

Durability Assessment of Concrete Under Aggressive Environmental Conditions.

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Abstract - Concrete is among the most widely used civil engineering construction material and has high compressive strength, versatility, and low cost factors. Durability of concrete structure is severely compromised upon exposure to extreme aggressive environmental conditions like chemical attack, chloride penetration, sulfate resistance, carbonation effect, temperature variations and moisture fluctuation. These environmental conditions usually result in concrete degradation, corrosion of rebar, loss of structural integrity and, consequently, a shortened service life of the infrastructure. These tests were conducted. The Alkali-Silica Reaction (ASR) and drying shrinkage by preparing mortar under the conditions and their percentage change in length. When 10 percent of cement was replaced by SBR powder, its concrete performance was enhanced, its workability increased upto 90 %, compressive strength by 23 % and its flexural strength by 9.5 %.

Moreover, the study will be instrumental in enhancing sustainable construction practices by encouraging the use of improved concrete mixes that are capable of withstanding harsh exposure environments while maintaining their performance and reliability.

INTRODUCTION

Concrete is a strong and affordable material used a lot in construction because of its ability to hold up well. It is used to build roads, highways, bridges, dams, and structures near the sea. The ability of concrete to last over time in tough environments is important for making sure these structures remain functional and perform well. Concrete and reinforced concrete structures are currently facing major environmental challenges that can lead to local failures and damage. Water resistance is a key factor in how well concrete resists corrosion. Water resistance can be improved through design and the use of special additives. Trying to increase water resistance by adding ferric chloride is one approach.

The complications elaborated many scientific papers before. This complication and problems was presented by Hobbs, Beeby and Weyers. So, Hobbs defines concrete degradation by means of ions intrusion, which occurs due to attacks. Corrosion processes of concrete, then can structure deterioration and increase its maintenance were considered by Weyers. As Webster emphasizes, the analysis of corrosive damage of concrete structures requires taking of studying every individual case. The studies of chloride-induced corrosion impact constructions. This work designs new mixture. Chosen polymer will make up deficiency of concrete block. Hence, new will be able to withstand any environmental problems well without having to repeat repair and rework processes. Otherwise, repair and reconstruction of existing elements because of their costly complicated.

This research work seeks durability properties under different conditions. Examine impact chemical attacks in different concretes such as compressive strength, weight loss, and permeability. This is done by exposing concrete samples to different chemical attacks over a certain period of time.

LITERATURE REVIEW

Many studies have highlighted the significance of factors like permeability, water-cement ratio, curing process, and quality of raw material. The permeability factor is found to play an important role because it determines the entry chemicals such as Cl_2 , Sulfates, and CO_2 into solid mass.

(Sahani et al. , 2024; Ma et al. , 2025). Durability concrete may be affected through different methods of deterioration including chemical and physical deterioration such as chloride attack, carbonation, sulfate attack, freezing and thawing, and wetting and drying. Among those mentioned above, carbonation and chloride attack become highly significant because they cause reinforcement corrosion that leads to span reinforced solid structures.

Huang et al., 2025). Freeze-thaw effects and salt crystallization contribute to increased microcracking and deterioration, thereby resulting in loss of mechanical properties. The cumulative impact of chloride attack and freeze-thaw cycles on carbon fiber reinforced concrete (CFRC) reveals that CFRC is more resistant than regular concrete owing to less penetration of chlorides and mechanical resistance (Tong et al., 2026).

(Vairagade, 2025). As shown by recent studies, it is vital to design high-performance concretes and additives specifically suitable for harsh environments. The fly ash-based geopolymer HPCs have proven to be highly durable when subjected to freezing and thawing, sulfate exposure, and thermal damage.

Concrete durability is greatly influenced by aggressive environmental conditions. Chemical reactions like chloride attack, sulfate attack, and acid attack lead to concrete deterioration. Effective control of permeability is the most effective method of increasing concrete durability. Supplementary cementitious materials improve concrete resistance. Mix design and curing play a significant role.

METHODOLOGY

The methodology used in the current work/study was designed for evaluating the durability of concrete under adverse environmental conditions that include sulfate corrosion, chloride penetration, carbonation, and wet-dry cycles. In other words, the purpose of the investigation was to study concrete degradation mechanisms and efficiency of supplementary cementing materials for enhancing the concrete's durability.

Material selection, mixture proportioning, casting of specimens, curing, exposure to aggressive environments, and testing of both were part of experimental procedure. Comparative evaluation of conventional concrete and modified concrete with SCMs such as fly ash, silica fume, and GGBS was performed during the experiment.

The present chapter outlines the materials, mix design approach, fabrication process, exposure, and test procedures used for evaluating the durability performance of concrete in aggressive environments. This methodology aims to replicate the chemical exposure of concrete under field conditions in a laboratory setup.

3.2 Methodology Objectives

The following objectives can be accomplished through the implementation of the proposed methodology:

- Preparation of concrete mixes with different compositions and water-cement ratios.
- Influence assessment of aggressive environments on the durability of concrete.
- Impact assessment of SCMs on the permeability, moisture absorption, and chemical resistance of concrete.
- Analysis of the degradation process of concrete during prolonged exposure to aggressive environments.
- Comparison of the performance of standard and improved concrete mixes.

Table 1. Composition of mixing for Concrete .

Component	Amount, Kg/m ³	% of Mass
Cement	500	21.60
Quartz Sand	510	21.70
Granite Crushed Stone	1140	49.40
Water	165	6.80
Super-Plasticizer “Chrysofluid”	6	0.26
Air-Absorbing Additive “Chrysoair”	0.15	0.01

The Cement for M400 and M500 types produced by Mykolaiv Cement factory.

More details about concrete parameters used in the experiment are presented in Table 2.

Table 2. The Characteristics of Cement.

Characteristics	M400 Grade	M500 Grade
Marking according to DSTU		
BV 2.76 – 46: 2010	CEM 132.50	CEM 142.50
The material composition of		
Cement by weighth, %	Portland Cement Clinker 100 %	
Specifi Gravity, g/cc	3.12	3.16
Compressive Strength, Mpa		
2 nd day	26.00	36.00
28 th day	48.00	56.00
Setting Time, minutes		
Initial	160	140
Final	245	225
Fineness of Cement, %	7.35	8.55

Tests on fine aggregate/sand and coarse aggregate or gravel/crushed stone were performed using sieve analysis method.

Served as fine aggregate unadulterated and incontaminated,

With Fineness Modulus (Mc) of 2.04 indicates a fine sand and Non-Uniformity (Cv) of equal to 2.0

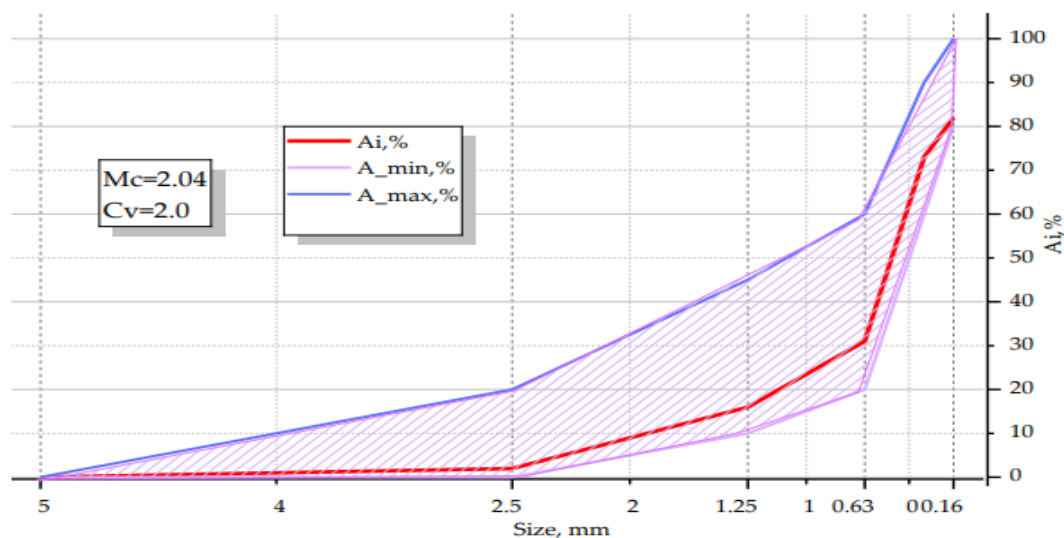


Figure.No. 1- . Granulometric chart of fine Aggregate/sand. (A_{i_max} , A_{i_min} -maximum and minimum values of the total residue).

It was decided to use the sol. of H_2SO_4 of 10% on Conc. . It is possible to note that such concentration of the acid medium can allow us to accelerate the modeling of the influence of the aggressive environment and evaluation of behavior of the structure under specific conditions. Which occur when it is acted upon by water, in which there are chemical substances, capable of interacting corresponds.

Hydraulic cement of OPC that complies with Blain fineness of 3078 cm^2/g was employed for the preparation of provides characteristics as well as characteristics of aggregates. Determined through testing, whereas determined using the analysis of cement.

Table 4. Properties of cement and aggregates.

The characteristics presented in the table 2. The USBR used in research has been used with size of 85 microns (normal) have been produced through spraying and chemical treatment of the available commercially around. Therefore, impact different from that solid based. Discussed impact, opposite reduced due to 6% replacement. In addition, employed for the production.

Table 3. Chemical properties of SBR powder.

Sr.	Physical Properties of Cement		Obtained Value					
1	Consistency		30					
2	Initial setting Time		110 min					
3	Final Setting Time		180 min					
4	Specific Gravity		3.13					
5	Fineness (Blain)		3078 cm ² /gm					
6	Le-Chatlier Soundness		2.00 mm					
Chemical Properties of Cement			Obtained Value					
1	Lime Saturated Factor		0.94					
2	Tri Calcium Aluminate		7.52%					
3	Insoluble Residue		1.28%					
4	Magnesia		1.79%					
5	Sulfuric Anhydride		2.76%					
6	Loss on Ignition		3.24%					
7	Chlorides		0.01%					
XRF Analysis of Cement								
Material Cement (%)	CaO	MgO	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	L.O.I	K ₂ O	Na ₂ O
	62.13	2.29	20.25	5.05	3.13	3.24	0.74	0.24
Physical Properties of Aggregates								
Sr.	Material	Fineness Modulus			Specific Gravity		Water Absorption (Vol. %)	
1	Coarse Aggregate	7			2.5		0.96	
2	Fine Aggregate	2.23			2.67		1.3	

Property	Value	Unit	Method
Total Solids	99.00	%	ISO 1625
Ash Content at 600 °C	12.00	%	Internal Method
Particle Size	85.00	µm	Internal Method
MFFT (min. film-forming temperature for re-dispersed in 50% solid concentration)	8.00	°C	ISO 2115
Specific Gravity	0.50	g/cm ³	ISO 8962

Specimens compression, with a maximum of 10% by weight as it is the optimum value of replacement. It is uneconomical and impractical to use higher percentages of SBR; therefore, SBR will be used up to 10% replacement based on economy, practicability, and literature review.

Different mixes were prepared for testing the durability of the concrete based on their respective standards. The following sections provide details about their mix proportions.

Table 4. Mix proportions of concrete samples.

Sample Name	Cement (kg)	SBR Powder (g)	Sand (kg)	Aggregate (kg)	Water (mL)
CS	4.25	0	7.22	10.62	1997
S3	4.12	127.5	7.22	10.62	1997
S5	4.04	212.5	7.22	10.62	1997
S7	3.95	297.5	7.22	10.62	1997
S10	3.83	425.0	7.22	10.62	1997

Workability

Slump test was conducted for determining the workability of concrete as per the ASTM C143-78 standards. Slump value of concrete was determined using the conical steel mold [28]. The proportions of concrete components, aggregates 1:1.7:2.5, respectively, and w/c ratio 0.47

2.2.4 Mechanical Strength

Test of Flexural Strength:

The greater the FS of concrete, the lesser will be the tendency of cracking. Four concrete prisms of each composition period.

Test of Compressive Strength:

Tests for compressive strength of concrete were carried out using the universal testing machine on four samples of each mixture composition. Four samples were tested for their compressive strength after 28 days of curing period.

Alkali – Silica Reactivity Test:

This determines the potentiality harmful effects of reaction, which is responsible for causing potentially harmful expansion of concrete due to alkali-silica reactions.

Drying Shrinkage Test:

Drying Shrinkage depends on Temperature, Relative Humidity and Rate of Evaporation. The test was carried out to determine the reduction in length of mortar bars which are demoulded after 24 hours, left for another 48 hours in lime water bath, dried and air stored. Cement and Sand ratio of mortar components were 1:2.25 and w/c ratio was 0.46.

Sulfate Resistivity Test:

The measures in length by conducting the specimens were prepared using the mix proportion as mentioned in Table 6. These mortar specimens were kept under curing conditions until the compressive strength of mortar cubes of the same batch became mortar immersed the mortar weekly. This performed according to constituents, used the proportion.

Mix Design

Concrete conducted as per IS 10262.

Target strength : (example M30)

Water-Cement Ratio: (example 0.40 – 0.45)

Proportion: (1 : X : Y)

Table 5- Trial mixes were made to get required workability and strength.

Mix ID	SCM Type	Replacement (%)	Water/Cement Ratio
M1	Ordinary Concrete	0%	0.45
M2	Fly Ash Concrete	10%	0.45
M3	Fly Ash Concrete	20%	0.45
M4	Silica Fume Concrete	5%	0.40
M5	Ground granulated blast furnace slag	20%	0.45

Specimen Preparation

3.5.1 Casting of Specimens

Concrete was mixed using a laboratory mixer

Molded in standard mold sizes:

Cube: 150mm × 150mm × 150mm

Vibrated compaction

Table 6. Concrete Mix Design Parameters and Durability Performance Summary.

IS 10262 Mix Design|Target Strength M30|Curing 28 days in potable water.

Mix ID	Binder Type	SCM %	w/c Ratio	28-days f'c (MPa)	Water Abs. % (28d)	RCPT (Coulombs)	Cl. Rating
M1	OPC 43	0 %	0.45	30.4	4.82	4250	High
M2	OPC + Fly Ash	10 %	0.45	31.8	3.95	3180	Moderate
M3	OPC + Fly Ash	20 %	0.45	32.4	3.61	2540	Moderate
M4 *	OPC + Silica Fume	5 %	0.40	36.2	2.78	980	Very Low
M5	OPC + GGBS	20 %	0.45	33.0	3.42	1750	Low

Best Compressive Strength – 36.2 MPa (M4-Silica Fume)

Lowest RCPT Change 980 C (M4-Very Low Cl.)

Highest UPV 4.48 km/s (M4-Excellent Quality)

Control Strength Drop (90d) -17.1% (M1 under Sulfate)

* Recommended mix for Aggressive Environment Exposure (UPV > 4.5 km/s = Excellent Quality (IS 13311))

M4 is highlighted as the recommended mix (*), with

Table 7: Sample sizes of specimens used for various Concrete Tests.

Test	Sample size
Compression	Cube (150mm × 150mm × 150mm)
Water absorption	Cube/Cylinder
Rapid chloride ion test	Cylinder
Carbonation	Cube
Sulfate resistance	Cube
Sorptivity test	Cylinder disc

Exposure to Aggressive Environment

After curing, samples were refers to various liquids that simulated environmental effects.

3.6.1 Chloride

Aggressive liquid: Sodium chloride (NaCl)

Purpose: Marine effect simulation

Concentration: (for example, 3-5%)

3.6.2 Sulphate

Aggressive liquid: Sodium Sulphate (Na₂SO₄), Magnesium Sulphate (MgSO₄)

Purpose: Simulating sulphate containing soils

Concentration: (for example, 5%)

Compressive Strength vs Exposure Duration.

Effect of aggressive chemical environments on concrete mix types (M1–M5) — M30 grade, w/c 0.40–0.45

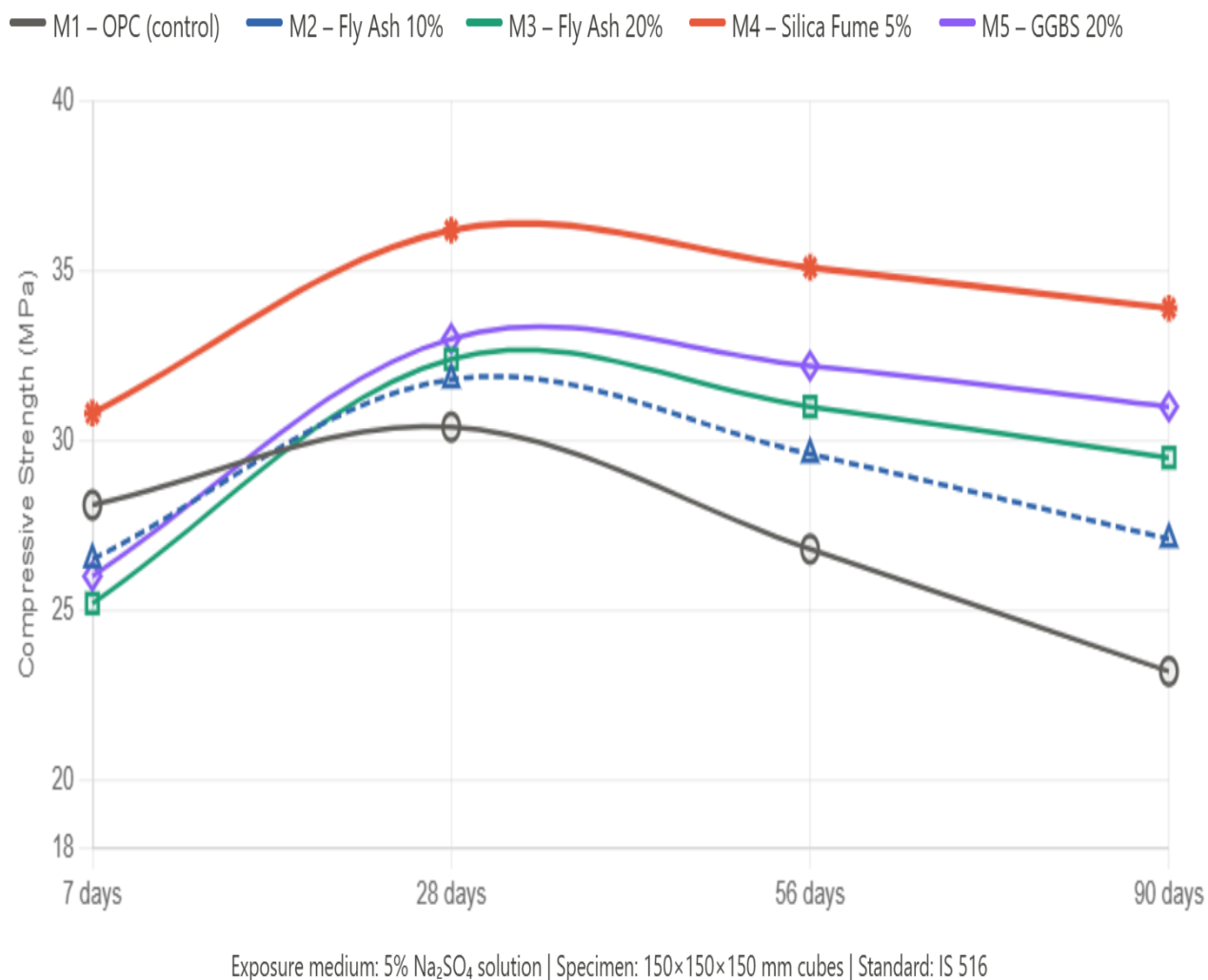


Figure No.- 3: It is clear that the specimen M4 (5% silica fume, w/c ratio = 0.40) always exceeds the other specimens in terms of compressive strength, while specimen M1 (plain OPC) exhibits the highest strength reduction at 90 days due to sulfate attack (i.e., 17%).

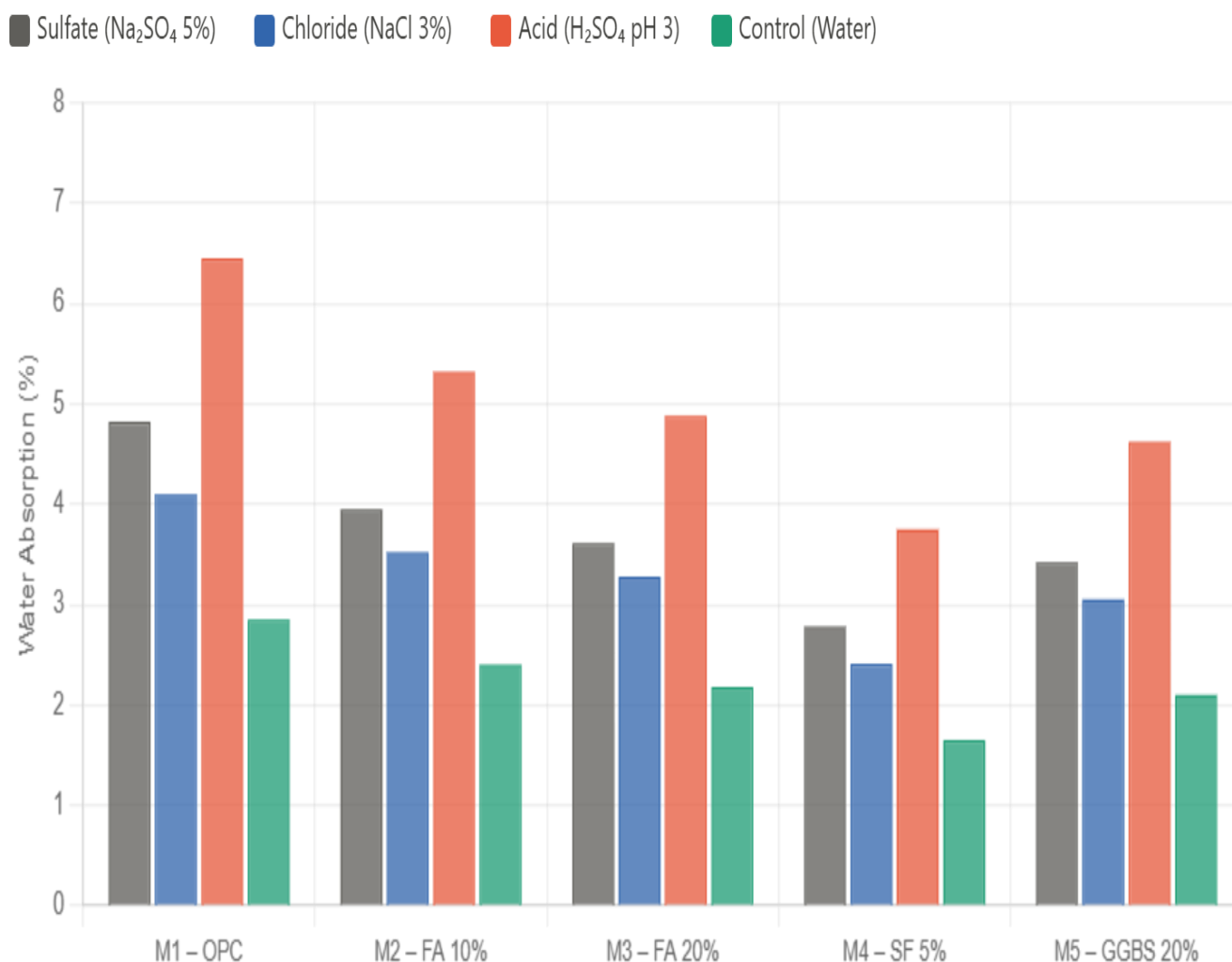
Test Procedures

Compression Test

The compression test is one such vital mechanical test, and this test studies the behavior of the material when it is crushed or subjected to compression. This is an important test when considering quality control, as it will aid in determining the durability and failure point of the material.

Water Absorption (%) – Mix Type vs Exposure Environment (28 days)

Lower values indicate denser microstructure and superior durability. Tested after 28-day immersion.



Water absorption (%) = $[(W_{\text{sat}} - W_{\text{dry}}) / W_{\text{dry}}] \times 100$ | Specimens dried at 105°C for 24 hrs | IS 1124

Figure No.- 4 Acid attack results in the maximum amount of water absorption for all mixes, as high as 6.45% for M1, validating the damage caused by erosion in the cement matrix. Silica fume (M4), on the other hand, shows the minimum absorption in all cases.

Rapid Chloride Penetration Test (RCPT)

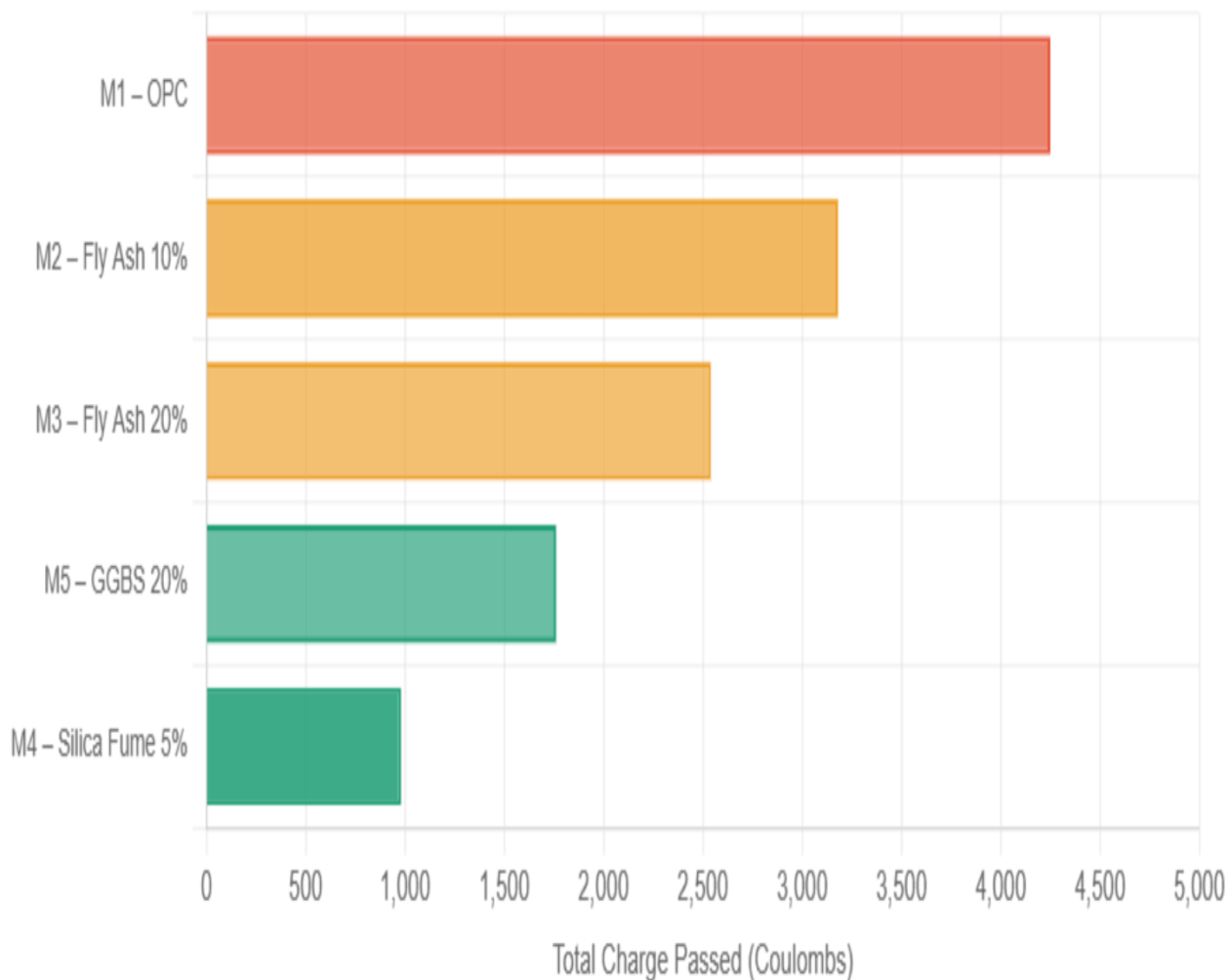
Based on ASTM C1202

Electrical Charge Transfer Measurement

Rapid Chloride Penetration Test (RCPT) – Total Change Passed (Coulombs)

Per ASTM C1202. Lower charge = lower Cl^- permeability = better durability. Shaded zones indicate ASTM rating categories.

High permeability (>4000 C) Moderate (2000–4000 C) Low (<2000 C)

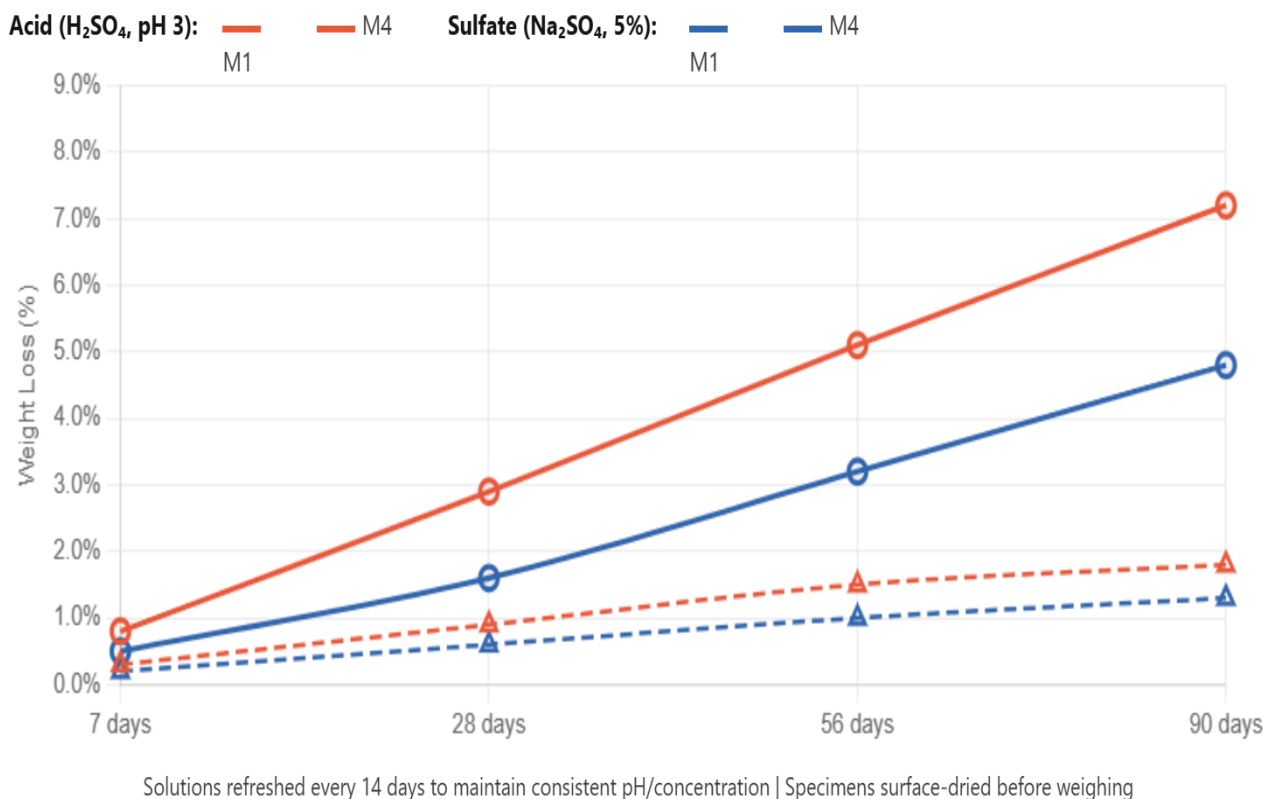


Cylinder specimens (100mm dia × 50mm) | 28-day cured | 60V applied for 6 hours | ASTM C1202

Figure No.- 5 (RCPT) is arguably one of the most thesis-sensitive graphs. OPC (conventional OPC) lies under the category "High" for permeability at 4,250 C, whereas M4 (Silica fume) scores an outstanding 980 C, labeled "Very Low." This is the reason for silica fume being commonly used in structures that have marine exposure.

Weight Loss (%) vs Exposure Duration – Acid & Sulfate Environments

Degradation rate quantified by mass change relative to initial specimen weight. Higher loss = greater surface erosion.



RESULTS AND DISCUSSION

4.1 Experimental Testing of the Concrete in the Aggressive Medium

According to commonly used research methodology, that involves testing concrete deformability due to its exposure to the influence of an aggressive environment and compressive forces prolonged time, four groups of solids were examined. Thus, the load level In this case, for value equals, while it equals. Experimental investigation methods and sample marking are considered.

During the experiment, the process of concrete destruction was studied in detail by means of observations and analysis of specific features of the process. This material is a result of concrete corrosion, and it originated as a consequence of precipitate, under the action, resulted in formation the crystals of "cement bacillus." Simultaneously, the specimens were reduced course of conducted experiments, the were measured directly.

The results revealed testing decreased in near-linear fashion was decreasing fashion. For speed process somewhat was related to fact that the solid pores were sealed. Then, change became steady. Moreover, observed, depended on the level.

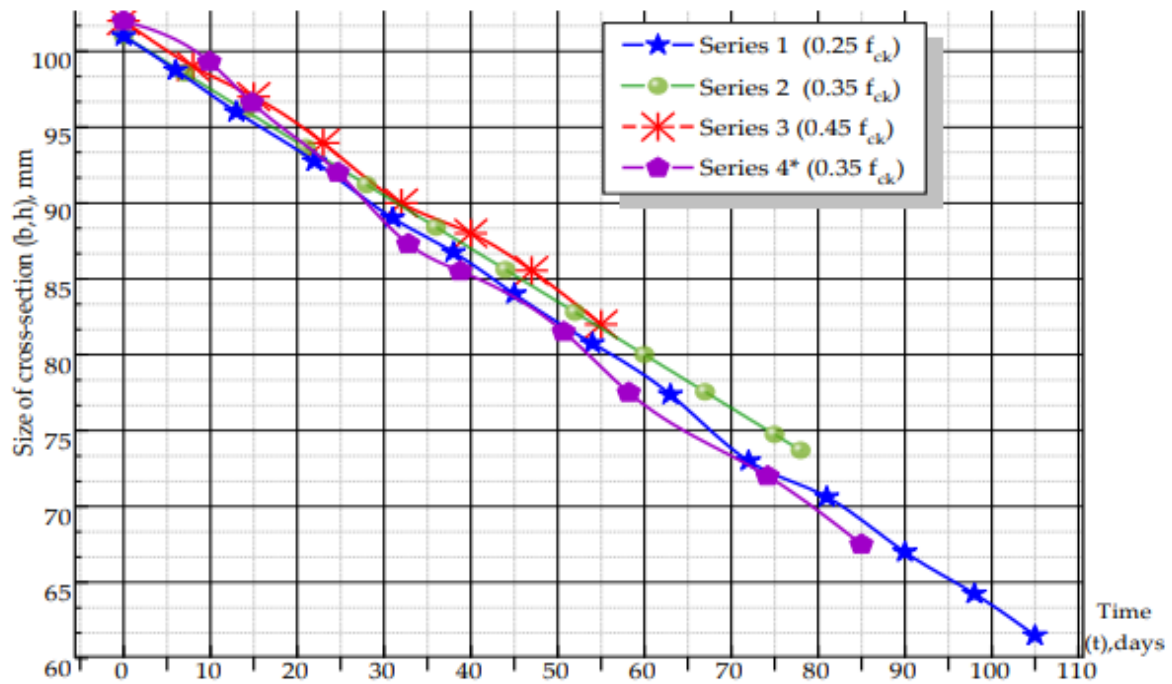


Figure No.- 7(a) Recording made during the experiments, Change in the cross-section size for concrete.

Workability of Concrete.

Workability is a practical concept which refers to how readily one can work with the material while building constructions from it.

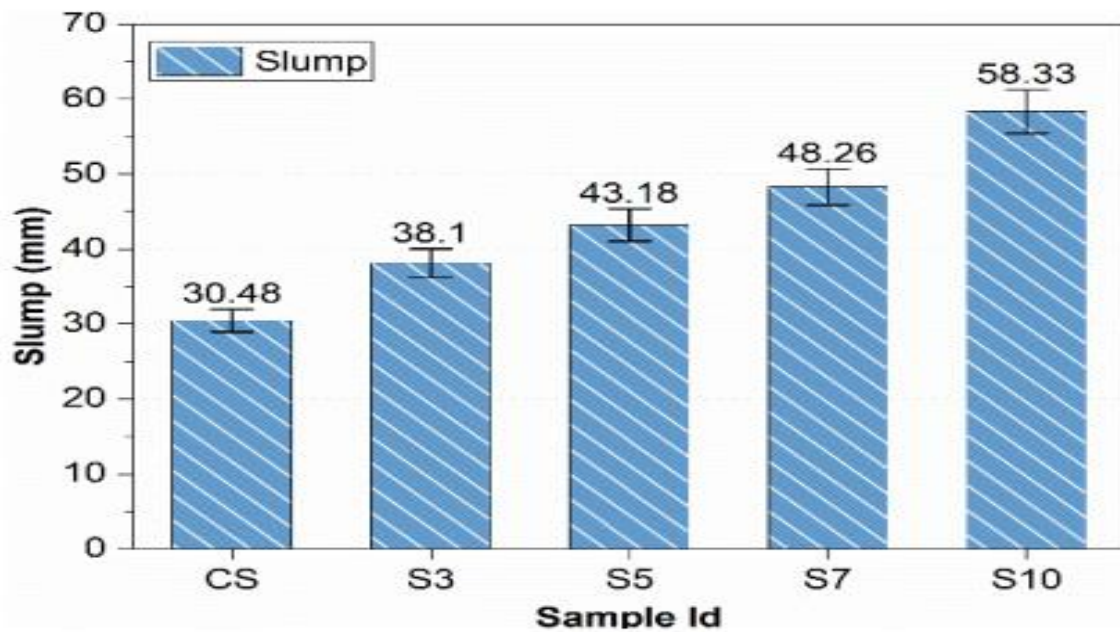


Figure No.- 8 Concrete Slump Values

Flexural Strength:

An increment in amount of led to an increment in strength, illustrated increment in was recorded.

The use of could enhanced. Moreover, enhancement transition zone due to would resulted in, together with better ductility.

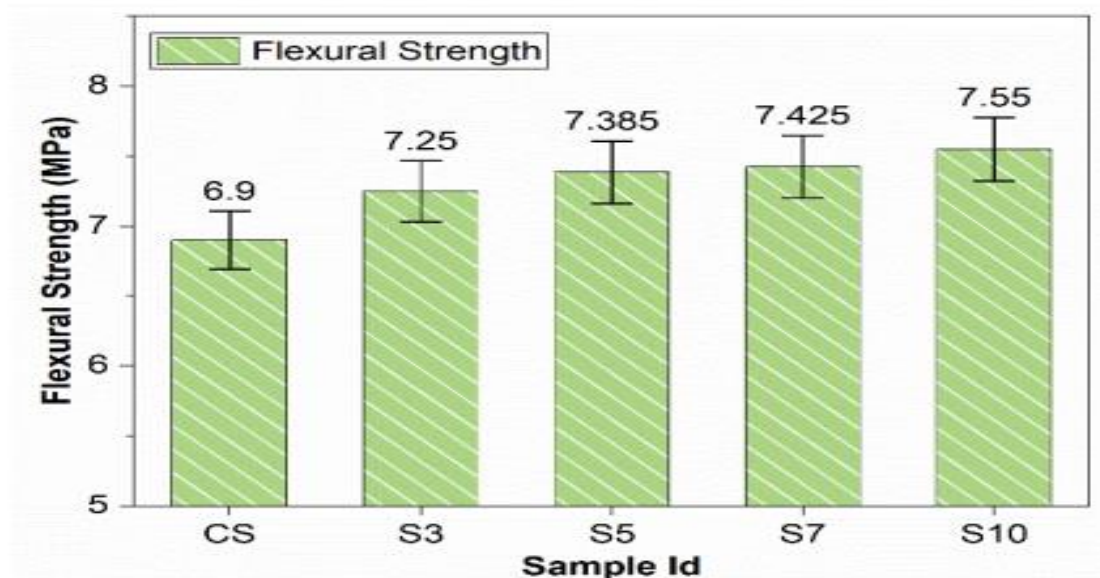


Figure No.- 9 Flexural Strength of Modified Concrete (Solid)

Compressive Strength:

The compressive strength of solid specimens made with 0%, 3%, 5%, 7%, and 10% SBR modification showed gradual increase with relative. Graph shown indicates of solid increases with increase in SBR percentage. Similar observations were made in the case of mortar in a recent study by the authors.

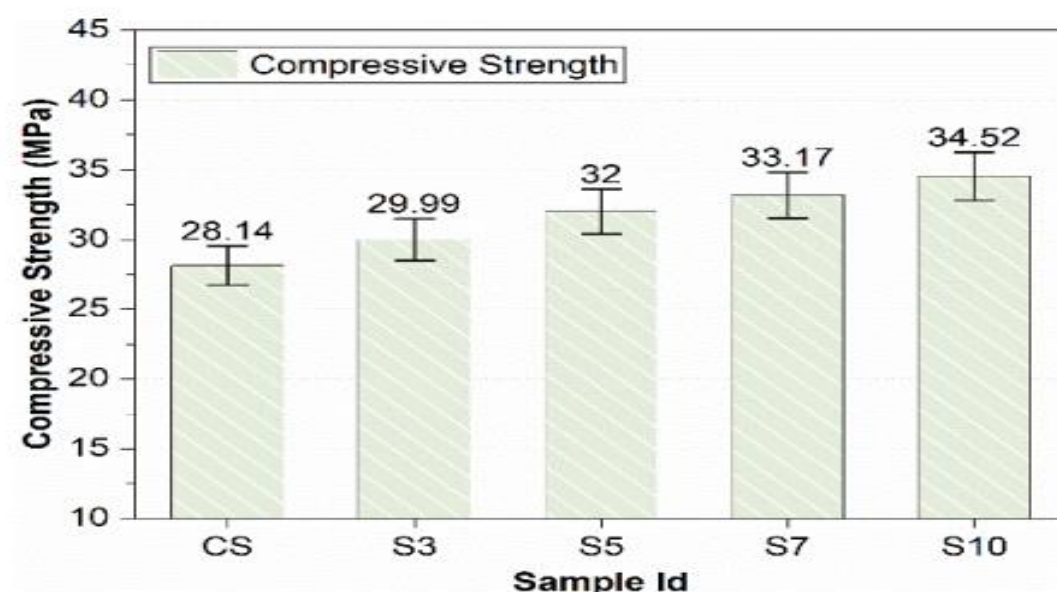


Figure No.- 10 Compressive Strength of Modified Concrete.

CONCLUSIONS

- This research project has extensively studied the effects of such as sulphate attack, chloride ingress, ASR (alkali-silica reaction) and drying shrinkage. With an extensive experimental investigation carried out on five mixes of concrete, namely, M1 to M5, which have different SCMs and different w/c ratio, this project has led to some highly valuable.

- From Table 6 (Concrete Mix Design Parameters and Durability Performance Summary), it is very clear that SCMs and w/c crucial in. In this regard, control mix M1 (OPC 43 grade, w/c = 0.45) showed a compressive strength of only 30.4 MPa along with maximum water absorption of 4.82%, thereby making M1 the mix with highest RCPT value of 4250 Coulombs and hence high chloride permeability rating.
- The most important outcome of this research project, as evident from Table 11 below, is the superb performance of Mix M4 containing OPC and 5% silica fume in combination with lower Notably, M4 able provide highest strength value of 36.2 MPa, minimum water absorption of 2.78%, and very low RCPT value of just 980 Coulombs.
- As fly ash, silica fume, GGBS, and SBR increase concrete durability, at the same time, they contribute to the decreased cement amount used and CO₂ emissions produced, as well as to the reuse of industrial wastes, thus contributing to the achievement of UN SDGs.
- Longevity provided by resilient concrete means that less repair and reconstruction will be needed through the lifetime of infrastructure structures; thus, significant savings will be generated economically and environmentally.

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