	1	0.42		3		21.22
	40	7.5	5	2	1	0.42		7		29
	40	7.5	5	2	1	0.42		28		32.22
8	50	7.5	5	0	1	0.42		1	95	9.23
	50	7.5	5	0	1	0.42		3		19.34
	50	7.5	5	0	1	0.42		7		23.25
	50	7.	5	0	1	0.		28		61.77

		5				42				
9	50	7.5	5	1	1	0.42		1	102	9.11
	50	7.5	5	1	1	0.42		3		19.78
	50	7.5	5	1	1	0.42		7		25.11
	50	7.5	5	1	1	0.42		28		36.44
10	50	7.5	5	2	1	0.42		1	115	10.89
	50	7.5	5	2	1	0.42		3		18
	50	7.5	5	2	1	0.42		7		25.67
	50	7.5	5	2	1	0.42		28		33.88
11	40	7.5	5	1	1	0.42		1	85	15.34
	40	7.5	5	1	1	0.42		3		20
	40	7.5	5	1	1	0.42		7		25.67
	40	7.5	5	1	1	0.42		28		33.99

12	40	7.5	5	1	1	0.42		1	104	13.34
	40	7.5	5	1	1	0.42		3		17.89
	40	7.5	5	1	1	0.42		7		25.88
	40	7.5	5	1	1	0.42		28		33.55

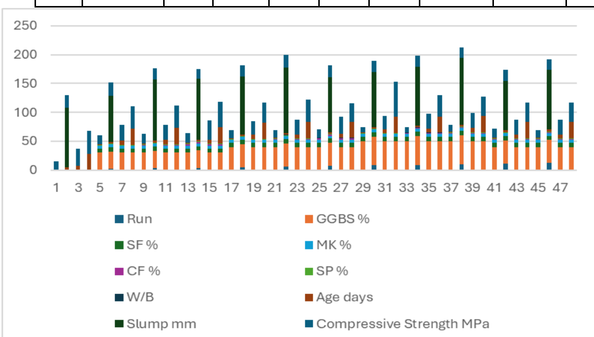


TABLE-4- **Experimental Design**

GRAPH-2- **Experimental Design**

V.CONCLUSIONS

This study investigated the accelerated strength development of high-volume GGBS concrete incorporating Silica Fume, Metakaolin, and Calcium Formate. Based on experimental investigation, the following conclusions are drawn:

- The incorporation of Calcium Formate significantly enhanced early-age compressive strength, particularly at 1 day. The optimized mix proportion of 30% GGBS and 2% Calcium Formate yielded the highest early-age strength of approximately 16.77 MPa, confirming the effectiveness of chemical acceleration in compensating for delayed hydration associated with GGBS.
- At 7 days, the optimized combination again produced superior strength (≈31.99 MPa), demonstrating that acceleration

does not adversely affect mid-term strength development. The synergistic action of Silica Fume and Metakaolin contributed to improved microstructure through secondary C–S–H formation.

- At 28 days, the optimized mix achieved a predicted compressive strength of approximately 40.71 MPa, indicating that accelerated early hydration did not compromise long-term strength performance.

Overall, the study demonstrates that sustainable GGBS concrete can achieve accelerated strength development with Calcium Formate and without compromising long- term performance.

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