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Experimental Investigation on Mechanical Durability and Microstructural performance of M60 High - Performance Concrete incorporating Silica fume, GGBS, Superplasticizer and Steel fiber Reinforcement

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KEYWORDS

GGBS; silica fume; fiber-reinforced concrete; M60 concrete; compressive strength; acid attack; alkali attack; sustainable concrete.

ABSTRACT

The present experimental study evaluates the influence of Ground Granulated Blast Furnace Slag (GGBS), silica fume and fiber addition on the compressive strength of M60 concrete. The source experimental programme used Ordinary Portland Cement (OPC) 53 grade, fine and coarse aggregates, silica fume, GGBS and a superplasticizer. The mix design was developed in accordance with IS 10262, with a reported water–cement ratio of 0.40 and a target average strength of 68.25 MPa. Phase I investigated GGBS replacement levels of 0%, 5%, 10%, 15% and 20%, while silica fume was maintained at 5% for the blended mixes. Phase II examined fiber contents of 0.5%, 1.0% and 1.5% in selected blended mixes. Three cube specimens of 150 mm × 150 mm × 150 mm were cast for each test condition and compressive strength was evaluated at different ages. The reported normal-water curing results show that the 15% GGBS + 5% silica-fume mix (M3N) achieved the highest 28-day strength within the Phase I series, at 72.77 MPa. In the separate fiber-comparison table, M3N is reported as 81.52 MPa at 28 days, while M3NF1, M3NF2 and M3NF3 reached 74.77, 75.27 and 76.27 MPa, respectively. Because these two source tables report different values for M3N and the source abstract states a 1.0% fiber optimum whereas the tabulated fiber series peaks at 1.5%, these values require verification against the laboratory records before journal submission. The study also describes hydrochloric-acid and sodium-hydroxide exposure procedures; however, numerical post-exposure strength and weight-loss results are not available in the supplied document and therefore are not fabricated in this paper.

1. Introduction

Concrete is the dominant construction material considered in the supplied study because of its high strength, versatility, durability and relatively low maintenance requirements. At the same time, the manufacture of Portland cement is associated with carbon dioxide emissions and consumption of natural resources. The source document therefore investigates partial cement replacement using supplementary cementitious materials, particularly GGBS and silica fume, together with fiber addition to improve the mechanical performance of the concrete.

GGBS is introduced in the source document as a finely ground, glassy by-product of iron and steel production that can replace a portion of Portland cement. Silica fume is described as a highly reactive pozzolanic by-product of silicon or ferrosilicon production. The combined use of these materials is intended to reduce cement consumption while improving the hardened concrete matrix. The source also notes that fibers can increase crack resistance, ductility and strength, although excessive or poorly dispersed fibers may reduce workability.

The research gap identified in the source is the need to compare concrete with and without pozzolanic materials, examine the effect of fiber content, and investigate resistance to chemical exposure. The source literature additionally identifies permeability, flexural strength, split tensile strength, sulphate attack and chloride penetration as areas for further investigation.

Figure 1. Steel fibers used in the experimental programme

2. Review of Related Studies

The literature review in the source document covers pervious concrete, fiber-reinforced concrete and supplementary cementitious materials. Radha Kiranmaye et al. are reported to have investigated glass-fiber modification and fine-aggregate fractions in pervious concrete, including compressive, flexural, split-tensile, void-ratio and permeability measurements. Akand and co-workers examined treatment of polypropylene fibers to improve fiber–cement interfacial bonding, which is particularly important in porous concrete. The source also reports that alkali-resistant glass fibers increased compressive, splitting-tensile and flexural strengths of high-strength concrete up to the investigated threshold.

Studies summarized in the source further indicate that aggregate grading, porosity and binder composition strongly influence pervious-concrete strength and permeability. Research involving fly ash and GGBS is reported to support partial replacement of cement for economic and environmental reasons. GGBS-based concretes may show slower early-age strength development but continued strength gain at later ages. These observations support the present investigation of combined GGBS, silica fume and fiber modification.

The critical review in the source identifies the need to compare pozzolanic and non-pozzolanic mixes, examine fiber addition, and extend durability assessment to acid, sulphate, chloride, permeability and elevated-temperature exposure. The present paper focuses on the strength data actually reported in the supplied document and describes, without inventing results, the chemical-exposure programme.

3. Materials and Experimental

3.1 Materials

OPC 53-grade cement conforming to IS 12269 is reported as the principal binder. The reported specific gravity of cement is 3.13. Fine aggregate has a reported specific gravity of 2.50 and was described as conforming to Grading Zone II of IS 383. The 20-mm coarse aggregate has a reported specific gravity of 2.80. A superplasticizer, identified in the source as ECMAS HP 890 and stated to conform to IS 9103, was used to control water demand and workability.

Silica fume and GGBS were used as supplementary cementitious materials. The source provides a silica-fume chemical-composition entry indicating 85% silica dioxide (SiO_2) and 3% moisture. Fiber contents of 0.5%, 1.0% and 1.5% were investigated in Phase II. The source document contains images of several fiber types; the steel-fiber image is the most directly relevant visual replacement for this paper.

Table 1. Principal materials and design parameters

Material / parameter	Reported value	Source basis
Cement	OPC 53 grade; specific gravity 3.13	Source pp. 24, 53
Fine aggregate	Specific gravity 2.50; Zone II	Source pp. 53–54
Coarse aggregate	20 mm; specific gravity 2.80	Source pp. 53–54
Water–cement ratio	0.40 adopted for final mix	Source pp. 54–56
Target average strength	68.25 MPa	IS 10262-based calculation in source
Superplasticizer	ECMAS HP 890; 0.4% by cement weight reported	Source p. 55
Silica fume	5% in principal blended mixes	Source p. 59
GGBS	0–20% in Phase I; 10% in Phase II	Source p. 59
Fibers	0.5%, 1.0%, 1.5% in Phase II	Source p. 59

3.2 Mix Design

The M60 mix was proportioned using IS 10262. The source reports a target average compressive strength of 68.25 MPa, an adopted water–cement ratio of 0.40, and final base quantities of 350 kg/m³ cement, 896 kg/m³ fine aggregate, 1140 kg/m³ coarse aggregate and approximately 140 kg/m³ water. Several trial batches were performed before selection of the reported final proportion.

Table 2. Reported final M60 mix-design parameters.

Parameter	Value
Grade	M60
Cement	350 kg/m³
Fine aggregate	896 kg/m³
Coarse aggregate	1140 kg/m³
Water	140 kg/m³
w/c ratio	0.40
Target strength	68.25 MPa
28-day strength reported for final trial	69.27 MPa

3.3 Experimental Mix Matrix

Table 3. Phase I mix matrix reproduced

Mix	GGBS (% cementitious basis)	Silica fume (%)	Fiber (%)
MSN	0	0	0
MSS	0	5	0
M1N	5	5	0
M1S	5	5	0
M2N	10	5	0
M2S	10	5	0
M3N	15	5	0
M3S	15	5	0
M4N	20	5	0
M4S	20	5	0

Table 4. Phase II mix matrix

Mix	GGBS (%)	Silica fume (%)	Fiber (%)
MSN	0	0	0
MSS	0	0	0
M2N	10	5	0
M2NF1	10	5	0.50
M2NF2	10	5	1.00
M2NF3	10	5	1.50
M2S	10	5	0
M2SF1	10	5	0.50
M2SF2	10	5	1.00
M2SF3	10	5	1.50

The source table uses the designations M2NF1–F3 and M2SF1–F3, while the results table later reports M3NF1–F3. This designation difference is retained as a source-data issue and should be checked before final manuscript submission.

3.4 Specimen Preparation and Compressive-Strength Testing

The source reports casting of 150 mm × 150 mm × 150 mm cube specimens. Cement and fine aggregate were initially mixed in dry condition, followed by coarse aggregate and then water. Approximately 50–70% of the water was initially introduced, and the mixture was mechanically mixed for 3–4 min. Fresh concrete was placed in moulds and compacted using a vibrating table. After 24 h at room temperature, specimens were demoulded and cured. Three cubes were cast for each parameter, and compressive strength was measured at 3, 7, 14 and 28 days in the results section.

The compressive-strength procedure follows IS 516 as stated in the source. The specimen is centered in the compression-testing machine and loaded gradually until failure. The reported compressive strength is obtained from the failure load divided by the loaded cross-sectional area.

Figure 2. Specific-gravity bottle/apparatus used in the preliminary material investigation

3.5 Acid and Alkali Exposure Programme

For acid exposure, the source reports that cubes were water-cured for 28 days, dried for one day and weighed before immersion. Hydrochloric acid was added to water at 5% by weight, with a reported pH of approximately 2 maintained during 28- and 90-day immersion periods. After exposure, specimens were tested for compressive strength and the resistance was intended to be quantified using percentage loss of weight and compressive strength.

For alkaline exposure, 28-day water-cured cubes were similarly dried and weighed, then immersed in water containing 3% sodium hydroxide by weight for 28 and 90 days. The source specifies evaluation through weight loss and residual compressive strength. The supplied document does not provide the numerical acid- or alkali-exposure results, so these values are deliberately not reproduced or estimated here.

4. Results and Discussion

4.1 Strength Development of GGBS–Silica Fume Mixes

Table 5. Average compressive strength of mixes cured with normal water

Mix	3 days (MPa)	7 days (MPa)	14 days (MPa)	28 days (MPa)
MSN	39.74	48.62	63.74	69.27
MSS	38.2	46.3	59.95	66.5
M1N	37.01	45.32	58.79	64.5
M2N	39.1	48.5	63.29	69.5
M3N	41.04	51.75	66.54	72.77
M4N	39.54	47.5	63.29	68.77

The reported data show progressive strength development with curing age for all mixes. In the normal-water series, M3N, containing 15% GGBS and 5% silica fume, gives the highest reported 28-day strength of 72.77 MPa. Relative to MSN at 69.27 MPa, this corresponds to an increase of approximately 5.05%. M4N, with 20% GGBS and 5% silica fume, decreases to 68.77 MPa, indicating that the increase in GGBS does not continue to improve strength beyond the reported optimum in this series.

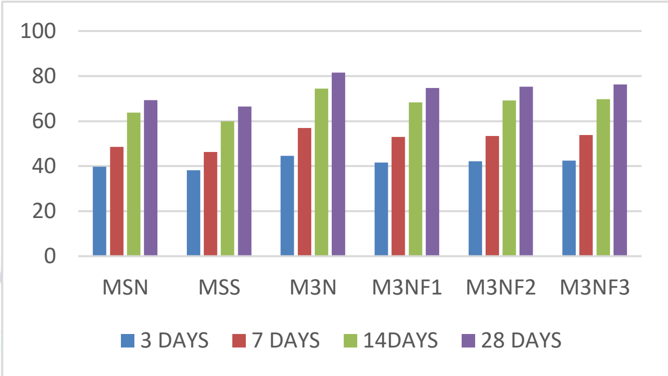

Figure 3. 28-day compressive strength of GGBS–silica fume mixes.

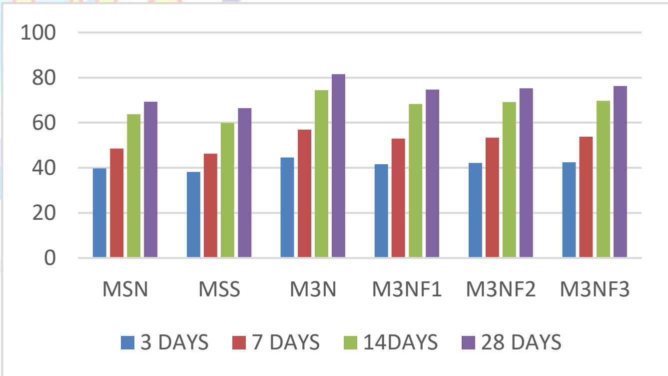

Figure 4. Compressive-strength development with curing age.

4.2 Effect of Fiber Addition

Table 6. Fiber-series compressive strength reported in the source document

Mix	Fiber (%)	3 days	7 days	14 days	28 days
MSN	0	39.74	48.62	63.74	69.27
MSS	0	38.2	46.3	59.95	66.5
M3N	0	44.54	57.0	74.39	81.52
M3NF1	0.5	41.54	52.95	68.34	74.77
M3NF2	1.0	42.14	53.4	69.14	75.27
M3NF3	1.5	42.44	53.85	69.69	76.27

The fiber-series data show that all investigated fiber mixes exceed MSS at 28 days. M3NF1, M3NF2 and M3NF3 are reported at 74.77, 75.27 and 76.27 MPa, respectively. Within the fiber-modified series, the reported strength increases from 74.77 MPa at 0.5% fiber to 76.27 MPa at 1.5% fiber. Therefore, the numerical table itself identifies 1.5% as the highest-strength fiber content among the three fiber levels. However, the source abstract states that 1.0% gives the maximum strength. This discrepancy should be resolved from the original laboratory records rather than corrected by assumption.

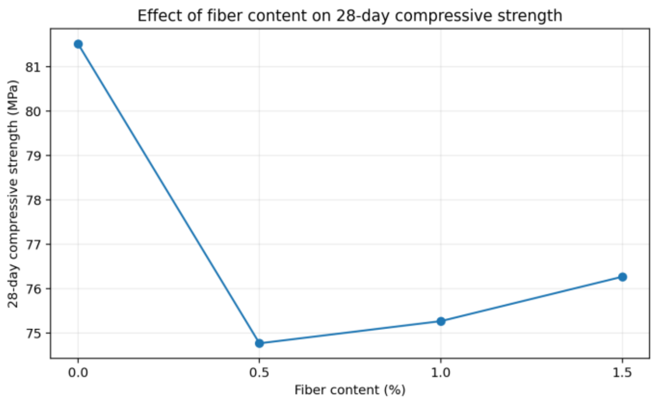

Figure 5. Effect of fiber content on 28-day compressive strength using the fiber-series values

4.3 Workability

The source concludes that workability decreases with the incorporation of pozzolanic materials and fibers. This is consistent with the experimental programme in which a superplasticizer was used to control water demand. The reported trial mixes show slump values of 59, 57, 54 and 52 mm for the four recorded M60 trial batches, while the final mix-design discussion also specifies a desired workability range of 100–120 mm for the design stage. Because the source presents trial and design-stage workability values in different contexts, these should not be treated as one uniform dataset.

Table 7. M60 trial-mix observations report

Trial entry	**Water (kg/m³)**	**Slump (mm)**	**28-day strength (MPa)**
1	148.50	59	69.27
2	132.00	57	68.42
3	125.40	54	64.90
4	165.00	52	65.34

4.4 Acid and Alkali Exposure

The experimental design includes chemical exposure to hydrochloric acid and sodium hydroxide after 28 days of water curing. The acid programme uses 5% HCl solution at approximately pH 2, whereas the alkali programme uses 3% NaOH solution. Exposure durations of 28 and 90 days are specified. These tests are intended to quantify the deterioration of concrete through residual compressive strength and weight loss.

5. Key Findings and Engineering Interpretation

The experimental evidence supplied in the document indicates that partial cement replacement with GGBS and silica fume can produce a higher 28-day compressive strength than the reported control in the Phase I normal-water series. The best reported Phase I value is associated with 15% GGBS and 5% silica fume. Increasing GGBS to 20% reduces the reported 28-day strength, suggesting that an optimum replacement level exists for the particular materials, water–cement ratio and curing conditions used.

Fiber addition also increases the reported compressive strength relative to the MSS reference within the fiber-comparison series. Nevertheless, the source tables contain an internal discrepancy in the M3N value and the source abstract contains a different optimum fiber percentage from the tabulated data. These discrepancies are significant because they directly affect the stated optimum mix and should be resolved before the results are used for design recommendations or journal publication.

The chemical-exposure programme is a useful extension of the strength investigation because GGBS and silica fume are introduced partly for durability-related benefits. However, durability conclusions require the missing residual-strength and mass-loss data. The present paper therefore limits its quantitative conclusions to the normal-water compressive-strength results available in the source.

6. Conclusions

- Under normal-water curing, the reported Phase I data identify M3N (15% GGBS + 5% silica fume) as the highest-strength mix, reaching 72.77 MPa at 28 days.
- The 20% GGBS + 5% silica-fume mix (M4N) records 68.77 MPa at 28 days, lower than M3N, indicating that

the optimum replacement level in the reported series is not the maximum GGBS content.

• The fiber-series table reports 28-day strengths of 74.77, 75.27 and 76.27 MPa for 0.5%, 1.0% and 1.5% fiber, respectively.

• The source document reports reduced workability with the incorporation of pozzolanic materials and fibers and uses superplasticizer to manage water demand.

• Acid and alkali exposure testing was undertaken using HCl and NaOH solutions for 28- and 90-day exposure periods, but the numerical deterioration results are not available in the supplied document.

• Before journal submission, the M3N strength discrepancy (72.77 MPa versus 81.52 MPa) and the stated optimum fiber content discrepancy (1.0% in the abstract versus 1.5% in the fiber table) must be verified against the original laboratory records.

7. Scope for Further Work

Future work identified in the source includes permeability, flexural strength, split-tensile strength, sulphate attack, chloride penetration, corrosion-related durability and elevated-temperature exposure. For a stronger journal contribution, the next stage should also report specimen-level data, standard deviations, coefficient of variation, statistical significance, mass loss, residual strength and microstructural characterization such as SEM/EDS where available.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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