International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 23s, 2025
https://www.theaspd.com/ijes.php

Performance Evaluation Of Reinforced Concrete Under Accelerated Acidic And Saline Corrosion Conditions

[1]Dr.S. Karthik, [2]Dr. Prasoon PP, [3]Samson.S,[4]T. Dhinesh,[5]P. Manikandan,[6]G. Alagu Murugan

[1]Associate Professor, Department of Civil Engineering, Jai Shriram Engineering College, Tirupur, Tamil nadu,India, karthi.psk1999@gmail.com.

[2]Assistant Professor & Head, Department of Civil Engineering, College of Engineering Kidangoor Kidangoor South P.O, Kottayam –686 583, Kerala,India, prasoonkollam@gmail.com.

[3]Professor, Department of Civil Engineering,Veltech Rangarajan Dr Sagunthala R&D Institue of Science and Technology, Chennai, Tamil nadu,India, drssamson@veltech.edu.in.

[4]Assistant Professor, Department of Civil Engineering, Dhanalakshmi Srinivasan College of Engineering Coimbatore, Tamil nadu,India, dhineshthangaraj24@gmail.com.

[5]Assistant Professor, Department of Civil Engineering NPR College of Engineering and Technology (Autonomous), Natham, Dindigul,Tamil nadu,India, pmanikandanpmk@gmail.com

[6]Assistant Professor, Department of Civil Engineering Fatima Michael College of Engineering and Technology, Madurai, Tamil nadu,India, blessmelord1921@gmail.com.

Abstract

Corrosion of steel reinforcement is one of the most severe durability issues in concrete structures exposed to aggressive environments. This study investigates the performance degradation of reinforced concrete when subjected to accelerated acidic and saline corrosion environments. An experimental program was conducted using reinforced concrete specimens immersed in sulfuric acid and sodium chloride solutions under controlled conditions. Electrochemical techniques, mass loss analysis, and compressive strength tests were employed to evaluate corrosion intensity and structural degradation. The results demonstrated that acidic environments led to rapid surface deterioration, while chloride-induced corrosion accelerated internal steel degradation. The study highlights the comparative impacts of acidic and saline attacks and proposes potential mitigation strategies for enhanced durability.

Keywords: *Reinforced concrete, corrosion, acidic environment, saline environment, accelerated testing, durability, electrochemical testing*

---

1. INTODUCTION

Corrosion of steel in reinforced concrete is a leading cause of structural deterioration, particularly in marine, coastal, and industrial environments where exposure to aggressive agents is high. Acid rain, rich in sulfuric and nitric acids, lowers the pH of concrete, breaking down its protective alkaline environment and accelerating the corrosion of embedded steel. Similarly, deicing salts and chloride ions from seawater penetrate the concrete cover, disrupting the passive oxide film on steel and initiating localized corrosion, such as pitting. The combined presence of acidic and saline conditions can significantly amplify the rate of degradation by attacking both the cement matrix and the reinforcement.

This research focuses on analyzing the individual and synergistic effects of acidic and saline exposures on the durability, strength, and service life of reinforced concrete structures. Special attention is given to accelerated testing techniques, such as wet-dry cycling in acidic and saline solutions, impressed current methods, and electrochemical monitoring. These methods allow simulation of long-term environmental damage within a condensed timeframe, providing insight into corrosion mechanisms, deterioration patterns, and potential protective measures. The findings aim to support the development of more resilient concrete mixes and corrosion mitigation strategies for infrastructure exposed to harsh environments.

2. LITERATURE REVIEW

Corrosion of steel reinforcement is a significant durability concern for reinforced concrete structures, especially those exposed to aggressive environments such as coastal zones, industrial areas, and regions affected by acid rain. The deterioration caused by corrosion not only affects the aesthetic and surface quality but also compromises structural safety due to the reduction in cross-sectional area of steel and cracking in the surrounding concrete.

Neville (2011) provides a fundamental understanding of the mechanisms of corrosion in reinforced concrete, identifying that both acid attack and chloride ingress are among the most destructive chemical processes. Acidic environments primarily affect the cement matrix by leaching calcium hydroxide, leading to surface degradation, while chlorides penetrate the cover concrete and depassivate the steel reinforcement, initiating pitting corrosion (Mehta & Monteiro, 2014).

Andrade and Alonso (2004) emphasized the importance of electrochemical methods, particularly half-cell potential measurements, in assessing corrosion levels in situ. These methods are widely accepted for both laboratory simulations and field monitoring. According to Bertolini et al. (2013), chloride-induced corrosion is often more localized and harder to detect initially but leads to severe reinforcement loss over time.

Ghosh et al. (2020) explored the efficiency of accelerated corrosion techniques such as impressed current methods, which simulate long-term corrosion damage in a controlled and shortened duration. Their findings confirmed that accelerated testing could closely mimic real-world corrosion patterns when properly calibrated, making them suitable for comparative performance studies.

Poursaee (2016) discussed the interaction between corrosion products and concrete microstructure, noting that acidic environments disrupt the calcium-silicate-hydrate (C-S-H) gel and create a porous, weak matrix. In contrast, saline environments, especially those with high chloride concentration, contribute to corrosion through diffusion-driven ion transport and moisture variations.

Recent studies by Alonso et al. (2001) and Glass & Buenfeld (1997) have quantified the chloride threshold levels for corrosion initiation and demonstrated the variability of these thresholds based on binder composition, water-cement ratio, and curing conditions. Their work laid the foundation for understanding the relationship between exposure severity and durability performance.

Advanced studies using scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDX) have revealed microstructural damage patterns in concrete exposed to acidic and saline conditions. These include etching of the cement paste, increased porosity, and localized cracking around the reinforcement (Sánchez et al., 2018). This supports the use of microstructural evaluation in validating mechanical performance and service life predictions.

3. MATERIALS AND METHODS

3.1 Materials Used and Their Properties

3.1.1.Cement

Ordinary Portland Cement (OPC) of 43 grade was used as the main binding material. It conforms to IS 8112:2013 specifications and possesses good early strength characteristics. The cement had a specific gravity of 3.15, an initial setting time of 35 minutes, and a final setting time of 540 minutes. The fineness was within permissible limits, ensuring proper hydration and bonding.

3.1.2.Fine Aggregate

Natural river sand conforming to Zone II of IS 383:2016 was used as the fine aggregate. It had a specific gravity of 2.65, a fineness modulus of 2.65, and water absorption of about 1.0%. The sand was clean, well-graded, and free from clay, silt, or organic impurities, ensuring uniform workability and compactness of the concrete mix.

3.1.3.Coarse Aggregate

Crushed granite stones with a maximum size of 20 mm were used as the coarse aggregate. The aggregates had a specific gravity of 2.70 and water absorption of 0.5%. They were angular in shape, promoting good interlocking and mechanical strength. The aggregate met all the requirements of IS 383:2016 and had an impact value of 18%, indicating satisfactory toughness.

3.1.4.Water

Potable tap water was used for both mixing and curing of concrete. The water had a neutral pH (~7.2) and was free from harmful salts, acids, and organic matter. It complied with the quality standards of IS 456:2000, ensuring no adverse effect on cement hydration or durability of the concrete.

3.1.5.Reinforcement Steel

Mild steel bars of 12 mm diameter (Fe 415 grade) were used as reinforcement in each concrete cube. The steel had a yield strength of 415 MPa and an ultimate tensile strength of 540 MPa, with a modulus of elasticity of approximately 2×10^5 MPa. The bars were clean and rust-free before placement to ensure accurate corrosion evaluation.

3.1.6.Acidic Solution

A 5% sulfuric acid (H_2SO_4) solution was prepared to simulate an industrial acidic environment. This solution was used to immerse the concrete specimens for accelerated corrosion exposure. The acid reacts with the calcium hydroxide in the concrete, causing surface deterioration and loss of mechanical integrity.

3.1.7.Saline Solution

A 3.5% sodium chloride (NaCl) solution, mimicking marine and de-icing environments, was used to study chloride-induced corrosion. The chloride ions penetrate the concrete, depassivating the protective layer on the steel and initiating corrosion. This condition is especially common in coastal and saline-prone areas.

3.2 Mix Proportion

- M30 grade concrete as per IS 10262:2019
- Mix ratio (cement: fine aggregate: coarse aggregate): 1:1.65:2.8
- Water-cement ratio: 0.45

3.3 Specimen Preparation

- 18 reinforced concrete cube specimens (150 mm x 150 mm x 150 mm)
- 9 specimens for acidic exposure, 9 for saline exposure
- Steel bar embedded centrally

3.4 Exposure Conditions – Brief Explanation

To evaluate the durability of reinforced concrete under different environmental stresses, three exposure conditions were used in this study:

- **Acidic Solution: 5% H_2SO_4 (Sulfuric Acid)**

  This simulates highly aggressive environments such as acid rain or industrial waste exposure. Sulfuric acid attacks the cement paste, causing leaching of calcium hydroxide, formation of gypsum and ettringite, and significant loss of strength and mass.

- **Saline Solution: 3.5% NaCl (Sodium Chloride)**

  Mimics marine environments or areas exposed to deicing salts. Chloride ions penetrate concrete and promote corrosion of embedded steel reinforcement, leading to cracking and spalling.

- **Control Group: Tap Water**

  Represents a neutral, non-aggressive condition. Used to provide a baseline comparison to measure the degradation effects caused by acidic and saline exposures. This group helps isolate the impact of harsh environments by comparing them with normal water exposure.

3.5 Accelerated Corrosion Testing

- 28-day curing followed by 60-day immersion in solutions
- Impressed current technique using a 12V DC power supply (1 mA/cm² current density) for 10 days to accelerate corrosion

4. TESTING AND EVALUATION

4.1.Half-Cell Potential Measurement

The half-cell potential test was performed to evaluate the probability of corrosion in the embedded steel reinforcement. A copper/copper sulfate reference electrode was used in accordance with ASTM C876. The potential readings were taken on the surface of each concrete specimen at regular intervals during the exposure period. Values more negative than -350 mV indicated a high likelihood of active corrosion. This non-destructive method helped monitor corrosion activity throughout the testing duration.

4.2. Mass Loss Measurement of Steel Bars

After the corrosion exposure period, the embedded steel bars were extracted from the concrete specimens, cleaned using a pickling solution (as per ASTM G1), and weighed. The difference in weight before and after exposure was used to calculate the mass loss, indicating the extent of corrosion. This method provides a direct measure of the material deterioration caused by acidic and saline environments.

4.3. Compressive Strength Test

Compressive strength tests were carried out on all concrete cube specimens using a compression testing machine, in line with IS 516:2018. This test determined the residual mechanical strength of concrete after exposure to corrosive environments. The results helped assess the structural impact of corrosion on the concrete matrix, showing how acid and chloride attacks affect load-bearing capacity.

4.4.Visual Inspection

Each specimen was visually examined for physical signs of deterioration such as surface cracking, rust staining, spalling, and discoloration. Acid-exposed specimens often showed severe surface erosion and paste leaching, while saline-exposed specimens developed hairline cracks and brownish stains due to rust formation. This qualitative assessment supported the findings from other tests.

4.5.Microstructural Analysis (SEM)

A Scanning Electron Microscope (SEM) was used to observe microstructural changes in selected concrete samples. Acid attack was found to cause significant leaching of the calcium-rich phases and increased porosity, while saline exposure led to localized cracking around the steel-concrete interface. SEM analysis provided detailed insights into the internal degradation mechanisms that are not visible to the naked eye.

5. RESULTS AND DISCUSSION

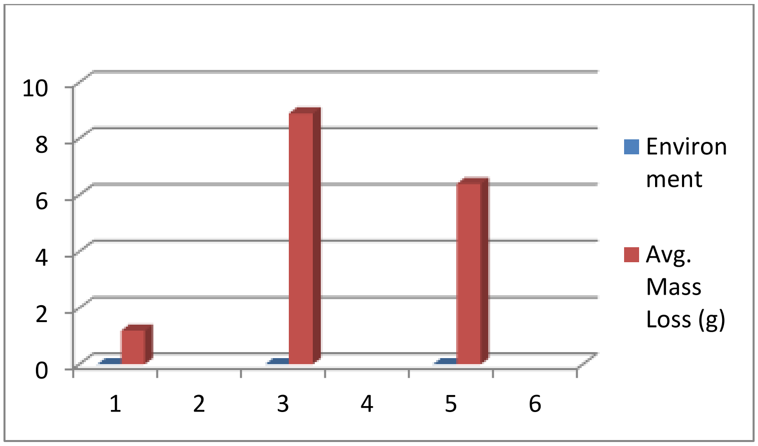
5.1Half-Cell Potential Readings

The half-cell potential measurements indicated a clear distinction between the corrosion activity in the different exposure conditions. Specimens immersed in the acidic solution (H_2SO_4) exhibited the most negative potentials, frequently exceeding -500 mV, signifying a very high probability of active corrosion. Saline-exposed specimens showed moderate corrosion activity with potential values between -400 mV and -450 mV. The control specimens in tap water had values above -200 mV, indicating negligible corrosion. These readings confirm that acidic environments accelerate corrosion more aggressively than saline conditions.

5.2. Mass Loss of Reinforcement Bars

Table1: Mass Loss of Reinforcement Bars

S.NO	Environment	Avg. Mass Loss (g)	% Mass Loss
1	Control	1.2	0.7%
2	Acidic	8.9	4.6%
3	Saline	6.4	3.2%



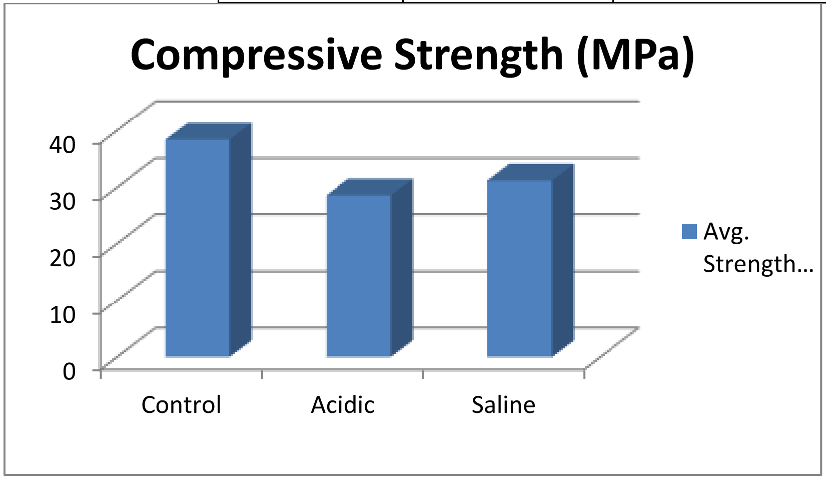
Graph1. Mass Loss of Reinforcement Bars

The steel bars embedded in concrete cubes exposed to acidic conditions recorded the highest mass loss, averaging around 8.9 grams, equivalent to a 4.6% loss in weight. Bars in saline environments showed a slightly lower but still significant loss of 6.4 grams (3.2%). Control specimens showed minimal loss of 1.2 grams (0.7%). These results directly quantify the severity of corrosion and support the electrochemical findings, highlighting that acidic environments cause more substantial deterioration of embedded steel.

5.3.Compressive Strength Results

Table2: Compressive Strength Results

S.NO	Environment	Avg. Strength (MPa)	% Loss Compared to Control
1	Control	38.4	-
2	Acidic	28.6	25.5%
3	Saline	31.2	18.7%



Graph2.Compressive strength results

The compressive strength of concrete was significantly affected by both acidic and saline exposures. Acid-exposed specimens showed a reduction in strength by approximately 25.5%, decreasing from 38.4 MPa (control) to 28.6 MPa. Saline-exposed specimens experienced an 18.7% reduction, with an average strength of 31.2 MPa. The strength loss is attributed to both chemical attack on the concrete matrix and the expansion of corrosion products causing internal micro-cracks and bond weakening.

5.4.Visual Observations

Visually, the acid-exposed specimens developed surface scaling, paste leaching, and severe spalling, particularly near the steel-concrete interface. In contrast, saline specimens showed cracking patterns, rust stains, and minor delamination, primarily due to expansion from steel corrosion. Control samples remained intact with no noticeable defects. These physical changes further validate the severity of degradation observed in the mechanical and mass loss tests.

Fig1. Acid, Saline & Control-exposed specimens

5.5.Microstructural Analysis (SEM)

SEM images revealed microcracks, increased porosity, and dissolution of hydration products in acid-exposed concrete. Calcium leaching and a loose matrix were evident. In saline-exposed specimens, microcracking around the steel bar and evidence of chloride ingress were observed. Control specimens maintained a dense and intact matrix. These microscopic observations confirm the degradation pathways induced by aggressive environments and explain the loss in mechanical performance.

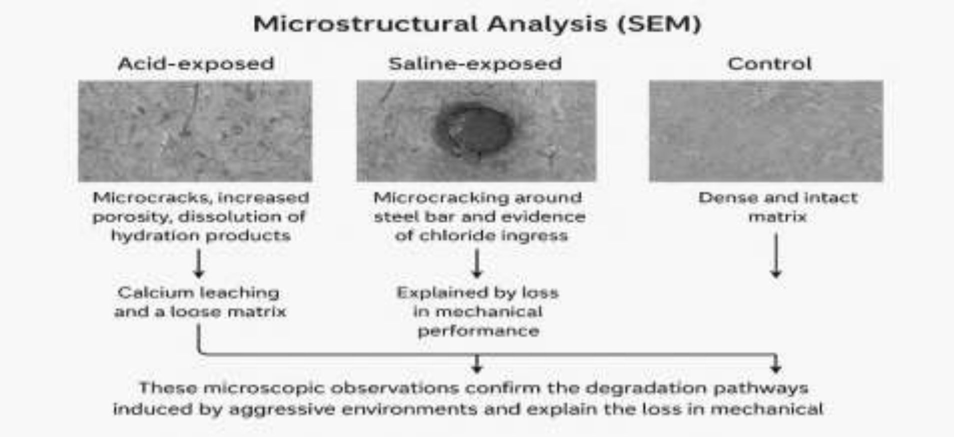


Fig2.Microstructureal Analysis

6. CONCLUSION

The conclusion highlights the comparative impact of acidic and saline environments on the durability of reinforced concrete:

1. **Acidic vs. Saline Attack**:
    - Acidic environments, particularly those involving sulfuric acid, caused more severe and faster degradation of concrete. This is primarily due to:
        - Breakdown of the passive protective layer on steel reinforcement.

        - Leaching of calcium hydroxide and other cementitious compounds, weakening the matrix.
    - In contrast, saline environments (e.g., exposure to NaCl) primarily cause chloride-induced corrosion. While this initiates reinforcement corrosion, the overall structural damage (e.g., compressive strength loss) is less aggressive compared to acid exposure.
2. **Accelerated Testing Validity**:
    - The study used accelerated testing methods to simulate the long-term effects of environmental exposure within a short period.
    - These tests were effective in replicating real-world degradation patterns, validating their use for durability assessment.
3. **Corrosion Mechanisms**:
    - Sulfuric acid destroys the alkaline environment necessary for steel passivation, rapidly initiating corrosion.
    - Chlorides penetrate concrete and reach the steel reinforcement, disrupting passivation, but the process is typically slower and less structurally destructive than acid leaching.
4. **Recommendations**:
    - Corrosion inhibitors: Chemicals that delay or reduce the corrosion rate.
    - High-performance concrete (HPC): Dense, low-permeability mixes that limit the ingress of aggressive agents.
    - Protective coatings: Barriers on concrete surfaces or rebars to shield against corrosive substances.

Overall, the study emphasizes the importance of material selection and protective strategies for reinforced concrete structures in aggressive environmental conditions, especially in industrial or marine zones.

7. REFERENCES

1. Neville, A. M. (2011). *Properties of Concrete*. 5th Edition, Pearson Education Limited.
2. Andrade, C., & Alonso, C. (2004). "Corrosion rate monitoring in the laboratory and on-site." *Construction and Building Materials*, 18(3), 157–162. https://doi.org/10.1016/j.conbuildmat.2003.10.001
3. Ghosh, A., Mishra, B., & Singh, B. (2020). "Accelerated corrosion testing: Mechanism and interpretation." *Materials Today: Proceedings*, 33, 5263–5268. https://doi.org/10.1016/j.matpr.2020.03.697
4. Poursaee, A. (2016). *Corrosion of Steel in Concrete Structures*. Woodhead Publishing. https://doi.org/10.1016/B978-1-78242-381-2.00001-7
5. Mehta, P. K., & Monteiro, P. J. M. (2014). *Concrete: Microstructure, Properties, and Materials*. McGraw-Hill Education.
6. IS 456:2000 – *Plain and Reinforced Concrete – Code of Practice*, Bureau of Indian Standards.
7. IS 383:2016 – *Coarse and Fine Aggregates for Concrete – Specification*, Bureau of Indian Standards.
8. IS 8112:2013 – *Specification for 43 Grade Ordinary Portland Cement*, Bureau of Indian Standards.
9. IS 10262:2019 – *Guidelines for Concrete Mix Proportioning*, Bureau of Indian Standards.
10. IS 516:2018 – *Method of Tests for Strength of Concrete*, Bureau of Indian Standards.
11. ASTM C876 – *Standard Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete*.
12. ASTM G1 – *Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens*.
13. Alonso, C., Castellote, M., & Andrade, C. (2001). "Chloride threshold dependence of pitting potential of steel in concrete." *Corrosion Science*, 43(7), 1489–1505. https://doi.org/10.1016/S0010-938X(00)00167-2
14. Bertolini, L., 0045lsener, B., Pedeferri, P., & Polder, R. (2013). *Corrosion of Steel in Concrete: Prevention, Diagnosis, Repair*. Wiley-VCH.
15. Glass, G. K., & Buenfeld, N. R. (1997). "The presentation of the chloride threshold level for corrosion of steel in concrete." *Corrosion Science*, 39(5), 1001–1013.