Sustainable Performance and Structural Resilience of Concrete Incorporating Time-Degraded Cement Activated by Hybrid Admixtures

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ABSTRACT
The present research explores the behaviour of concrete with replacement of a certain percentage of cement with expired cement along with other materials like Ground Granulated Blast Furnace Slag (GGBS), silica fume, and glass powder. As it is known, expired cement generally has low strength because of lower reactivity, and hence it was planned to investigate whether the above-mentioned mineral admixtures can enhance its performance. Thus, three mixes of M25 grade concrete, designated as S-A, S-B, and S-C, were produced. They were tested for their compressive strength after 7, 14, and 28 days using concrete and mortar cubes made by the standard procedure. Durability tests included Ultrasonic Pulse Velocity (UPV), Rebound Hammer, and Carbonation test methods. The obtained data have confirmed that the use of up to 10% of expired cement along with the other admixtures enables obtaining the necessary strength of 31.6 MPa in 28 days.

Keywords: Expired cement, GGBS, Silica fume, Glass powder, Compressive strength, Ultrasonic pulse velocity (UPV), Carbonation depth, M25 grade concrete.

1. INTRODUCTION

Concrete is one of the most widely used construction materials due to its strength, durability, versatility, and economic advantages in infrastructure development [1,11,12]. However, rapid urbanization and increasing construction activities have significantly increased the demand for cement production, resulting in major environmental concerns such as excessive carbon dioxide emissions, energy consumption, and depletion of natural resources. Therefore, sustainable construction practices are increasingly focusing on reducing cement usage through the incorporation of industrial by-products, recycled materials, and supplementary cementitious materials (SCMs) [5,9,13].

One emerging area of sustainable concrete research is the utilization of time-degraded or aged cement, commonly referred to as expired cement. Cement loses part of its reactivity when exposed to moisture and atmospheric conditions during prolonged storage, leading to premature hydration and deterioration in its binding properties [4,18]. As a result, concrete produced using degraded cement may exhibit reduced strength, poor workability, and lower durability performance. Despite these limitations, recent investigations have shown that the adverse effects of time-degraded cement can be minimized through the use of suitable mineral and chemical admixtures [1–3].

Supplementary Cementitious Materials (SCMs) are widely recognized for their ability to enhance concrete performance while reducing cement consumption and promoting sustainability [5,11,14]. These materials react with calcium hydroxide produced during cement hydration and form additional calcium silicate hydrate (C-S-H) gel, which improves the microstructure, strength, and durability of concrete. Among the commonly used SCMs, Ground Granulated Blast Furnace Slag (GGBS), silica fume, and finely ground glass powder have gained significant importance due to their pozzolanic and cementitious properties [5,7,9,10,13,16,17].

GGBS, an industrial by-product obtained from the steel manufacturing industry, improves long-term strength, reduces permeability, and enhances resistance against aggressive chemical exposure [5,17]. Silica fume, owing to its ultrafine particle size and high silica content, enhances particle packing density and strengthens the interfacial transition zone, thereby improving the mechanical and durability properties of concrete [7,16]. Similarly, glass powder derived from waste glass acts as a pozzolanic material and contributes to durability improvement through secondary hydration reactions and pore refinement [9,10,13]. The combined use of these materials as hybrid admixtures provides a synergistic effect that can compensate for the reduced reactivity of time-degraded cement and improve the overall quality of concrete.

Durability performance is another critical aspect in modern concrete technology, particularly under aggressive environmental conditions [6–10]. Carbonation-induced deterioration significantly affects reinforced concrete structures by reducing alkalinity and accelerating reinforcement corrosion [7,8]. Concrete incorporating SCMs exhibits modified pore structures and hydration mechanisms, which directly influence carbonation resistance and long-term durability [7–10]. Recent studies have emphasized the importance of evaluating durability parameters such as compressive strength, ultrasonic pulse velocity (UPV), permeability, and carbonation resistance for sustainable blended concrete systems [7–10].

Structural resilience in concrete not only depends on compressive strength but also on the ability of the material to maintain integrity, durability, and serviceability throughout its design life [6,11,12]. Hence, the development of sustainable concrete using time-degraded cement and hybrid admixtures requires comprehensive evaluation of both mechanical and durability performance. Although several studies have individually investigated expired cement, GGBS, silica fume, and glass powder [1–3,5,7,9,10,13,16,17], limited research has focused on their combined application in concrete for achieving sustainable performance and structural resilience.

In this study, the primary objective is to evaluate the sustainable performance and structural behaviour of concrete incorporating time-degraded cement activated by hybrid admixtures. The term hybrid admixtures refers to the combined use of GGBS, silica fume, and glass powder to enhance the properties of concrete. The investigation aims to determine whether partial replacement of fresh cement with time-degraded cement, along with the incorporation of SCMs, can produce concrete with satisfactory strength and durability suitable for structural applications.

For this purpose, M25 grade concrete mixes are prepared with varying proportions of time-degraded cement and hybrid admixtures in accordance with relevant Indian Standard guidelines [1–8]. The mechanical performance of concrete is evaluated through compressive strength testing at 7, 14, and 28 days, while durability and quality assessment are carried out using Ultrasonic Pulse Velocity (UPV) and accelerated carbonation tests. These tests help in understanding the internal quality, uniformity, density, and long-term performance characteristics of the developed concrete mixes.

The significance of this research lies in promoting the effective reuse of deteriorated cement materials that are otherwise treated as construction waste. The utilization of time-degraded cement along with industrial by-products and recycled materials supports sustainable construction practices by reducing material wastage, lowering environmental impact, and conserving natural resources [1–3,5,9,13]. Furthermore, the study provides practical insights for engineers, researchers, and construction professionals regarding the safe and efficient use of sustainable blended concrete materials. Overall, this investigation addresses an important challenge in the construction industry by integrating sustainability with structural performance. The study demonstrates that the limitations associated with time-degraded cement can potentially be overcome through the proper use of hybrid mineral admixtures, leading to stronger, more durable, and environmentally responsible concrete systems.

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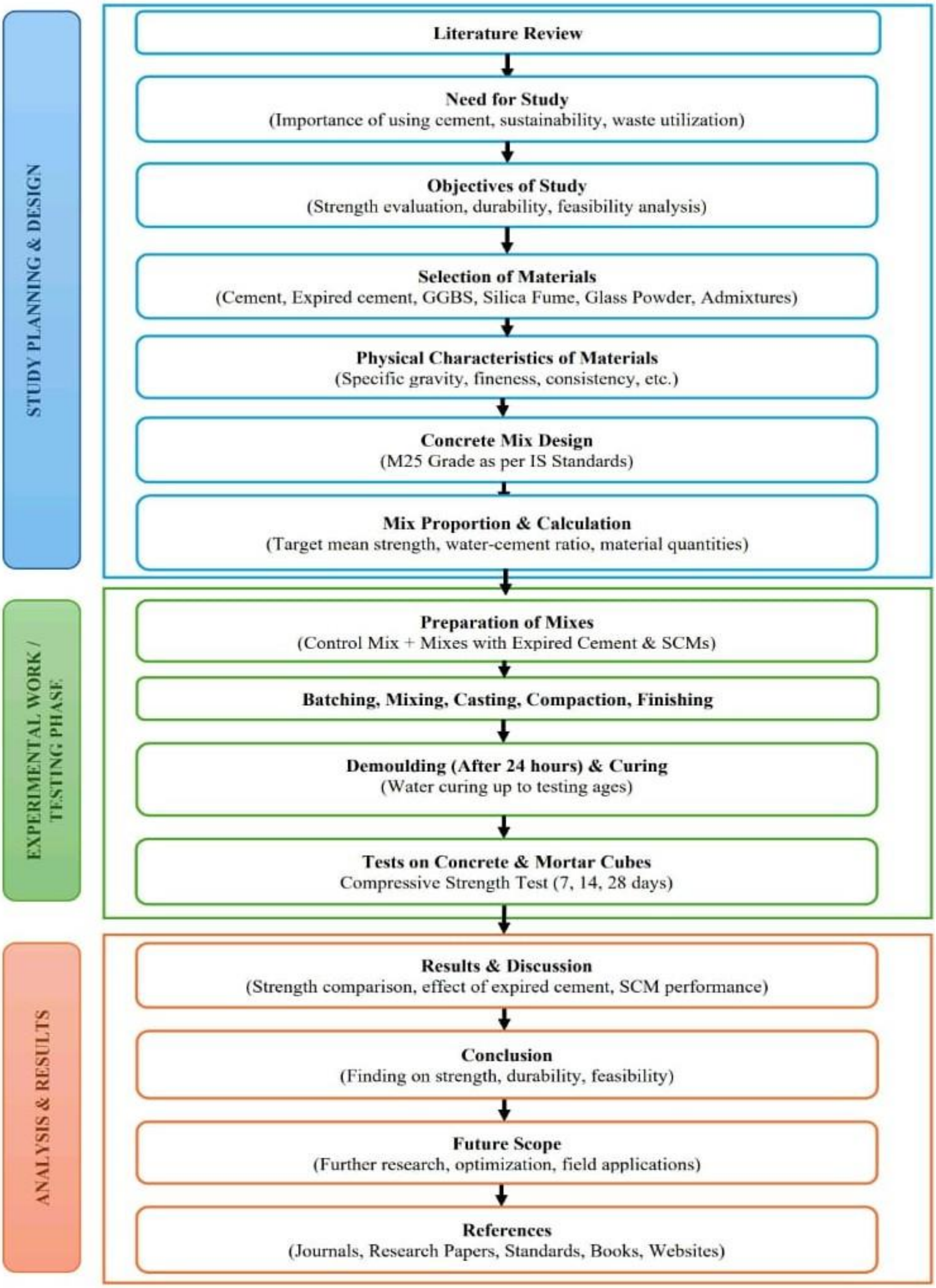
2. METHODOLOGY

Table 2.1: Methodology



3. LITERATURE REVIEW

Several researchers have investigated the utilization of supplementary cementitious materials (SCMs) and the effects of cement deterioration on concrete performance.

1. Sanaul Chowdhury et al. (2018) studied the application of glass powder in green concrete and reported that the incorporation of finely ground glass significantly enhances durability and resistance to chloride ion penetration, thereby contributing to sustainable concrete development.
2. Zameer Kalakada et al. (2017) conducted an experimental investigation on the use of glass powder as a partial replacement for cement and concluded that replacement levels up to 30% yield comparable compressive strength while improving workability characteristics.
3. P. K. Mehta and Paulo J. M. Monteiro (2014) explained that SCMs such as Ground Granulated Blast Furnace Slag (GGBS) and silica fume refine the microstructure of concrete through pozzolanic reactions, leading to enhanced mechanical strength and long-term durability.
4. A. M. Neville (2011) reported that prolonged storage of cement results in moisture ingress and pre-hydration, causing a reduction in strength in the range of 20–30%, which adversely affects concrete performance.
5. A. Shayan and A. Xu (2006) demonstrated that waste glass, when finely ground, exhibits pozzolanic properties and contributes to improved strength and durability of concrete.
6. M. S. Shetty (2005) emphasized that mineral admixtures such as silica fume and GGBS significantly enhance the strength and durability of concrete, particularly when low-quality or partially deteriorated cement is used.
7. M. Iqbal Khan (2003) investigated the influence of mineral admixtures on durability and concluded that their incorporation improves resistance to carbonation, reduces permeability, and enhances resistance to chemical attack.
8. B. B. Sabir et al. (2001) reported that silica fume increases compressive strength and reduces porosity due to its ultrafine particle size and high pozzolanic reactivity.
9. K. Ganesh Babu and V. Sree Rama Kumar (2000) highlighted that GGBS improves long-term strength development, reduces the heat of hydration, and enhances sulphate resistance in concrete.
10. H. F. W. Taylor (1997) discussed the chemical aspects of cement aging and noted that pre-hydration of cement particles during storage reduces their reactivity, leading to diminished strength development in hardened concrete.

4. NEED FOR STUDY

A substantial quantity of cement is rendered unusable annually due to prolonged storage and exposure to adverse environmental conditions at construction sites, warehouses, and institutional storage facilities. This results in significant material loss and economic inefficiency within the construction sector.

The deterioration and expiry of cement contribute to increased solid waste generation, thereby exacerbating construction and demolition (C&D) waste management challenges and imposing additional environmental burdens associated with disposal.

Conventional disposal practices for deteriorated cement, which primarily involve landfilling without any recovery or recycling strategies, represent an unsustainable approach and lead to inefficient utilization of natural resources and embodied energy.

The utilization of industrial by-products such as Ground Granulated Blast Furnace Slag (GGBS) and silica fume offers potential for developing alternative binder systems. These supplementary cementitious materials (SCMs) can facilitate the effective reutilization of degraded cement through pozzolanic and latent hydraulic reactions.

Despite extensive research on SCMs in conventional concrete, limited studies have focused on the synergistic use of deteriorated cement in combination with SCMs and chemical admixtures for the production of structural-grade concrete, particularly M25 grade.

The growing emphasis on sustainable construction practices necessitates the development of innovative methodologies for recycling waste materials and optimizing resource efficiency. In this context, the reuse of deteriorated cement integrated with SCMs presents a viable approach toward achieving environmental sustainability and circular economy objectives in the construction industry.

5. OBJECTIVES

To evaluate the mechanical and durability performance of concrete incorporating deteriorated (expired) cement as a partial binder component.

To investigate the influence of glass powder, as a supplementary cementitious material (SCM), on the fresh and hardened properties of concrete, including workability, strength, and durability characteristics.

To examine the effect of latex-based chemical admixtures on the microstructural properties, bonding characteristics, and overall performance of concrete.

To determine the compressive strength behaviour of M25 grade concrete with partial replacement of conventional cement by deteriorated cement under controlled curing conditions.

To assess the feasibility of developing a sustainable and cost-effective concrete mix by optimizing the utilization of waste cement and industrial by-products.

6. MATERIALS

Cement:

Portland Pozzolana Cement (PPC) was selected as the primary binder for the preparation of concrete specimens. The study incorporates both fresh cement and deteriorated (aged) cement to evaluate the influence of cement ageing on the mechanical and durability properties of concrete. The PPC used in this investigation conforms to the requirements specified in IS 1489 (Part 1).

PPC is manufactured by intergrinding Ordinary Portland Cement (OPC) clinker with pozzolanic materials such as fly ash or calcined clay. The inclusion of pozzolanic constituents imparts improved long-term strength, reduced permeability, lower heat of hydration, and enhanced resistance to sulphate attack, making it suitable for durable concrete applications.

In the present study, the cement samples were procured from an active construction site. A portion of the cement had exceeded its recommended storage period by approximately 5–6 months or more, thereby undergoing partial deterioration due to exposure to atmospheric moisture and environmental conditions. These aged cement samples were utilized to investigate the effect of reduced reactivity and pre-hydration on concrete performance in comparison with fresh PPC.

Fig. 6.1 Fresh cement

Fig. 6.2 Expired cement

Ground Granulated Blast Furnace Slag (GGBS):

Ground Granulated Blast Furnace Slag (GGBS) is an amorphous, glassy, granular material obtained through the rapid quenching of molten blast furnace slag using water or steam. This rapid cooling process inhibits crystallization, resulting in a highly reactive vitreous structure. GGBS exhibits latent hydraulic properties and, in the presence of an activator such as calcium hydroxide released during cement hydration, it participates in secondary hydration reactions, forming additional calcium silicate hydrate (C–S–H) gel. When incorporated into cementitious systems, GGBS enhances long-term strength, reduces heat of hydration, improves resistance to sulphate attack, and decreases permeability, thereby contributing to the durability of concrete.

The GGBS used in the present study conforms to the specifications of IS 16714:2018 and was procured from a reliable local supplier to ensure consistency in material properties.

Fig. 6.3 GGBS

Silica Fume (Micro Silica):

Silica fume is an ultrafine pozzolanic material obtained as a by-product during the production of silicon and ferrosilicon alloys. It consists predominantly of amorphous silicon dioxide (SiO_2) with spherical particles and an extremely high specific surface area (>15,000 m^2/kg). Due to its high reactivity, silica fume participates in pozzolanic reactions with calcium hydroxide released during cement hydration, forming additional calcium silicate hydrate (C–S–H) gel. This enhances the microstructure by reducing porosity and refining the pore system. Consequently, it improves the compressive strength and durability of concrete. The silica fume used in this study conforms to IS 15388.

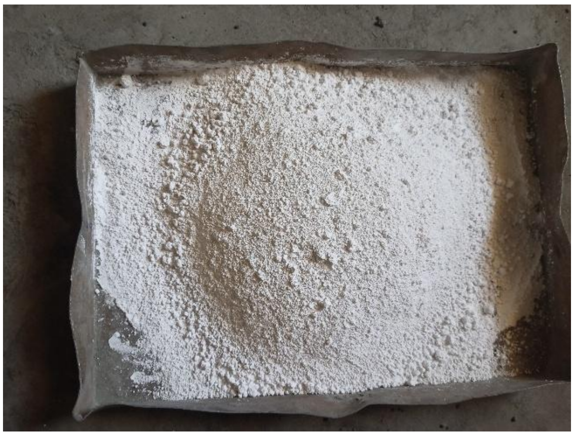


Fig. 6.4 Silica Fume

Glass Powder:

Glass powder is produced from waste glass bottles by grinding them into a fine powder with particle size typically less than 75 µm. Due to its high amorphous silica content, it exhibits pozzolanic behaviour when incorporated into cementitious systems. It reacts with calcium hydroxide [$Ca(OH)_2$] released during cement hydration to form secondary calcium silicate hydrate (C–S–H) gel. This reaction enhances the microstructure by reducing porosity and improving strength and durability. The use of glass powder promotes sustainable construction by recycling waste materials and reducing cement consumption.

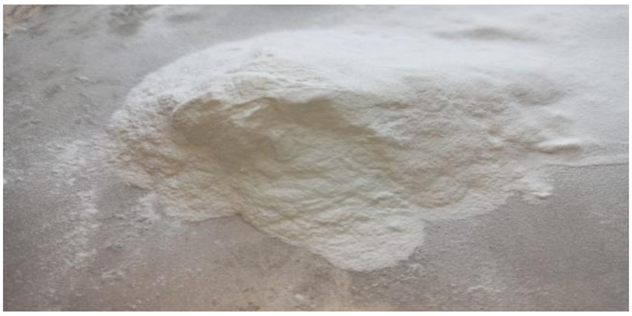


Fig. 6.5 Glass Powder

Fine Aggregate:

Manufactured sand (M-sand) was used as the fine aggregate in this study. It conforms to Zone II grading requirements as specified in IS 383:2016. M-sand provides a uniform particle size distribution and consistent quality compared to natural sand. Its availability and suitability as a sustainable alternative to river sand justify its selection.

Fig. 6.6 Fine Aggregate

Coarse Aggregates:

Crushed angular aggregates with a nominal maximum size of 20 mm were used as coarse aggregates in the concrete mix. The angular shape enhances interlocking, contributing to improved strength and durability. The aggregates exhibit suitable mechanical properties for structural concrete applications. They conform to the requirements specified in IS 383:2016.

Fig. 6.7 Coarse Aggregate

Chemical Admixtures

Chemical admixtures were incorporated to enhance the fresh and hardened properties of concrete, including workability, bonding, and strength development. A latex-based polymer (0.4% of binder) was used to improve flexibility, adhesion, and microstructural integrity. A polycarboxylate ether (PCE) superplasticizer (0.3% of binder) was added to reduce water demand and improve dispersion of cement particles. Triethanolamine (TEA) (0.02% of binder) was utilized as a set accelerator to enhance early hydration kinetics. The combined use of these admixtures contributes to improved performance and durability of the concrete mix.

Fig. 6.8 Latex

Fig. 6.9 TEA

Fig. 6.10 PCE

Water:

Potable water free from deleterious substances was used for both mixing and curing of concrete specimens. The water quality satisfies the requirements specified in IS 456:2000. It ensures no adverse effects on hydration, strength, or durability of concrete.

7. PHYSICAL PROPERTIES OF THE MATERIALS

Fine Aggregates Sieve Test

The fine aggregate was tested in accordance with the provisions of IS 383:2016. The results indicate that the aggregate possesses good quality characteristics and is suitable for use in structural concrete. The grading falls under Zone II, meeting the requirements for structural applications.

Table 7.1: Sieve Analysis of Fine Aggregates.

Weight of Sample taken = 1000 gm					
S. No	**IS Sieve Designation**	**Weight retained in Grams**	**Percentage of weight retained**	**Cumulative % of weight retained**	**% of Passing**
1	4.75 mm	0	0	0	100
2	2.36 mm	23	2.3	2.3	97.7
3	1.18 mm	425	42.5	44.8	55.2
4	600 µ	213	21.3	66.1	33.9
5	300 µ	188	18.8	84.9	15.1
6	150 µ	103	10.3	95.2	4.8
7	Pan	43	4.3	99.5	0.5
8	**TOTAL**	**995**	**99.5**	**∑ 293.3**	–

Fineness modulus of Fine Aggregate = 293.3/100 = 2.93

Fig. 7.1 Sieve Analysis

Material tests

Table 7.2: Materials Testing

Materials	**Specific Gravity**	**Water absorption**	**Fineness** (m^2/kg)	**Initial Setting** (min)	**Final Setting** (min)
Fresh Cement (PPC)	3.01	-	320	35	600
Expired Cement (PPC)	2.88	-	305	55	720
Glass Powder	2.50	-	380	-	-
GGBS	2.85	-	400	-	-
Silica Fume	2.64	-	15000	-	-
Fine Aggregate (M-Sand)	2.78	3%	-	-	-
Coarse Aggregate	2.77	0.38%	-	-	-

8. CONCRETE MIX DESIGN

Grade : M25

Type of cement : PPC

Maximum size of aggregate	: 20mm
Exposure condition	: Moderate
Minimum cement content	: 300kg/m^3 (IS 456, Table 5)
Type of coarse aggregate	: Crushed
Maximum cement content	: 450kg/m^3 (IS 456, Cl 8.2.4.2)

Target mean strength (IS 10262)

f'ck= fck + 1.65 s

= 25 + 1.65 × 4

= 31.6 MPa

Water-Cement Ratios

Table 8.1: w/c ratio

Sample	W/C Ratio	Chemical Admixture
S-A	0.48	-
S-B	0.43	Latex (0.4%)
S-C	0.42	TEA (0.02%)
S-D	0.39	PCE (0.3%)

Final Estimated Quantities are:

Table 8.2: Materials quantity of 1 m^3

Sample ID	Cement (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	Water (kg/m^3)	Mineral Admixture (1) (kg/m^3)	Mineral Admixture (2) (kg/m^3)	Chemical Admixture (kg/m^3)
S-A	411.00	664.93	1129.23	197.16	-	-	-
S-B	371.43	648.33	1149.25	200.22	41.27	-	1.65
S-C	300.00	692.60	1205.40	192.96	86.00	32.00	0.039
S-D	341.24	840.38	1145.96	147.87	37.92	-	1.14

Final Ratios

Table 8.3: Ratios

Sample	Cement	Fine aggregate	Coarse aggregate	Remarks
S-A	1	1.62	2.75	Cement only system
S-B	1	1.75	3.10	Glass powder binder system
S-C	1	1.67	3.01	GGBS + Silica fume system
S-D	1	1.60	3.20	GGBS only system

9. MIX PROPORTION AND CALCULATION

Mix Proportion

Table 9.1: Mix Proportion of all Samples

Binder Component	S-A (%)	S-B (%)	S-C (%)	S-D (%)
Fresh Cement (PPC)	100	80	70	80
Expired Cement (PPC)	-	10	5	10
Glass Powder	-	10	-	-
GGBS	-	-	17	10
Silica Fume	-	-	8	-
Total	100	100	100	100

Test on concrete

Slump Cone Test

The workability of each concrete mix was evaluated using the slump cone test in accordance with IS 1199. A target slump of 100 mm was maintained to ensure uniform workability across all mixtures.

The desired slump was achieved by adjusting the dosage of chemical admixtures, while keeping the water content constant for all mixes.

The experimental results indicate that all four concrete mixes attained the specified workability range.

The measured slump values confirm that the mixes possess adequate consistency and are suitable for placement and compaction.

Fig. 9.1 Slump Cone Test

Table 9.2: Slump test value

Sample	**Target Slump (mm)**	**Achieved Slump (mm)**
S-A	100	70
S-B	100	85
S-C	100	87
S-D	100	93

Sample– A (Binder composition)

Sample-A Material quantities

Table 9.3: Sample-A Required materials

Components	**Concrete cubes** (150mm, 9 cubes + 15% extra)	**Mortar cube** (70mm, 9 cubes + 10% extra)
Fresh cement	12.51 kg	1.328 kg
Fine aggregate	20.196 kg	4.451 kg
Coarse aggregate	34.299 kg	-
Water	5.985 kg	597.78 ml

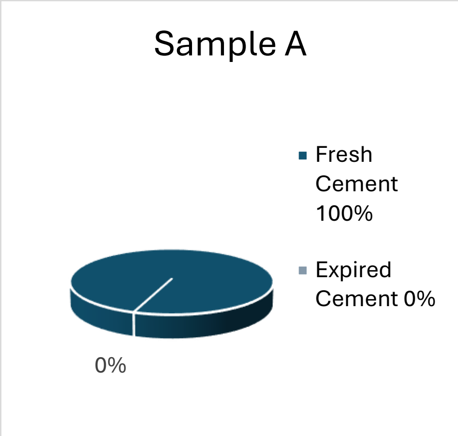


Fig. 9.2 Sample A

Compressive Strength Results

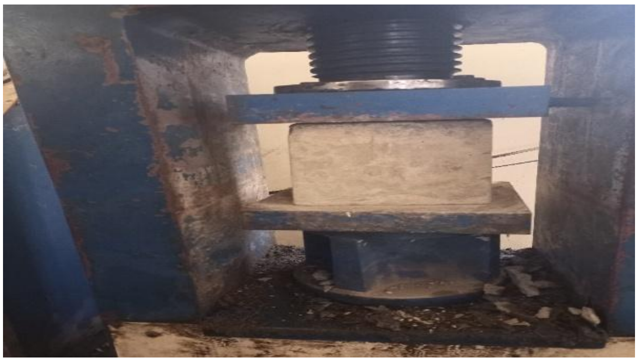


Fig. 9.3 Compressive strength test

Table 9.4: Sample-A Compressive Strength Values

Curing Age	Concrete cube (MPa)	Mortar cube (MPa)
7- Days	18.98	18.52
14- Days	26.28	25.65
28- Days	29.2	28.5

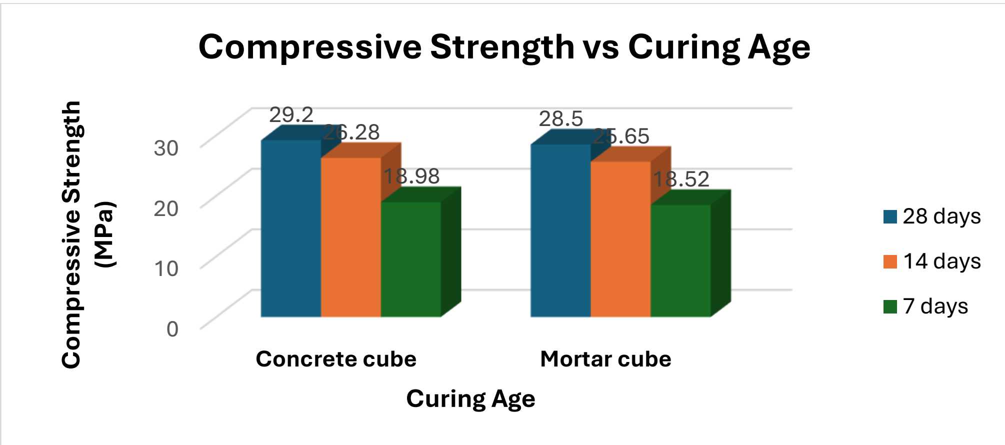


Fig. 9.4 Sample-A Compressive Strength Graph

The compressive strength tests on concrete and mortar cubes were carried out at **JMA Builders Services Centre, Srirangam, Trichy.** Using a calibrated Compression Testing Machine (CTM) as per IS 516 (Part-1/Sec 1):2021

SAMPLE-B STRENGTH AND DURABILITY ASSESSMENT

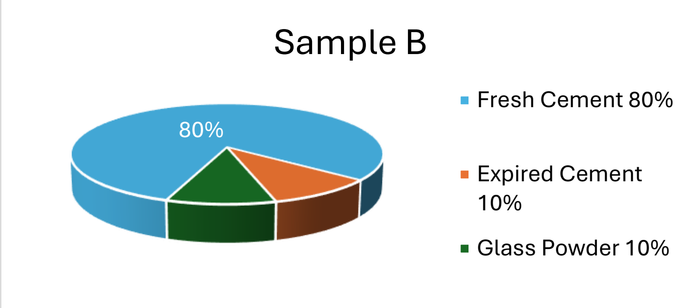


Fig. 9.5 Sample B

S-B- Material quantities (Concrete (150mm, 9 cubes + 15% extra), Mortar (70mm, 9 cubes + 10% extra))

Table 9.5: Sample B Material quantities

Components	**Concrete cubes**	**Mortar cubes**
Fresh cement	11.592 kg	1.362 kg
Expired cement	1.449 kg	0.171 kg
Glass powder	1.449 kg	0.171 kg
Fine aggregate	22.752 kg	5.661 kg
Coarse aggregate	40.338 kg	-
Water	6.24 kg	765 ml
w/c ratio	0.43	0.45
Latex	0.4% of binder	6.81 ml

Sample - B Compressive Strength Test

Table 9.6: Sample B Compressive Strength Values

Curing Age	**Concrete cubes (MPa)**	**Mortar cubes (MPa)**
7- Days	19.82	11.24
14- Days	27.45	15.57
28- Days	30.5	17.3

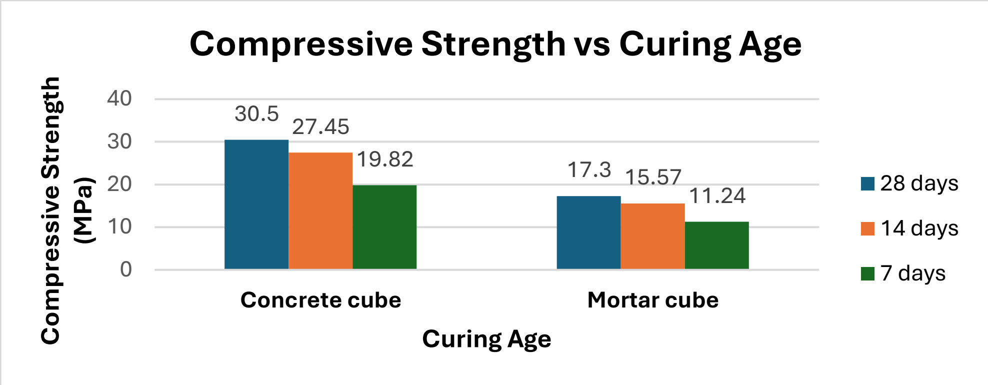


Fig. 9.6 Sample B Compressive Strength Graph

Sample - B Ultrasonic Pulse Velocity (UPV) Test

Fig. 9.7 Sample B UPV test

Table 9.7: UPV Range and Quality

UPV Range (m/s)	Concrete Quality
Above 4500	Excellent
3500 – 4500	Good
3000 – 3500	Medium
Below 3000	Doubtful

Table 9.8: Sample B UPV values obtained

Sample	Cube Size	7- Day (m/s)	14- Day (m/s)	28- Day (m/s)
S-B-1	150 mm	3035	4203	4670
S-B-2	150 mm	3009	4167	4630
S-B-3	150 mm	3048	4221	4690

Sample - B Carbonation Depth Test

Table 9.9: Carbonation depth obtained

Sample-B	Carbonation Depth (28 Days, mm)
S-B-1	0.0
S-B-2	0.0
S-B-3	0.0

All experimental investigations for Sample S-B were conducted at the **National Test House (SR), Chennai**, in accordance with relevant standard testing procedures.

SAMPLE– C STRENGTH AND DURABILITY ASSESSMENT

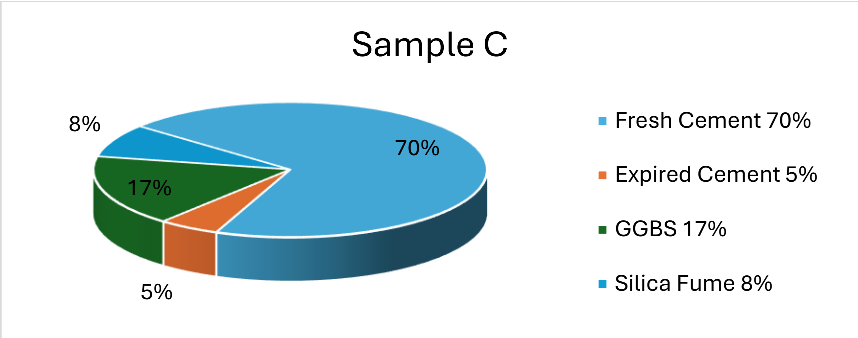


Fig. 9.8: Sample C

Sample- C Material Quantities

Concrete (150mm, 9 cubes + 15% extra), Mortar (70mm, 9 cubes + 10% extra).

Table 9.10: Sample C Required materials

Components	Concrete cube	Mortar cube
Fresh cement	9.645 kg	1.143 kg
Expired cement	0.69 kg	0.0819 kg
GGBS	2.34 kg	0.279 kg
Silica Fume	1.11 kg	0.1314 kg
Fine aggregate	23.04 kg	5.481 kg
Coarse aggregate	41.52 kg	-
Water	5.79 kg	774 ml
w/c ratio	0.42	0.45

TEA	0.02% of binder	0.35 ml

Sample- C Compressive Strength Test

Table 9.11: Sample C Compressive Values

Curing Age	Concrete cube (MPa)	Mortar cube (MPa)
7- Days	16.18	15.34
14- Days	22.41	21.24
28- Days	24.9	23.6

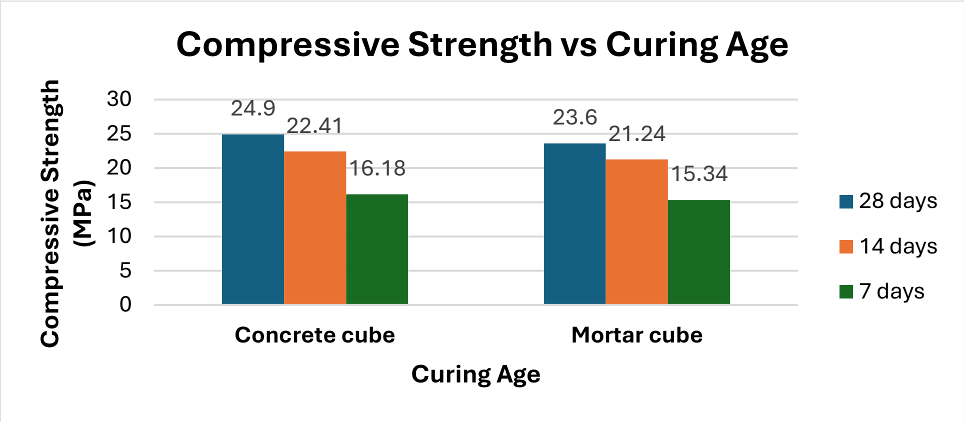


Fig. 9.9 Sample C Compressive Strength Graph

The compressive strength tests for Sample S-C, including both concrete and mortar cubes, were carried out at the **Time Institute for Materials Testing Lab Trichy** using a duly calibrated Compression Testing Machine (CTM), in accordance with the relevant Indian Standard (IS) specifications.

SAMPLE- D STRENGTH AND DURABILITY ASSESSMENT

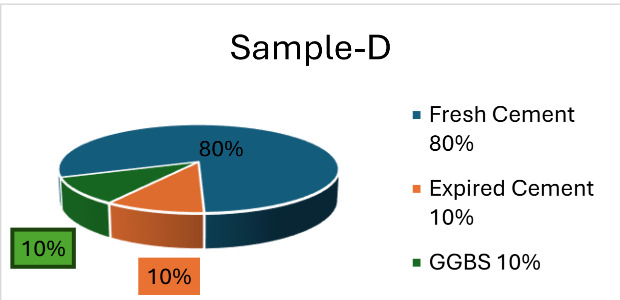


Fig. 9.10: Sample-D

Sample-D Material quantities- Concrete (150mm, 9 cubes + 15% extra), Mortar (70mm, 9 cubes + 10% extra).

Table 9.12: Sample-D Required materials

Components	Concrete cube	Mortar cube
Fresh cement	11.97 kg	1.503 kg
Expired cement	1.494 kg	0.195 kg
GGBS	1.494 kg	0.195 kg
Fine aggregate	32.184 kg	7.056 kg
Coarse aggregate	45.075 kg	-
Water	5.85 kg	900 ml
w/c ratio	0.39	0.47
PCE	0.3% of binder	5.68 ml

Compressive Strength Test Result

Table 9.13: Sample-D Compressive Strength Values

Curing Age	Concrete cube (MPa)	Mortar cube (MPa)
7- Days	19.89	17.22
14- Days	27.54	23.85
28- Days	30.60	26.50

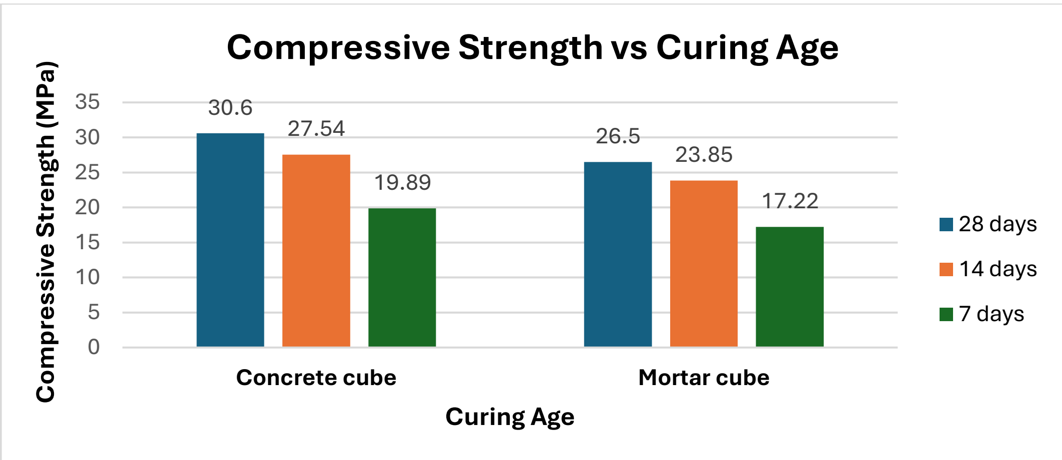


Fig. 9.11: Sample-D Compressive Strength Graph

The compressive strength tests for both concrete and mortar cube specimens of Sample S-D were conducted at the **Time Institute for Materials Testing Lab Trichy** using a duly calibrated Compression Testing Machine (CTM), in accordance with the relevant Indian Standard (IS) provisions.

10. CONCLUSION

This study investigated the performance of concrete incorporating partially replaced expired cement in combination with supplementary cementitious materials (SCMs) such as Ground Granulated Blast Furnace Slag (GGBS), silica fume, and glass powder, along with chemical admixtures including latex, Polycarboxylate Ether (PCE), and Triethanolamine (TEA).

The results indicate that the standalone use of expired cement adversely affects strength development due to reduced hydration potential caused by pre-hydration and moisture-induced deterioration. However, the synergistic incorporation of SCMs significantly mitigates this effect through pozzolanic activity and filler action, leading to enhanced formation of calcium silicate hydrate (C–S–H) gel and improved microstructural densification.

Among the investigated mixes, Sample S-D (GGBS + expired cement + PCE) and Sample S-A (glass powder + expired cement + latex) exhibited superior mechanical performance, achieving compressive strengths close to the target mean strength of M25 grade concrete (31.6 MPa) at 28 days. This demonstrates that up to 10% replacement of cement with expired cement is structurally viable when blended with appropriate mineral and chemical admixtures.

Non-destructive evaluation using Ultrasonic Pulse Velocity (UPV) confirmed good to excellent quality concrete, indicating a dense, homogeneous, and defect-free internal matrix. Durability assessment through carbonation testing revealed negligible carbonation depth, highlighting enhanced resistance to CO_2 ingress, particularly in mixes containing SCMs.

Furthermore, the use of chemical admixtures effectively maintained adequate workability without increasing the water content, thereby preserving the designed water–cement ratio and contributing to overall performance efficiency.

11. Future Scope

The present study can be extended to higher-strength concrete grades such as M30, M40, and above to evaluate the applicability and performance of expired cement under increased strength and durability demands.

Further research should focus on comprehensive durability evaluation, including resistance to chloride ion penetration, sulphate attack, and water permeability, in order to assess long-term performance under aggressive environmental conditions.

Detailed microstructural characterization using advanced techniques such as Scanning Electron Microscopy (SEM) and X-ray Diffraction (XRD) is recommended to better understand hydration mechanisms, phase composition, and pore structure evolution.

Optimization of mix proportions should be carried out by systematically varying the dosage of mineral and chemical admixtures to determine the maximum feasible replacement level of expired cement without compromising mechanical and durability properties.

In addition, long-term performance studies involving creep, shrinkage, and carbonation resistance over extended curing periods are necessary to evaluate the lifecycle behaviour of concrete incorporating expired cement.

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