Experimental Study on High-Performance Concrete Incorporating GGBS and Silica Fume

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Abstract—**High-Performance Concrete (HPC) is engineered to achieve superior strength, durability, and sustainability compared to conventional concrete. This study investigates the combined effect of Ground Granulated Blast Furnace Slag (GGBS) and silica fume as partial replacements of cement in M80 grade HPC. Trial mixes were prepared with varying proportions of GGBS (20–30%) and silica fume (5–10%). Mechanical properties (compressive, flexural, and split tensile strength) and durability indicators (chloride permeability, water absorption) were evaluated. Results indicate that the synergistic use of GGBS and silica fume enhances microstructural refinement, reduces permeability, and achieves compressive strengths exceeding 80 MPa at 28 days. The findings highlight the potential of SCMs in producing sustainable HPC with reduced cement consumption and improved long-term performance.**

Index Terms—**High-Performance Concrete; GGBS; Silica Fume; Flexural Strength; Compressive Strength**

I. INTRODUCTION

High-Performance Concrete (HPC) is defined by its ability to meet special performance requirements such as high compressive strength, low permeability, and enhanced durability. The incorporation of supplementary cementitious materials (SCMs) such as GGBS and silica fume has proven effective in refining pore structure, improving interfacial transition zones, and reducing environmental impact. This study focuses on the combined influence of GGBS and silica fume in M80 HPC, aiming to balance early strength development with long-term durability.

A. Objectives

1. To determine the mix design of High-Performance Concrete by recalling codal provisions.
2. To conduct a comparative study of HPC with normal concrete in a structural element.

II. MATERIALS AND METHODS

A. Materials

Cement (OPC 53): Ordinary Portland Cement (OPC 53) has a typical specific gravity of 3.15, ensuring adequate density and strength contribution as the primary binder.

GGBS: Ground Granulated Blast Furnace Slag generally exhibits a specific gravity of 2.90, which is slightly lower than cement, aiding in reduced heat of hydration and improved durability.

Silica Fume: Silica fume possesses a specific gravity of about 2.20, reflecting its ultra-fine, lightweight nature that enhances pore refinement and ITZ properties.

Fine Aggregate (Sand): Zone II sand typically has a specific gravity of 2.65, influencing mix proportions, water demand, and workability.

Coarse Aggregate: Coarse aggregates usually show a specific gravity of 2.70, providing the load-bearing skeleton and contributing to strength and dimensional stability.

Water: Potable water is taken as a reference with a specific gravity of 1.00, serving as the baseline for mix proportioning.

Superplasticizer (PCE): Polycarboxylate ether-based superplasticizers are liquid admixtures with specific gravity typically ranging between 1.08, enabling effective dispersion and reduced water demand.

B. Mix design

The mix designs for High-Performance Concrete (HPC) and normal concrete were carried out in accordance with the guidelines of IS 10262:2019.

Materials	Mix design of HPC	
	Trial 1 Quantity (kg/m^3)	Trial 2 Quantity (kg/m^3)
Cement OPC 53	430.84kg	450kg
GGBS	114.8kg	166.833kg
Silica Fume	28.72kg	50.5kg
Fine Aggregate	585.3kg	636.54kg
Coarse Aggregate	1212.14kg	987.24kg
Superplasticizer	5.74	6.7
Water	143.59	143.59
W/C ratio	0.25	0.25

C. Casting and curing of the cube

In order to assess the strength development, six cubes of 150 × 150 × 150 mm were prepared for each trial mix. The specimens were cured under water for 7 days to determine early-age strength and for 28 days to establish the characteristic compressive strength of HPC.

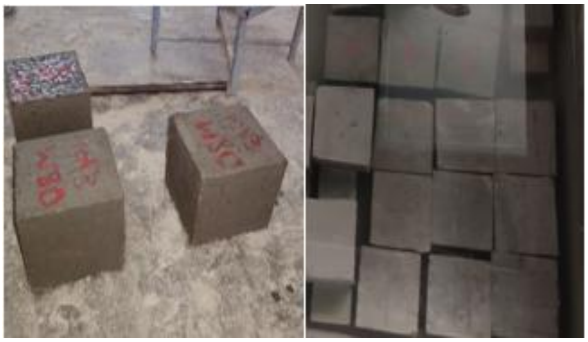

FIG.1 Casting and curing of the cube and the prism

D. Instrumentation and testing

Cube testing was carried out under a calibrated 2000 kN CTM, with load applied at a uniform rate until failure. The compressive strength was calculated as the ratio of ultimate load to the loaded area, and average values at 7 and 28 days were reported for each trial mix.

III. RESULTS AND DISCUSSION

A. compressive strength of the HPC

The table below shows the compressive strength of the HPC cubes for 7 and 28 days as follows.

Mix trial	Compressive strength of HPC	
	7 days	28 days
Trial 1	49.4	81.5
Trial 2	67.55	91.34

FIG.2 Failure pattern of cubes

The above result shows that an increase in binder materials like cement, GGBS, and silica fume leads to an increase in compressive strength of the concrete.

The synergistic action of OPC 53, GGBS, and silica fume reduces entrapped air voids and refines the microstructure, thereby increasing the compressive strength of HPC. Silica fume fills micro-pores, while GGBS reacts with calcium hydroxide to form additional C–S–H gel, resulting in a denser and stronger matrix.

Trial 2 is an optimum mix design but uneconomical compared to Trial 1 due to an increase in binder percentage

B. Comparative study of HPC with normal concrete

The comparative study reveals that HPC significantly outperforms conventional concrete in strength, stiffness, ductility, crack control, and durability, thereby establishing its suitability for modern structural applications.

High-Performance Concrete demonstrates superior mechanical strength, durability, crack control, and sustainability compared to conventional concrete, thereby enabling efficient structural design and extended service life in modern construction.

IV. CONCLUSION

The comparative evaluation clearly establishes that High-Performance Concrete (HPC) offers significant advantages over conventional concrete in structural applications. By incorporating supplementary cementitious materials and adopting optimized mix designs, HPC achieves superior compressive strength, flexural capacity, stiffness, and ductility. Its reduced permeability and enhanced resistance to chemical attack ensure long-term durability, making it highly suitable for aggressive environmental conditions. Furthermore, the ability to design slender sections and longer spans improves structural efficiency, while the use of industrial by-products contributes to sustainability by lowering cement consumption and reducing CO_2 emissions.

Thus, HPC not only enhances structural performance and service life but also aligns with modern engineering demands for durability, efficiency, and sustainability, positioning it as a preferred material for advanced construction projects.

V. FUTURE STUDY

Extended Mix Proportions: Investigate the performance of HPC with varying proportions of SCMs (fly ash, silica fume, GGBS) to optimize strength and durability with nano-materials.

Durability in Aggressive Environments: Conduct long-term exposure studies under marine, sulphate, and industrial conditions to validate service life predictions.

Structural Behavior Under Dynamic Loads: Explore HPC’s performance under seismic, fatigue, and impact loading to assess resilience in bridges and high-rise structures.

Hybrid SCM Combinations: Examine synergistic effects of multiple SCMs in different ratios to achieve balanced mechanical and durability properties.

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