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Carbonation Behaviour of M30 Concrete with Partial Cement Replacement Using GGBS and Fly Ash

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Abstract: ***This study experimentally examines the use of Ground Granulated Blast Furnace Slag (GGBS) and Fly Ash as partial replacements for cement in M30 grade concrete, focusing on compressive strength and carbonation depth. GGBS replacement levels of 10–70% and Fly Ash replacement levels of 10–40% were considered. The reported compressive-strength measurements were evaluated at 7, 14 and 28 days, while carbonation depth was assessed at the same ages. The highest 28-day compressive strength in the reported GGBS series was 45.5 MPa at 50% replacement. For the Fly Ash series, the highest reported 28-day strength was 41.5 MPa at 30% replacement. Carbonation depth increased with increasing replacement level in both series, reaching 12 mm at 70% GGBS and 10 mm at 40% Fly Ash after 28 days. The results indicate that replacement level influences both strength development and carbonation behaviour; therefore, an optimum mixture should be selected by considering these properties together. The findings are limited to the mix proportions and curing ages reported in this study.***
Keywords: M30 concrete, carbonation, GGBS, Fly Ash, compressive strength, mineral admixtures, cement replacement.

I. INTRODUCTION

Concrete is extensively used in construction because of its strength, durability and versatility. However, ordinary Portland cement production is energy-intensive and contributes to carbon dioxide emissions. The partial replacement of cement with suitable industrial by-products is one approach to reducing cement consumption and making concrete production more sustainable.

Carbonation is an important durability-related process in reinforced concrete. Atmospheric carbon dioxide penetrates the concrete pore system and reacts with alkaline constituents, including calcium hydroxide. The resulting reduction in pore-solution alkalinity can reduce the protection provided to reinforcing steel and may initiate reinforcement corrosion when moisture and oxygen are available. Corrosion products can cause cracking, delamination and deterioration of the concrete cover.

The present work investigates M30 grade concrete incorporating Ground Granulated Blast Furnace Slag (GGBS) and Fly Ash as partial cement replacements. The study compares compressive strength and carbonation depth at different replacement levels and curing ages. The experimental programme reported in the source presentation considers GGBS replacement from 10% to 70% and Fly Ash replacement from 10% to 40%.

II. REVIEW OF RELATED LITERATURE

Previous studies summarized in the project presentation have examined carbonation and strength in concrete containing supplementary cementitious materials. Singh and Singh [1] investigated concrete incorporating recycled aggregates and metakaolin. Hussain et al. [2] compared accelerated carbonation behaviour of plain cement and Fly Ash concrete and reported that carbonation depth was affected by Fly Ash content. Pravalika and Rao [3] studied carbonation effects in concrete with Fly Ash replacement and reported a strength response that varied with replacement percentage.

Moon et al. [4] examined pozzolan-blended concrete containing Fly Ash, silica fume and nano-silica, reporting differences in compressive strength and carbonation depth among the mixtures. Gruyaert et al. [5] investigated the influence of cement replacement and curing duration on the carbonation coefficient. Khalil and Anwar [6] studied ternary cementitious systems containing Fly Ash and silica fume. Zhao et al. [7] investigated GGBS cement concrete under natural and accelerated carbonation exposure.

The literature summarized in the source indicates that carbonation response depends on binder composition, replacement level, curing and exposure conditions. The present experimental work focuses on comparing two individual replacement series—GGBS and Fly Ash—in M30 concrete.

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III. OBJECTIVES AND SCOPE

The objectives of the study are: (i) to investigate GGBS and Fly Ash as partial replacements for cement; (ii) to evaluate compressive strength at different curing ages; (iii) to measure carbonation depth using a phenolphthalein indicator; (iv) to compare the response of the two mineral admixtures; and (v) to identify replacement levels that provide a favourable balance between compressive strength and carbonation behaviour.

The scope is restricted to the M30 concrete mixtures and replacement ranges reported in the project presentation. The tabulated experimental results provide strength and carbonation-depth values at 7, 14 and 28 days. Long-term field exposure, reinforcement corrosion measurements, permeability testing and life-cycle assessment are not reported in the source material and are therefore not evaluated in this paper.

IV. MATERIALS AND MIX PROPORTION

The study used cement, fine aggregate, coarse aggregate, water, GGBS and Fly Ash. The presentation reports a reference mix proportion of water:cement:fine aggregate:coarse aggregate as 0.45:1:2.1:3.1 by mass. The corresponding quantities are presented in Table I.

TABLE I. REPORTED M30 CONCRETE MIX PROPORTION

Material	Quantity (kg/m³)	Proportion
Water	158	0.45
Cement	370	1.00
Fine aggregate	782.36	2.10
Coarse aggregate	1154.57	3.10

GGBS was used at replacement levels of 10%, 20%, 30%, 40%, 50%, 60% and 70%. Fly Ash was used at 10%, 20%, 30% and 40%. The presentation does not provide detailed chemical composition, specific gravity, fineness, source or manufacturer details for the cement, GGBS and Fly Ash. These material properties should be added from laboratory records before final submission.

V. EXPERIMENTAL METHODOLOGY

The experimental sequence comprised material selection and procurement, preliminary material tests, mix design, casting and curing, testing of hardened concrete, result analysis and preparation of conclusions. Concrete specimens were prepared for the different replacement levels and tested after the specified curing periods. Compressive strength was determined by subjecting hardened concrete specimens to compression testing. The reported results are expressed in N/mm², which is equivalent to MPa. The project presentation provides tabulated strength values at 7, 14 and 28 days for both GGBS and Fly Ash mixtures.

Carbonation depth was assessed using a phenolphthalein indicator solution. The presentation describes preparation of a 1% phenolphthalein solution using phenolphthalein powder, ethanol and de-ionized water. After the specimen was fractured to expose a fresh concrete surface, the indicator was sprayed on the exposed surface. The non-carbonated region developed a pink colour, whereas the carbonated region remained colourless. The depth of the colourless region was measured and reported in millimetres.

The project presentation describes casting, curing and testing but does not state the number of replicate specimens, exact specimen dimensions, carbonation exposure conditions, carbon dioxide concentration, relative humidity, temperature or detailed test standard. These details are important for repeatability and should be inserted from the original laboratory records.

VI. RESULTS AND DISCUSSION

The results are discussed separately for compressive strength and carbonation depth. The values below reproduce the tabulated results in the project presentation. No unreported control-mixture values have been estimated or added.

TABLE II. COMPRESSIVE STRENGTH OF GGBS CONCRETE

Curing age	10%	20%	30%	40%	50%	60%	70%
7 days	22.0	23.0	25.0	28.5	30.1	26.0	25.0
14 days	28.0*	29.7	31.2	33.8	35.2	31.7	30.1
28 days	42.0	43.0	43.6	44.5	45.5	43.0	40.3

The GGBS series shows an increase in compressive strength up to 50% replacement, followed by a reduction at 60% and 70% replacement. At 7 days, the maximum reported value is 30.1 MPa at 50% GGBS. At 28 days, the maximum is 45.5 MPa at 50% GGBS. The 28-day strength decreases to 40.3 MPa at 70% replacement.

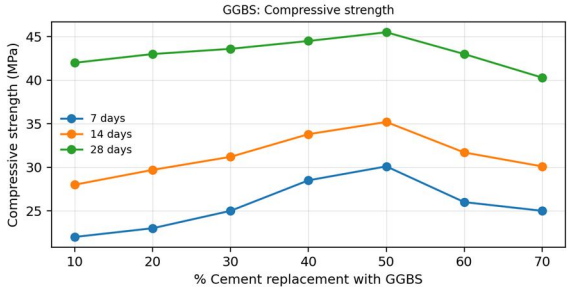


Fig. 1. Compressive strength of GGBS concrete at 7, 14 and 28 days.

Table III. Compressive Strength Of Fly Ash Concrete

Curing age	10%	20%	30%	40%
7 days	22.0	23.0	25.0	23.0
14 days	27.0	29.5	31.9	28.3
28 days	39.0	41.0	41.5	39.0

For the Fly Ash series, the maximum reported 28-day compressive strength is 41.5 MPa at 30% replacement. The strength decreases to 39.0 MPa at 40% replacement. The 7-day results also show the highest value at 30% replacement, at 25.0 MPa.

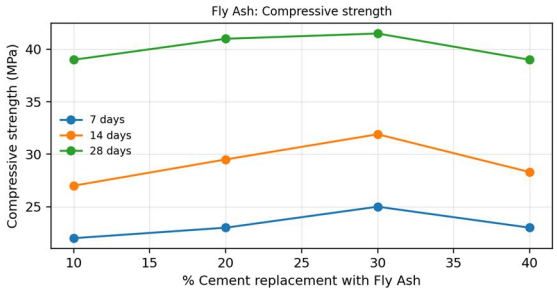


Fig. 2. Compressive strength of Fly Ash concrete at 7, 14 and 28 days.

TABLE IV. CARBONATION DEPTH OF GGBS CONCRETE

Curing age	10%	20%	30%	40%	50%	60%	70%
7 days	3.0	3.0	4.0	5.0	6.0	6.0	7.0
14 days	4.0	5.0	6.0	6.3	6.5	7.0	8.0
28 days	7.0	7.0	8.0	8.5	9.0	11.0	12.0

Carbonation depth in the GGBS series generally increases as the replacement percentage increases. At 28 days, the reported depth rises from 7 mm at 10% replacement to 12 mm at 70% replacement. The 50% GGBS mixture has a reported carbonation depth of 9 mm at 28 days, while the highest depth is recorded at 70% replacement.

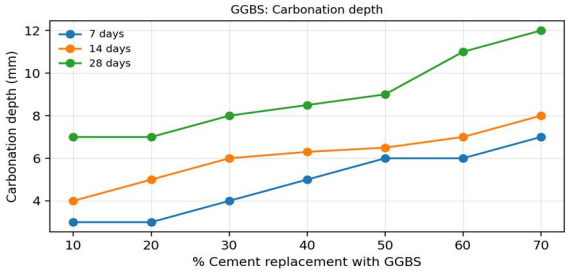


Fig. 3. Carbonation depth of GGBS concrete at 7, 14 and 28 days.

TABLE V. CARBONATION DEPTH OF FLY ASH CONCRETE

Curing age	10%	20%	30%	40%
7 days	3.2	4.0	5.0	6.0
14 days	6.7	7.0	7.4	8.0
28 days	8.6	9.2	10.0	10.0

The Fly Ash series also shows an increase in carbonation depth with increasing replacement level. At 28 days, the measured depth is 8.6 mm at 10% replacement and 10 mm at both 30% and 40% replacement. The tabulated values therefore show that higher Fly Ash replacement levels are associated with greater carbonation depth within the reported test series.

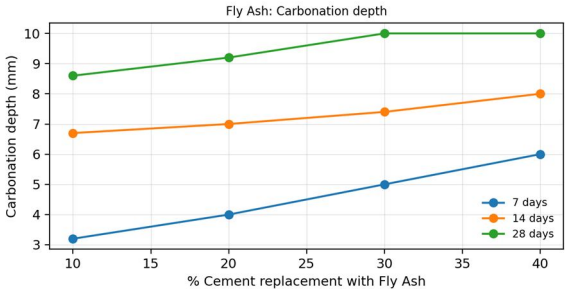


Fig. 4. Carbonation depth of Fly Ash concrete at 7, 14 and 28 days.

VII. COMPARATIVE DISCUSSION

Considering the 28-day compressive-strength results, 50% GGBS gives the highest reported value (45.5 MPa) among the GGBS mixtures, while 30% Fly Ash gives the highest value (41.5 MPa) among the Fly Ash mixtures. The corresponding carbonation depths are 9 mm for 50% GGBS and 10 mm for 30% Fly Ash. These results suggest that the GGBS mixture at 50% replacement provides the strongest balance among the peak-strength mixtures reported in the two series.

The comparison should be interpreted within the limits of the reported experimental programme. The source presentation does not provide replicate counts, standard deviations or statistical significance tests. In addition, the control mixture values are not tabulated alongside the replacement series. Consequently, percentage improvements over control concrete cannot be independently verified from the tabulated data included here.

VIII. CONCLUSIONS

1) Among the tested GGBS mixtures, 50% replacement produced the highest reported 28-day compressive strength of 45.5 MPa.
2) Among the tested Fly Ash mixtures, 30% replacement produced the highest reported 28-day compressive strength of 41.5 MPa.
3) For GGBS concrete, the 28-day carbonation depth increased from 7 mm at 10% replacement to 12 mm at 70% replacement. The value at 50% replacement was 9 mm.
4) For Fly Ash concrete, the 28-day carbonation depth increased from 8.6 mm at 10% replacement to 10 mm at 30% and 40% replacement.
5) The results indicate that replacement percentage affects both compressive strength and carbonation depth. Selection of a suitable replacement level should therefore consider both strength and durability-related performance.
6) Within the reported test results, 50% GGBS is the preferred mixture when the criterion is the highest measured 28-day compressive strength among the tested mixtures. Further durability testing is required before making conclusions about long-term service life.

IX. LIMITATIONS AND FURTHER WORK

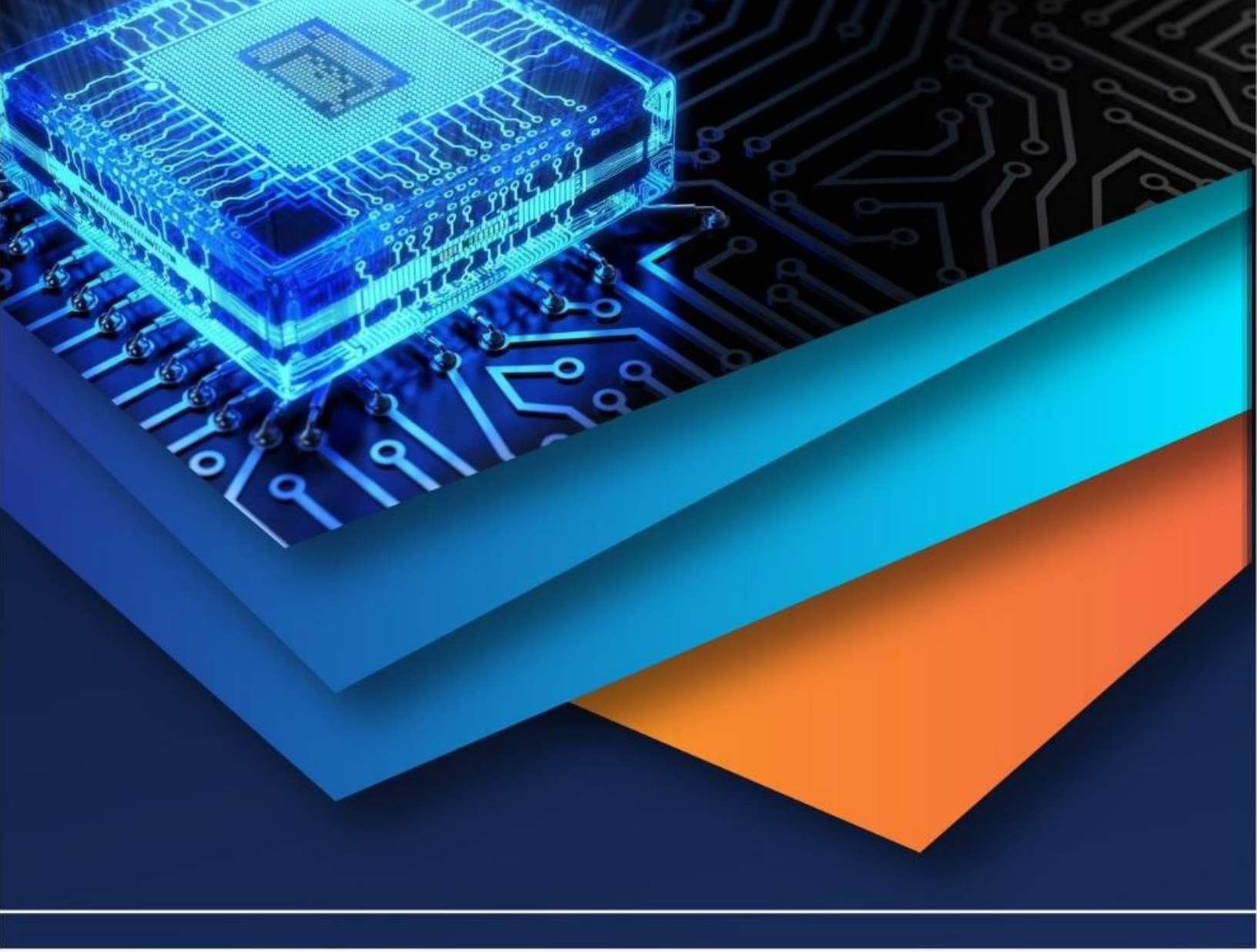
The current dataset is limited to the results reported in the project presentation. Future work should report complete material characterization, specimen dimensions and number of replicates; specify the curing and carbonation exposure conditions; include the control mixture data; and provide statistical analysis. Longer-term natural or accelerated carbonation testing, water absorption, porosity and reinforcement-corrosion measurements would help establish durability performance under practical exposure conditions.

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