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Strength Test and UPV Test on GGBS Concrete with Metakaolin

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ABSTRACT: This study evaluates the mechanical properties and structural integrity of sustainable concrete incorporating Ground Granulated Blast Furnace Slag (GGBS) and Metakaolin as partial replacements for ordinary Portland cement. Specimen mixes were formulated by varying percentages of GGBS and Metakaolin to assess their synergistic effects on concrete performance at curing intervals of 7 and 28 days. Destructive testing was performed to measure compressive strength and split tensile strength, revealing that the pozzolanic reactivity of Metakaolin accelerates early-age strength, while GGBS enhances long-term microstructural development. To evaluate matrix homogeneity and density, a non-destructive Ultrasonic Pulse Velocity (UPV) test was systematically conducted on all specimens. The inclusion of the optimal blend of GGBS and Metakaolin significantly refines the pore structure, yielding a denser interfacial transition zone (ITZ). Consequently, maximum values for both compressive and split tensile strength were achieved alongside higher pulse velocities, confirming excellent concrete quality. This research confirms that the combined use of GGBS and Metakaolin produces high-strength, eco-friendly concrete with reliably predictable structural integrity.

KEYWORDS: Metakaolin, Ground granulated blast furnace slag(GGBS), pozzolanic, yielding, Compressive strength, Split tensile strength.and ultrasonic pulse velocity.

I. INTRODUCTION

Concrete is the world's most widely used man-made construction material, prized for its exceptional versatility and high compressive strength. It is a composite material traditionally manufactured by mixing ordinary Portland cement (OPC), water, and coarse and fine aggregates. Over time, a hydration reaction occurs between the water and cement, binding the ingredients together into a rock-like mass. As modern infrastructure demands grow, the concrete industry is increasingly focusing on enhancing durability while reducing carbon emissions. Consequently, traditional mixes are frequently modified using supplementary cementitious materials to improve both environmental sustainability and long-term performance.

Ground Granulated Blast Furnace Slag (GGBS) is a sustainable by-product obtained from the manufacture of iron in a blast furnace. When molten slag is rapidly quenched with water, it forms a glassy, granular product that is subsequently dried and ground into a fine powder. Utilizing GGBS as a partial replacement for ordinary Portland cement significantly reduces the carbon footprint and energy consumption associated with concrete production. Its chemical composition allows it to function as a latent hydraulic binder, slowly reacting with water and calcium hydroxide over time. This slower hydration process reduces the peak heat of hydration, which drastically lowers the risk of thermal cracking in mass concrete structures. Furthermore, GGBS refines the concrete's pore structure, significantly enhancing its resistance to sulfate attack and chloride ingress. Ultimately, it improves long-term durability and workability, although it typically exhibits slower strength gain at early ages compared to pure cement mixes.

Metakaolin is a highly reactive supplementary cementitious material produced by the controlled calcination of purified kaolin clay at temperatures between 650°C and 800°C. Unlike industrial by-products like GGBS or fly ash, metakaolin is a manufactured material processed under strict quality control to optimize its mineralogical purity. When incorporated into concrete, its exceptionally fine particle size allows it to act as an efficient physical filler within the matrix. Chemically, it exhibits high pozzolanic reactivity, rapidly consuming calcium hydroxide liberated during cement hydration to form additional strength-giving calcium silicate hydrate (C-S-H) gels.

II. OBJECTIVES

1. To evaluate the mechanical strength development and optimization of binary concrete mixes.
2. To assess the durability performance and microstructure refinement of the modified concrete matrix.
3. To investigate the thermal behavior and workability characteristics during the hydration process.

III. MATERIALS

- a) **Cement**:-An essential hydraulic binder manufactured by burning limestone and clay at intense heat to create a clinker, which is then pulverized. It serves as the primary glue in construction, chemically reacting with water to bond all the ingredients into a solid mass. Without its adhesive properties, the entire concrete mixture would fail to set and harden.
- b) **Fine Aggregate**:- Naturally sourced sand or finely crushed stone particles small enough to pass through a standard 4.75 mm sieve mesh. These particles act as a dense filler that packs tightly into the microscopic gaps between larger stones in the mix. They are crucial for creating a smooth, workable consistency while preventing internal structural voids.
- c) **Coarse Aggregate**:-Substantial pieces of gravel, quarry-split stone, or crushed boulders that are too large to pass through a 4.75 mm sieve. They form the rugged, load-bearing skeletal framework of the concrete, offering the primary resistance against heavy compressive forces. Their structural presence dramatically minimizes the overall volume of expensive cement paste needed.
- d) **Water**:-The vital liquid activator that triggers the chemical process of hydration required to transform dry cement into rock-hard paste. It simultaneously behaves as a fluid lubricant, making the raw concrete plastic enough to be mixed, poured, and molded. Striking the right balance in its quantity is critical, as excess liquid severely compromises final structural integrity.
- e) **Metakaolin**:-A premium, engineered mineral powder created by precisely heating pure kaolin clay to temperatures between 650°C and 800°C. Owing to its ultra-fine grain size, it acts as an immediate physical filler while triggering rapid pozzolanic reactions that boost early-stage structural strength. It specifically locks down free calcium hydroxide to build a denser, more cohesive concrete matrix.
- f) **GGBS (Ground Granulated Blast Furnace Slag)**:-An eco-friendly, glassy industrial by-product salvaged from molten iron manufacturing, quickly cooled with water jets, and milled into powder. It operates as a slow-acting hydraulic agent that minimizes internal heat build-up, greatly lowering the risk of thermal cracks in large structures. Over time, it systematically refines the internal pores to shield the concrete from harsh chemical, sulfate, and chloride degradation.

IV. RESULTS AND DISCUSSIONS

a. Compressive strength test: The compression test on concrete cubes is a fundamental quality control procedure used to determine the maximum compressive strength a hardened mix can sustain before structural failure. Standard concrete specimens, typically cast in molds of 150 mm×150 mm×150 mm are cured in water for specific periods, most commonly 7 and 28 days, to allow proper chemical hydration.

Table 1:- Compressive Strength result of concrete with GGBS as partial replacement of cement.

S.No	% of GGBS	Compressive Strength Results, N/mm ²	
		7 days	28 days
1	0%	33.09	49.73
2	10%	35.37	52.18
3	20%	36.68	53.24
4	30%	38.22	54.66
5	40%	39.34	55.71
6	50%	38.18	55.02

Table 2:- Compressive Strength result of concrete with Metakaolin as partial replacement of cement.

S.No	% of Metakaolin	Compressive Strength Results, N/mm ²	
		7 days	28 days
1	0%	33.09	49.73
2	3%	35.11	52.76
3	6%	35.95	53.51
4	9%	36.84	54.28
5	12%	37.73	54.77
6	15%	40.27	57.62
7	18%	36.89	53.94

Table 3:- Combined Compressive Strength result of concrete.

S.No	Combined Replacement(s)	Compressive Strength Results, N/mm ²	
		7 days	28 days
1	0%	33.09	49.73
2	40% GGBS+15% MK	41.72	59.65

b. Split tensile strength: At the Age of 7 and 28days, measuring 300 mm in length and 150 mm in diameter positioned horizontally between the loading platens of a Compression Testing Machine (CTM). A compressive load is applied diametrically and uniformly across the cylinder's length until it fails along its vertical diameter.

Table 4:- Split tensile Strength result of concrete with GGBS as partial replacement of cement.

S.No	% of GGBS	Split tensile Strength Results, N/mm ²	
		7 days	28 days
1	0%	3.13	4.84
2	10%	3.29	5.08
3	20%	3.42	5.22
4	30%	3.58	5.46
5	40%	3.99	6.01
6	50%	3.61	5.49

Table 5:- Split tensile Strength result of concrete with Metakaolin as partial replacement of cement.

S.No	% of Metakaolin	Split tensile Strength Results, N/mm ²	
		7 days	28 days
1	0%	3.13	4.84
2	3%	3.52	5.12
3	6%	3.48	5.29
4	9%	3.66	5.34
5	12%	3.74	5.46
6	15%	4.04	5.68
7	18%	3.65	5.31

Table 6:- Combined Split tensile Strength result of concrete.

S.No	Combined Replacement(s)	Split tensile Strength Results, N/mm ²	
		7 days	28 days
1	0%	3.13	4.84
2	40% GGBS+15% MK	4.17	5.89

c. Ultrasonic Pulse Velocity:- Ultrasonic Pulse Velocity (UPV) testing is a non-destructive method used to assess the quality, uniformity, and strength of concrete and other materials. The process involves transmitting high-frequency sound waves through a material using a transmitting transducer and receiving them with a second transducer. By measuring the precise time it takes for the pulse to travel a known distance, the velocity of the wave can be accurately calculated.

Table 7:- Ultrasonic Pulse Velocity Result of concrete with GGBS as partial replacement of cement.

S.No	% of GGBS	UPV Results, m/s	
		28 days	Quality of Concrete
1	0%	4451	Good
2	10%	4586	Excellent
3	20%	4632	Excellent
4	30%	4768	Excellent
5	40%	4864	Excellent
6	50%	4577	Excellent

Table 8:- Ultrasonic Pulse Velocity Result of concrete with Metakaolin as partial replacement of cement.

S.No	% of Metakaolin	UPV Results, m/s	
		28 days	Quality of Concrete
1	0%	4451	Good
2	3%	4567	Excellent
3	6%	4626	Excellent
4	9%	4785	Excellent
5	12%	4847	Excellent
6	15%	4898	Excellent
7	18%	4514	Excellent

Table 9:- Combined Ultrasonic Pulse Velocity Result of concrete.

S.No	Combined Replacement(s)	UPV Results, m/s	
		28 days	Quality of concrete
1	0%	4451	Good
2	40% GGBS+15% MK	5087	Excellent

V. CONCLUSION

1. The compressive strength for normal concrete for 7 and 28 days is 33.09 and 49.73 N/mm².
2. At 40% replacement of cement with GGBS the compressive strength for 7 and 28 days is 39.34 and 55.71 N/mm².
3. At 15% replacement of cement with Metakaolin the compressive strength for 7 and 28 days is 40.27 and 57.62 N/mm².
4. At 40%GGBS+15% MK the combined replacement of concrete the compressive strength for 7 and 28 days is 41.72 and 59.65 N/mm².
5. The Split tensile strength for conventional concrete for 7 and 28 days is 3.13 and 4.84 N/mm².
6. At 40% replacement of cement with GGBS the compressive strength for 7 and 28 days is 3.99 and 6.01 N/mm².
7. At 15% replacement of cement with Metakaolin the compressive strength for 7 and 28 days is 4.04 and 5.68 N/mm².
8. At 40%GGBS+15% MK the combined replacement of concrete the compressive strength for 7 and 28 days is 4.17 and 5.89 N/mm².
9. The Ultra pulse velocity for conventional concrete for 28 days is 4451 m/s.
10. At 40% replacement of cement with GGBS the Ultra pulse velocity for 28 days is 4864 m/s.
11. At 15% replacement of cement with Metakaolin the Ultra pulse velocity for 28 days is 4898 m/s.
12. At 40%GGBS+15%MK the combined replacement of concrete the Ultra pulse velocity for 28 days is 5087 m/s.

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