Strength and Durability Characteristics of High Volume GGBFS Based Pavement Quality Concrete

***BAGGU SANTOSH KUMAR [1], K. DILEEP CHOWDARY[2]**

[1]M.Tech Scholar (Structural Engineering), Department of Civil Engineering, Sanketika Vidya Parishad Engineering College, P.M. Palem, Visakhapatnam – 530041, Andhra Pradesh, India

[2]Assistant Professor, Department of Civil Engineering, Sanketika Vidya Parishad Engineering College, P.M. Palem, Visakhapatnam – 530041, Andhra Pradesh, India

Abstract

The growing demand for durable pavement infrastructure and the environmental burden associated with ordinary Portland cement (OPC) have encouraged the use of supplementary cementitious materials in pavement quality concrete (PQC). This experimental study evaluates M40 PQC incorporating ground granulated blast furnace slag (GGBFS) at replacement levels of 60%, 65% and 70% of the binder, compared with a conventional OPC–fly ash control mix. Fresh properties, compressive strength, flexural strength, resistance to 5% sulphuric acid and 5% sodium sulphate exposure, abrasion resistance and drying shrinkage were investigated. The GGBFS mixtures achieved 25 mm slump with fresh densities of 2482.73–2514.87 kg/m³. At 28 days, compressive strength was 7.5–7.9% lower than the respective controls; however, at 90 days, the GGBFS mixtures attained 55.53–56.24 MPa, exceeding their controls by 17.3–20.6%. Flexural strength at 90 days increased with GGBFS content, reaching 10.56 MPa at 70% replacement. The GGBFS mixtures also exhibited higher residual strength after chemical exposure and higher reported abrasion resistance, while drying-shrinkage values remained close to the control. The findings indicate that high-volume GGBFS can be a technically promising binder for M40 PQC when adequate curing and project-specific mix verification are ensured.

Keywords: Ground granulated blast furnace slag; Pavement quality concrete; High-volume replacement; Compressive strength; Flexural strength; Durability; Abrasion resistance.

1. INTRODUCTION

Pavement quality concrete is required to sustain repeated wheel loads, environmental exposure and long service periods with limited maintenance. Its performance depends not only on compressive strength but also on flexural strength, abrasion resistance, dimensional stability and resistance to aggressive chemicals. Conventional OPC-based concrete provides established performance, but cement manufacture is energy intensive and contributes substantially to construction-related carbon emissions. Reducing clinker consumption through supplementary cementitious materials is therefore an important route towards lower-impact pavement construction.

Ground granulated blast furnace slag is a finely ground, latent hydraulic by-product obtained during iron production. In the presence of water and calcium-bearing hydration products, GGBFS reacts to form additional calcium silicate hydrate (C–S–H), refining the pore structure and potentially improving later-age strength and durability. Its slower early reaction, however, can delay strength development, particularly when high replacement levels reduce the available OPC fraction.

The present work investigates 60%, 65% and 70% GGBFS replacement in M40 PQC. The study compares the mixes with a conventional OPC–fly ash control and examines fresh-state behaviour, strength development at 28 and 90 days, chemical resistance, abrasion and drying shrinkage. The research is directed towards identifying whether high-volume GGBFS can satisfy the performance requirements relevant to rigid pavement concrete.

2. REVIEW OF LITERATURE

Recent investigations have considered GGBFS in pavement concrete, blended binders and aggressive exposure conditions. Patel et al. examined high-volume GGBFS in PQC and reported its relevance to pavement applications [10], while their subsequent work focused on flexural and abrasion behaviour of GGBFS concrete pavements [11]. Nicula et al. evaluated GGBFS and air-cooled blast furnace slag for rigid pavement applications at 90 days [13]. Chittibabu and Durgarani considered drying shrinkage and durability in PQC containing recycled aggregate, GGBS and I-Crete [4].

Research on blended concrete indicates that GGBFS content and curing conditions influence strength development. Kumar studied the combined effect of GGBS and temperature curing in fly ash-based geopolymer concrete [8]. Shubbar et al. investigated early-age and long-term mechanical performance of mortars incorporating high-volume GGBS [17]. Sivakumar and Santhanam reported the influence of curing regimes on mechanical properties of GGBS concrete [32]. These findings emphasize the importance of curing and later-age assessment when high slag contents are used.

Durability is another key consideration. Elhussainy and Ibrahim examined acid attack in reactive powder concrete containing supplementary cementitious materials [3], while Lee and Na assessed high-volume GGBS concrete under cryogenic exposure [19]. Verma et al. reported durability assessment of high-volume GGBS concrete [39]. The present study contributes experimental data for high-volume GGBFS in M40 PQC, with a combined assessment of strength, chemical exposure, abrasion and drying shrinkage.

3. MATERIALS AND METHODOLOGY

3.1 Materials

The binder system consisted of OPC, GGBFS and fly ash. The conventional control used an OPC–fly ash binder, whereas the modified mixes used binary OPC–GGBFS binders. The GGBFS had a specific gravity of 2.88 and fineness of 372 m²/kg; fly ash had a specific gravity of 2.65 and fineness of 320 m²/kg. OPC had a specific gravity of 3.13. Fine and coarse aggregates were characterized for specific gravity, water absorption, impact, abrasion, crushing, flakiness and elongation indices. A polycarboxylate ether (PCE)-based superplasticizer was used at 0.40% by binder mass.

Table.1. Materials

Material / property	Reported value
GGBFS: specific gravity	2.88
GGBFS: fineness	372 m²/kg
Fly ash: specific gravity / fineness	2.65 / 320 m²/kg
OPC: specific gravity	3.13
Fine aggregate: specific gravity	2.64
Coarse aggregate: specific gravity (10 mm / 20 mm)	2.87 / 2.94
PCE admixture dosage	0.40% of binder mass

3.2 Mix Proportions

Four PQC mixtures were prepared: a conventional control and mixes containing 60%, 65% and 70% GGBFS. The binder contents and aggregate quantities adopted in the experimental programme are summarized in Table 2. The water-to-binder ratios ranged from 0.32 to 0.38.

Table.2. Mix Proportions

Constituent (kg/m³)	Conventional	60% GGBFS	65% GGBFS	70% GGBFS
Cement	330.00	176.00	157.00	138.00
Fly ash	80.00	0.00	0.00	0.00
GGBFS	0.00	264.00	293.00	322.50
Coarse aggregate (10 mm)	485.43	467.77	459.16	457.03
Coarse aggregate (20 mm)	688.08	720.22	706.96	703.68
River sand	768.32	777.40	763.08	759.55

Water	167.69	152.79	164.76	163.68
Superplasticizer	1.64	1.76	1.80	1.84
Water–binder ratio	0.38	0.32	0.34	0.33

3.3 Experimental Programme

The experimental programme included slump, fresh density and air-content measurements. Hardened concrete was evaluated through compressive and flexural strength tests at 28 and 90 days. Chemical resistance was assessed by exposing specimens to 5% H_2SO_4 and 5% Na_2SO_4 solutions and measuring compressive strength. Abrasion resistance and drying shrinkage (length change) were also determined at 28 days. Specimens were cast, demoulded and cured before testing in accordance with the procedures stated in the project report.

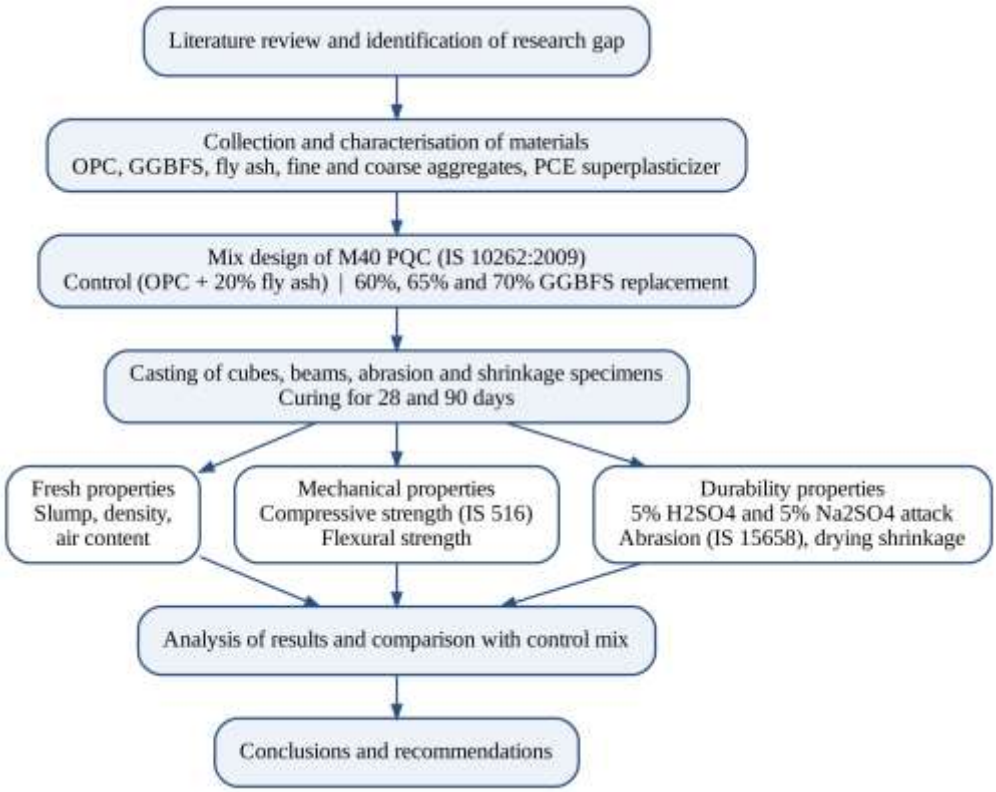


Fig. 1. Flow chart of the research methodology.

4. RESULTS AND DISCUSSION

4.1 Fresh Properties

The fresh properties of all mixtures are presented in Table 3. A PCE-based superplasticizer dosage of 0.40% by binder mass was required to obtain workable mixtures. The conventional mix recorded a slump of 30 mm, while the GGBFS mixtures recorded 25 mm. Fresh density varied from 2482.73 to 2514.87 kg/m³, compared with 2487.26 kg/m³ for the control. Air content was 1.00% for the GGBFS mixtures and 1.20% for the conventional mix. The small differences indicate that the high-volume slag replacement did not cause a major change in the measured fresh-state characteristics.

Table.3. Fresh Properties of Mixes

Mix	Binder system	w/b	Slump (mm)	Density (kg/m³)	Air (%)
Conventional	Cement:fly ash (80:20)	0.38	30	2487.26	1.20
60% GGBFS	Cement:GGBFS (40:60)	0.32	25	2482.73	1.00
65% GGBFS	Cement:GGBFS (35:65)	0.34	25	2498.80	1.00
70% GGBFS	Cement:GGBFS (30:70)	0.33	25	2514.87	1.00

4.2 Compressive Strength

The average compressive strengths at 28 and 90 days are compared in Table 4 and Fig. 2. At 28 days, the GGBFS mixtures developed 37.13–40.06 MPa, which was 7.5–7.9% lower than the corresponding conventional mixes. The 65% and 70% GGBFS mixtures were slightly below 40 MPa at this age. This early-age reduction is consistent with the slower hydration kinetics of GGBFS and the lower OPC fraction available to generate early calcium hydroxide and hydration products.

A substantial strength gain occurred between 28 and 90 days. The 60%, 65% and 70% GGBFS mixtures attained 56.24, 55.53 and 55.86 MPa, respectively, exceeding their respective controls by 17.3%, 17.7% and 20.6%. The corresponding GGBFS strength gains were 40.4%, 43.2% and 50.4%. Continued slag hydration and formation of additional C–S–H are likely contributors to matrix densification. These results underline the need for adequate curing and a suitable acceptance-age strategy for high-volume GGBFS PQC.

Table.4. Compressive strength

Mix comparison	28-day strength (MPa)	90-day strength (MPa)
Control for 60% series	43.50	47.93
60% GGBFS	40.06	56.24
Control for 65% series	41.95	47.18
65% GGBFS	38.78	55.53
Control for 70% series	40.16	46.31
70% GGBFS	37.13	55.86

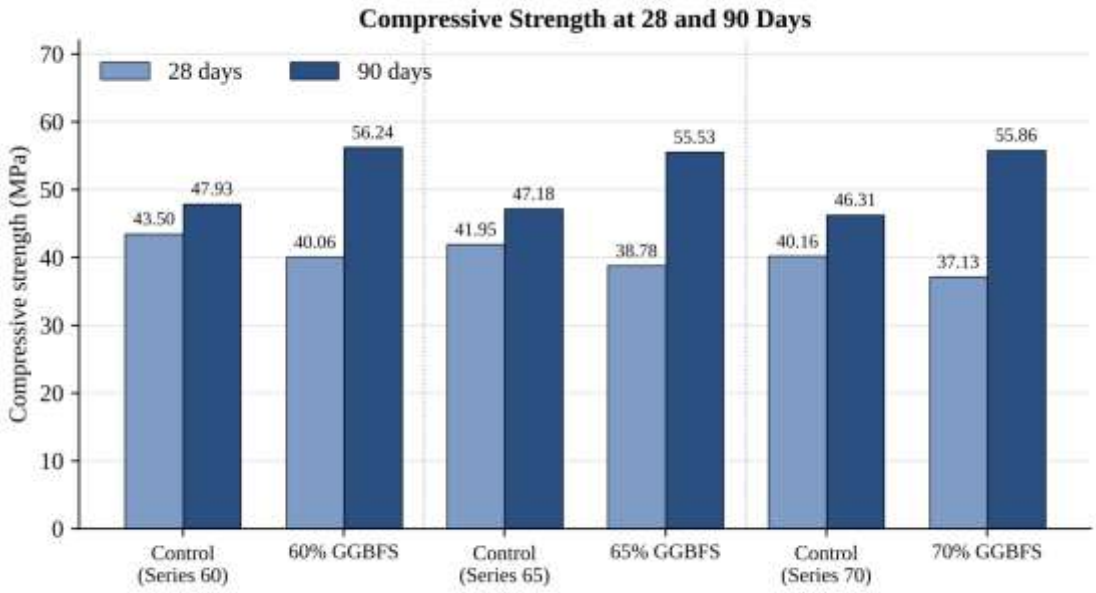


Fig. 2. Compressive strength of conventional and GGBFS mixes at 28 and 90 days.

4.3 Flexural Strength

Flexural strength is a principal performance parameter for rigid pavements because concrete slabs transfer wheel loads through bending. At 28 days, the GGBFS mixtures recorded 6.20–6.25 MPa, comparable with the conventional mixes (6.18–6.20 MPa). At 90 days, the 60%, 65% and 70% GGBFS mixtures attained 9.00, 9.77 and 10.56 MPa, respectively, compared with 8.90 MPa for the control. The relative improvements were approximately 1.1%, 9.8% and 18.7%. The increasing flexural strength with GGBFS content at 90 days may be associated with continued hydration and refinement of the paste–aggregate interfacial transition zone.

Table.5. Flexural strength

Mix	28-day flexural strength (MPa)	90-day flexural strength (MPa)
Conventional	6.20	8.90
60% GGBFS	6.20	9.00
65% GGBFS	6.22	9.77
70% GGBFS	6.25	10.56

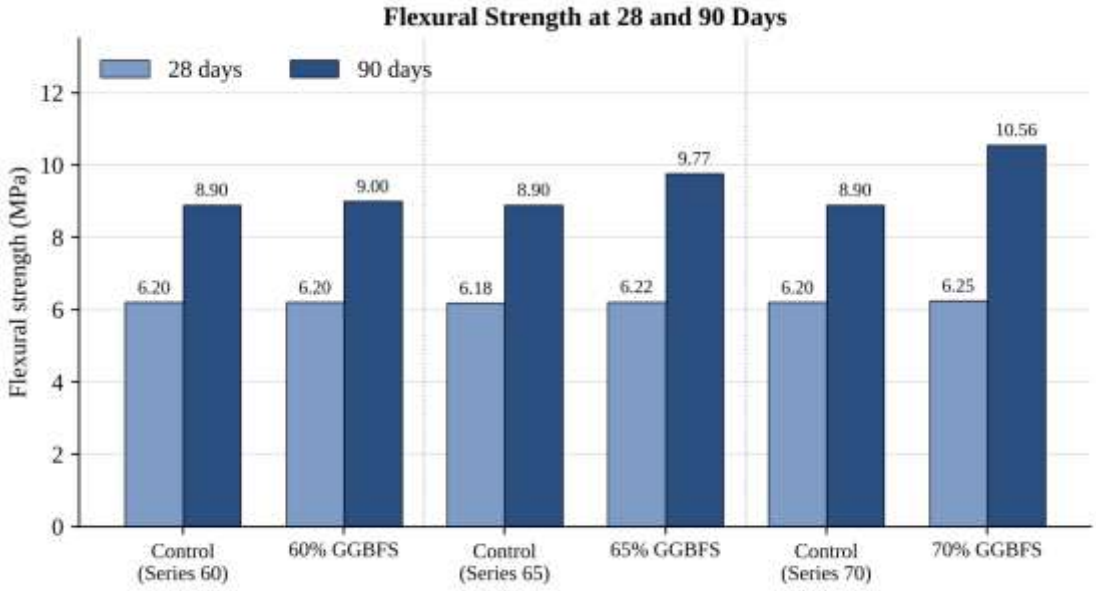


Fig. 3. Flexural strength of conventional and GGBFS mixes at 28 and 90 days.

4.4 Resistance to Acid and Sulphate Exposure

The residual compressive strengths after exposure to 5% H_2SO_4 and 5% Na_2SO_4 are presented in Table 6 and Fig. 4. Under sulphuric acid exposure, all mixtures experienced strength reduction, consistent with acid reaction with calcium-bearing hydration products and the formation of gypsum. At 28 days, GGBFS mixtures recorded 37.19–37.97 MPa compared with 31.37 MPa for the control. At 90 days, the 60%, 65% and 70% GGBFS mixtures retained 24.77, 26.30 and 28.82 MPa, respectively, compared with 23.76 MPa for the control. The 70% GGBFS mixture showed the highest residual strength, 21.3% above the control at 90 days.

Following 5% Na_2SO_4 exposure, 28-day strengths of the GGBFS mixtures (47.23–49.98 MPa) were comparable to the control (48.87 MPa). At 90 days, the GGBFS mixtures attained 58.20, 59.49 and 59.15 MPa, exceeding the control value of 50.59 MPa by 15.0%, 17.6% and 16.9%, respectively. The results indicate improved retained strength under the reported sulphate exposure regime. The interpretation is limited to the exposure conditions and test durations used in this investigation.

Table.6. Residual compressive strengths

Exposure / mix	28 days (MPa)	90 days (MPa)
H_2SO_4 – Conventional	31.37	23.76
H_2SO_4 – 60% GGBFS	37.19	24.77
H_2SO_4 – 65% GGBFS	37.44	26.30
H_2SO_4 – 70% GGBFS	37.97	28.82
Na_2SO_4 – Conventional	48.87	50.59
Na_2SO_4 – 60% GGBFS	49.98	58.20
Na_2SO_4 – 65% GGBFS	47.80	59.49
Na_2SO_4 – 70% GGBFS	47.23	59.15

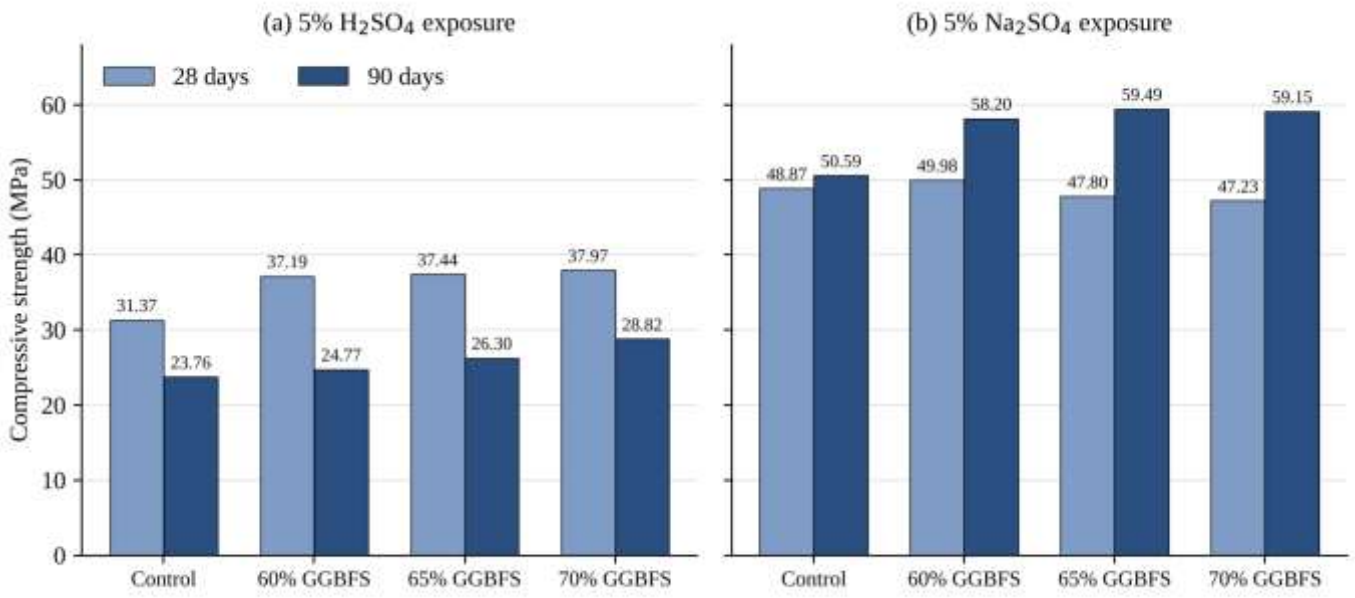


Fig. 4. Compressive strength after (a) acid and (b) alkaline/sulphate exposure at 28 and 90 days.

4.5 Abrasion Resistance

The 28-day abrasion resistance results are summarized in Table 7 and Fig. 5. The reported average values were 2500, 3500, 3750 and 4000 mm² for the conventional, 60%, 65% and 70% GGBFS mixtures in their respective series. Relative to the corresponding controls, the GGBFS mixtures showed increases of 40.0%, 36.4% and 33.3%. The project report interprets these results as improved abrasion resistance, attributed to a denser surface matrix resulting from continued slag hydration. The reported unit and test convention should be retained consistently when comparing these values with other studies.

Table.7. 28-day abrasion resistance results

Series	Conventional (mm²)	GGBFS mix (mm²)	Reported increase
60% GGBFS	2500	3500	40.0%
65% GGBFS	2750	3750	36.4%
70% GGBFS	3000	4000	33.3%

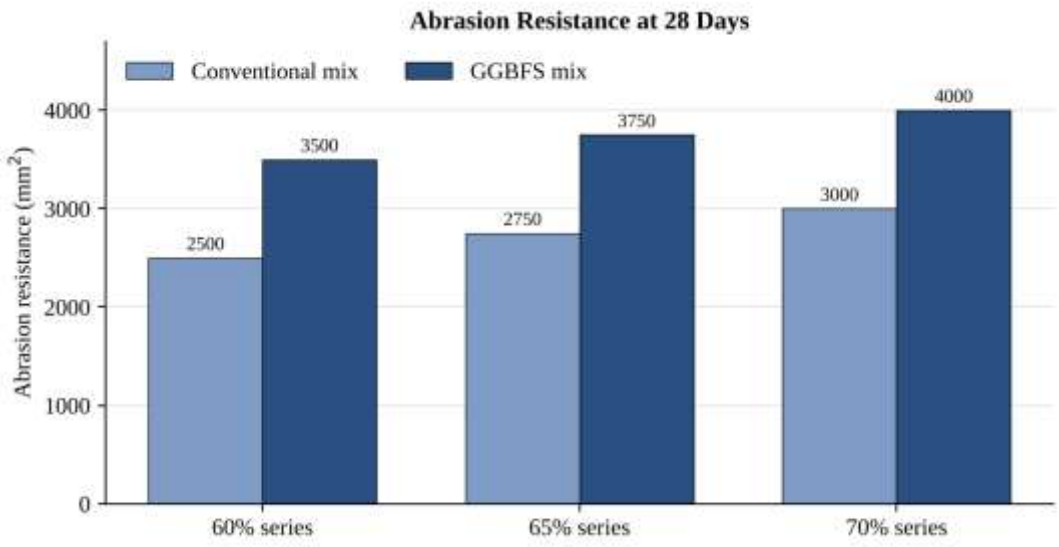


Fig. 5. Abrasion resistance of conventional and GGBFS mixes at 28 days.

4.6 Drying Shrinkage

The 28-day length-change values were 1.253% for the conventional mix and 1.256%, 1.253% and 1.246% for the 60%, 65% and 70% GGBFS mixtures, respectively. The values are closely grouped, with differences from the control of less than 0.01 percentage points as reported. This indicates that no appreciable difference in the measured length change was observed among the investigated mixtures during the test period.

Table.8. 28-day length-change values

Mix	Length change at 28 days (%)
Conventional	1.253
60% GGBFS	1.256
65% GGBFS	1.253
70% GGBFS	1.246

4.7 Overall Discussion

Across the experimental programme, the principal trade-off was lower early-age compressive strength against stronger later-age performance. Flexural strength was maintained at 28 days and improved at 90 days. The GGBFS mixtures also showed higher residual strengths after the reported chemical exposures and higher abrasion values, while fresh density and drying shrinkage remained comparable with the control. Among the investigated mixtures, 70% GGBFS gave the highest 90-day flexural strength, acid-exposure residual strength and reported abrasion value. The 60% and 65% mixtures, however, also demonstrated substantial later-age strength development. Selection of a field mix should therefore consider construction schedule, curing provisions, local exposure conditions and project-specific acceptance criteria.

5. CONCLUSIONS

1. Workable M40 PQC incorporating 60–70% GGBFS was produced using a PCE-based superplasticizer dosage of 0.40% by binder mass. The GGBFS mixes recorded 25 mm slump, fresh density of 2482.73–2514.87 kg/m³ and 1.00% air content.
2. At 28 days, the GGBFS mixtures exhibited 7.5–7.9% lower compressive strength than their corresponding controls. At 90 days, their compressive strengths reached 55.53–56.24 MPa, representing improvements of 17.3–20.6% over the controls.

3. Flexural strength at 28 days remained comparable with the conventional mix. At 90 days, the 70% GGBFS mix achieved the highest value of 10.56 MPa, followed by the 65% and 60% mixes at 9.77 and 9.00 MPa.
4. After 5% H_2SO_4 exposure, the 70% GGBFS mix recorded the highest 90-day residual compressive strength (28.82 MPa), 21.3% above the control. Under 5% Na_2SO_4 exposure, all GGBFS mixes exceeded the control at 90 days.
5. Reported abrasion values for the GGBFS mixtures were 33.3–40.0% higher than their respective controls. Drying-shrinkage length-change values were close to the conventional mix, indicating comparable measured dimensional change at 28 days.
6. Within the limits of the laboratory programme, high-volume GGBFS replacement of 60–70% is promising for M40 PQC. The 70% mix provided the strongest overall response in selected 90-day performance measures, but adequate curing and project-specific validation are essential.

REFERENCES

[1] Bhatt A, Kumar S, Prasad P, Sahu A, Kumar P, Hussein AB. Mechanical, Durability and Microstructural Performance of OPC–GGBFS–FGD Gypsum Ternary Concrete: Identification of an Operational Sulfate Activation Threshold. Materials. 2026;19(14):2962. https://doi.org/10.3390/ma19142962

[2] Karabaş B, Uzer AU. Road Subgrade Stabilization Using Ground Granulated Blast Furnace Slag: Pavement Design, Cost Optimization, and CO2 Emission Reduction. Materials. 2026;19(21):4639. https://doi.org/10.3390/ma19214639

[3] Elhussainy MS, Ibrahim EK. Effect of Acid Attack on the Performance of Reactive Powder Concrete Incorporating Supplementary Cementitious Materials. Journal of Engineering and Sustainable Development. 2026;30(1):66–74. https://doi.org/10.31272/jeasd.2227

[4] Chittibabu B, Durgarani K. Performance Evaluation of Drying Shrinkage and Durability in Pavement Quality Concrete with Recycled Aggregate, GGBS and I-Crete. Global NEST Journal. 2025;27(3):1–11. https://doi.org/10.30955/gnj.06845

[5] Wasil I, Ganvir D, Chopra T, Singh MK. Influence of GGBFS and Processed Coarse RAP in Pavement Quality Concrete. In: Pavement Systems Engineering. Singapore: Springer Nature; 2025. https://doi.org/10.1007/978-981-96-8110-5_14

[6] Akhlaq H, Peng T, Ajmal MM, Khan MS, Riaz M. Impact of GGBS on the Rheology and Mechanical Behavior of Pumpable Concrete. Frontiers in Materials. 2025;12:1614951. https://doi.org/10.3389/fmats.2025.1614951

[7] Scully K, Drewniok M. Sulfate Addition to Ground Granulated Blast-furnace Slag for use as a Supplementary Cementitious Material in Concrete. International Conference on Durability of Concrete Structures (ICDCS); 2025. https://doi.org/10.5703/1288284318162

[8] Kumar A. Effect of Ground Granulated Blast Slag and Temperature Curing on the Strength of Fly Ash-based Geopolymer Concrete. Engineering, Technology & Applied Science Research. 2024;14(2):13319–23.

[9] Yahyaee T, Elize HS. A comprehensive study on mechanical properties, durability, and environmental impact of fiber-reinforced concrete incorporating ground granulated blast furnace slag. Case Studies in Construction Materials. 2024;20(3):1–18.

[10] Patel VJ, Juremalani J, Kumavat HR. Incorporation of High Volume Ground Granulated Slag from Blast Furnaces in Pavement Quality Concrete. Engineering, Technology & Applied Science Research. 2024;14(4):14888–93. https://doi.org/10.48084/etasr.7466

[11] Patel VJ, Juremalani J, Kumavat HR, Patel J. Flexural and Abrasion Performance of High Volume GGBS Concrete Pavements. Engineering, Technology & Applied Science Research. 2024;14(5):17055–59. https://doi.org/10.48084/etasr.8534

[12] Hawileh RA, Abdalla JA, Mirghani A, Al Nassara A, Khartabil A, et al. Effects of Replacing Cement with GGBS and Fly Ash on the Flexural and Shear Performance of Reinforced Concrete Beams. Practice Periodical on Structural Design and Construction. 2024;29(2). https://doi.org/10.1061/PPSCFX.SCENG-1339

[13] Nicula LM, Manea DL, Simedru D, Cadar O, Dragomir ML, Ardelean I, Corbu O. Potential Role of GGBS and ACBFS Blast Furnace Slag at 90 Days for Application in Rigid Concrete Pavements. Materials. 2023;16(17):5902. https://doi.org/10.3390/ma16175902