

# EFFECTIVENESS OF CORROSION INHIBITORS AND GGBS IN ENHANCING DURABILITY OF REINFORCED CONCRETE STRUCTURES EXPOSED TO CHLORIDE-RICH ENVIRONMENTS

Sindhu Ravichandran\*, Natarajan Muthusamy and Thirugnanam Shanmugam

*Received: February 19, 2025; Revised: May 19, 2025; Accepted: May 27, 2025*

## Abstract

Corrosion presents a severe threat to the durability of reinforced concrete (RC) structures, particularly those exposed to chloride-rich environments. This study evaluates the efficacy of corrosion inhibitors, including calcium nitrate, sodium nitrate, and diethanolamine, incorporated at 3% by weight of cement in preventing corrosion in RC. In addition, to enhance sustainability and strength, 40% of the cement was replaced with ground granulated blast furnace slag (GGBS). Corrosion resistance was assessed through electrochemical evaluations. Diethanolamine exhibited superior inhibitory performance in both electrochemical studies. The findings suggest that using GGBS and inhibitors, particularly diethanolamine, enhances the corrosion resistance and durability of RC structures.

**Keywords:** Corrosion Inhibitors; Diethanolamine; Reinforced Concrete; Chloride Penetration; Electrochemical Evaluation

## Introduction

Corrosion of reinforced concrete (RC) structures in chloride-rich environments poses a major challenge in the construction industry, significantly impacting the durability and safety of infrastructure. (Aslam *et al.*, 2022). The presence of chlorides accelerates the deterioration of steel reinforcement, leading to reduced structural integrity and potential failures over time. (Teklegiorgis *et al.*, 2022) This issue not only compromises the performance of RC structures but also results in increased maintenance

expenses and shorter service life. (Ahmed ES and Mohan Ganesh, 2022) The long-term effects include higher repair costs, operational disruptions, and safety hazards. To address this, implementing effective preventive measures, such as advanced protective coatings, corrosion inhibitors, and improved design strategies. (Shwetha *et al.*, 2024).

Numerous studies have investigated strategies to mitigate corrosion in reinforced concrete structures, with an emphasis on material

---

Department of Civil Engineering, Karpagam Academy of Higher Education, Coimbatore, Tamilnadu, India. E-mail [sindhuravichandran8@gmail.com](mailto:sindhuravichandran8@gmail.com)

\* Corresponding author

DOI: <https://doi.org/10.55766/sujst8731>

Suranaree J. Sci. Technol. 32(5):010378(1-9)

modifications and the application of corrosion inhibitors. (Akpan *et al.*, 2024) These strategies aim to enhance the durability and longevity of concrete in harsh environments. Among the promising approaches is the use of supplementary cementitious materials (SCMs), such as fly ash, silica fume, and slag, which improve the microstructure of concrete and reduce its permeability to aggressive agents. (Al-Amiery *et al.*, 2024; Tan *et al.*, 2024) Corrosion inhibitors, including both organic and inorganic compounds, are also gaining attention for their ability to protect steel reinforcement by forming protective films. (Mohamed *et al.*, 2022) Accelerated corrosion testing methods play a vital role in evaluating the effectiveness of these inhibitors under simulated harsh conditions. (Liu *et al.*, 2024a) These tests provide valuable insights into the mechanisms of corrosion and the redistribution of corrosion products at the steel-concrete interface, especially in chloride-rich or high-humidity environments. (Qasim *et al.*, 2022; Kanwal *et al.*, 2024) Understanding these interactions is essential for developing innovative materials and techniques to prevent corrosion, ultimately improving the structural integrity and lifespan of reinforced concrete systems. (Yang *et al.*, 2021a) By combining advanced materials with rigorous testing and analysis, researchers aim to provide more reliable and cost-effective solutions for infrastructure exposed to aggressive conditions. (Li *et al.*, 2024).

One key material in combating corrosion is ground granulated blast furnace slag (GGBS), a byproduct of the steel manufacturing process, which plays a pivotal role in enhancing both the durability and sustainability of concrete. (Ghazaei *et al.*, 2024) GGBS-blended concrete significantly improves the microstructure by reducing permeability, thereby limiting the ingress of harmful substances such as chlorides and moisture that accelerate steel reinforcement corrosion. (Liu *et al.*, 2024b) Its use not only enhances corrosion resistance but also contributes to reducing the carbon footprint of construction materials. (Thangavel *et al.*, 2024).

In addition to GGBS, advanced electrochemical techniques, such as electrochemical impedance spectroscopy (EIS), have been employed to evaluate the effectiveness of corrosion inhibitors in reinforced concrete structures. (Taheri *et al.*, 2020) EIS studies provide critical insights into the protective mechanisms of these inhibitors, demonstrating their capacity to form durable passive films on steel reinforcement and improve long-term corrosion resistance. (Elsa Thomas *et al.*, 2023) The combination of GGBS

with effective inhibitors offers a synergistic approach, ensuring enhanced durability and extending the service life of RC structures in aggressive environments. (Gurusamy *et al.*, 2024) This dual strategy underscores the potential of integrating sustainable materials and cutting-edge technologies to address corrosion challenges comprehensively. (Purnima *et al.*, 2024).

The inclusion of green inhibitors and micro-silica in concrete mixes is emerging as a sustainable and effective solution to address corrosion challenges in reinforced concrete (RC) structures. (Bodian *et al.*, 2024; Min *et al.*, 2024) Green inhibitors, derived from environmentally friendly and renewable sources, are gaining popularity due to their low toxicity and biodegradability. (Ramshankar *et al.*, 2024) Micro-silica, a byproduct of silicon and ferrosilicon alloy production, enhances the concrete's durability by refining its microstructure and reducing permeability. Studies on the combined use of green inhibitors and micro-silica as partial cement replacements in RC structures exposed to sodium chloride (NaCl) environments have demonstrated significant improvements in corrosion resistance and structural longevity. (Yang *et al.*, 2021b).

Silane-based inhibitors have also been highlighted for their ability to reduce chloride ion diffusion effectively, creating a hydrophobic barrier that protects the embedded steel reinforcement. (Krishnadas *et al.*, 2024) This approach not only slows down the corrosion process but also extends the service life of RC elements in aggressive chloride-rich conditions. (Ramakrishnan *et al.*, 2024) Sustainable inhibitors like guar gum have shown promise in enhancing steel durability. Theoretical studies and electrochemical analyses reveal that guar gum can adsorb onto the steel surface, forming a protective layer that minimizes corrosion. (Liu *et al.*, 2021) These advancements underscore the importance of integrating innovative and eco-friendly materials into concrete technology to promote sustainability while tackling corrosion effectively. (Parthasaarathi *et al.*, 2024).

In addition to these materials, glass fibers, silica fume, and other admixtures have been investigated for their role in enhancing concrete's resistance to corrosion and mechanical degradation. (Tian *et al.*, 2023) The combination of glass fibers and silica fume in concrete, noting improvements in mechanical properties and durability. (Ayano *et al.*, 2021) The behavior of epoxy-coated rebars in marine environments, offering insights into both mechanical and electrochemical performance. Expanded understanding of corrosion mechanisms and the efficacy of various protective measures. (Manickaraj *et al.*, 2024) The behavior of

triethanolamine and imidazoline in concrete. The correlation between accelerated indoor corrosion tests and real-sea environmental testing, contributing to a more comprehensive view of corrosion behavior. (Prusty *et al.*, 2020).

The electrochemical process degrades the embedded steel, requiring repairs and rehabilitation of affected structures. To address this issue, corrosion inhibitors have been increasingly employed as admixtures in concrete. (Kim *et al.*, 2021) These chemicals retard or prevent the electrochemical reactions responsible for corrosion, thus prolonging the service life of structures. (Shankar *et al.*, 2024) The use of corrosion inhibitors to reduce the deterioration of RC structures. This research explores the effectiveness of various inhibitors - calcium nitrate, sodium nitrate, and diethanolamine - combined with 40% GGBS as a cement substitute to improve the corrosion resistance and durability of RC structures. (Chithra *et al.*, 2024) To enhance the sustainability and durability of the concrete, 40% of the cement was replaced with GGBS. (Kiran *et al.*, 2021; Owamah *et al.*, 2021) This partial replacement not only reduces the carbon footprint of the concrete mix but also improves the microstructural properties and compressive strength. (Hoy *et al.*, 2024a) The performance was evaluated through electrochemical tests. This study aims to investigate the role of these corrosion inhibitors and the use of GGBS in improving corrosion resistance and mechanical performance in RC structures.

## Materials

### Cement

Ordinary Portland Cement (OPC) of Grade 43 was used, adhering to IS 4031:1988 standards. OPC 43 grade is known for its ability to develop strength at a relatively fast rate, making it suitable for this experiment given the aggressive exposure conditions anticipated during testing. (Hoy *et al.*, 2024b).

### Fine Aggregate

Manufactured sand (M-sand) was selected as it exhibits superior angularity compared to natural sand, providing better interlocking and reducing voids within the concrete matrix. (Anbarasu *et al.*, 2024) The specific gravity and particle size distribution of M-sand were also tested to ensure compatibility with the mix design.

### Coarse Aggregate

Crushed granite aggregates of 10 mm and 20 mm were used to provide the required structural

strength. These aggregates were washed and oven-dried before being used to remove any impurities that could affect the hydration process.

### Cement Replacement

Ground granulated blast furnace slag (GGBS) was used as a 40% replacement for cement. GGBS has pozzolanic properties, reacting with calcium hydroxide ( $\text{Ca(OH)}_2$ ) formed during cement hydration to form additional calcium silicate hydrate (C-S-H), which improves the strength and durability of concrete. This material has been shown to reduce the permeability of concrete, thereby enhancing its resistance to chloride penetration.

### Admixture

A high-range water-reducing admixture (superplasticizer) was used to achieve the desired workability without increasing the water content of the mix. This was essential to maintain a low water-cement ratio of 0.36, which is critical for reducing porosity and enhancing strength.

### Corrosion Inhibitors

The corrosion inhibitors used were calcium nitrate, sodium nitrate, and diethanolamine. Calcium nitrate functions by increasing the alkalinity of the concrete environment, thus restoring the protective oxide layer around the steel. Sodium nitrate, meanwhile, reduces the migration of chloride ions by promoting the formation of a dense pore structure. Diethanolamine works by forming a barrier film over the steel surface, reducing the rate of oxidation.

Specifications for coarse and fine aggregates from IS 383-1970 and recommendations for plain and reinforced concrete in IS 456-2000 provide foundational guidelines for durable concrete design. Similarly, standards such as IS 10262-2009 for concrete mix design and IS 12089-1987 for GGBS cement production ensure the consistent quality and performance of materials used in corrosion-resistant concrete.

### Concrete Mix Design

The M40 grade concrete mix was designed as per IS 10262:2009 guidelines, which provide specifications for achieving a compressive strength of 40 MPa at 28 days. The mix design process involved calculating the appropriate quantities of cement, fine aggregate, coarse aggregate, and water. The water-cement ratio was set at 0.36 to ensure adequate strength while maintaining low permeability.

Each batch was prepared with the same proportions of aggregates, cement, and GGBS, with the only variation being the type of corrosion inhibitor added. For each type of inhibitor, the admixture was thoroughly blended with the dry materials before water and superplasticizer were added. After mixing, the concrete was poured into cylindrical molds (150 mm in diameter and 300 mm in height) and compacted to remove any air voids. The specimens were demolded after 24 h and submerged in a curing tank for 28 days. After curing, the specimens were exposed to a 5% NaCl solution to simulate marine-like exposure conditions. To accelerate corrosion, an external current was applied as part of the electrochemical tests. Table 1 shows the mix design propositions

## Experimental Studies

### Accelerated Corrosion Studies

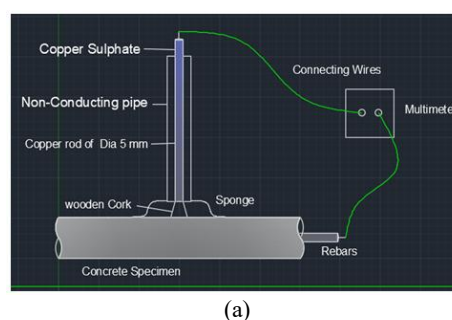
Electrochemical evaluations were conducted to assess the corrosion behavior of the reinforced concrete. Open-circuit potential (OCP) tests were performed for 60 days using 5% sodium chloride (NaCl) as the corrosive medium. Cylindrical concrete specimens from each mix were subjected to these tests, with a constant voltage of 12V applied to induce accelerated corrosion in Figure 1.

Readings were taken regularly to monitor the current flow and the resistivity of the specimens throughout the experiment. Faraday's Law was

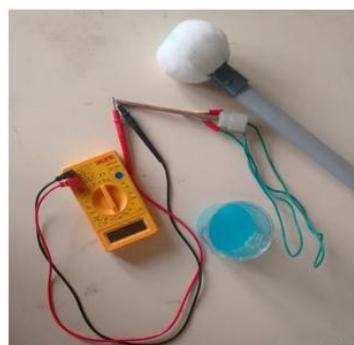
used to calculate steel loss, and periodic measurements of circumferential expansion were taken using circular collars placed at the mid-height of the cylinders. After desired steel loss was detected, compression tests were conducted on the specimens.

### Half Cell Potential Studies

The corrosion potential was measured using a half-cell potentiometer in accordance with ASTM C876 standards and its experimental setup is demonstrated in Figure 2(a) and Figure 2(b) respectively. A copper/copper sulfate ( $\text{Cu}/\text{CuSO}_4$ ) half-cell was used as the reference electrode. A high-impedance digital voltmeter was employed to measure the potential difference between the rebar and the reference electrode. Table 2 summarizes the interpretation of potential values based on ASTM C876 standards, providing insights into the probability of corrosion in the scanned area.



(a)



(b)

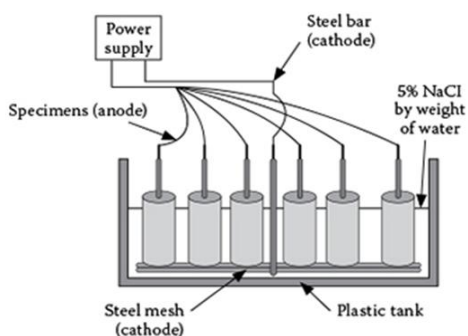


Figure 1. Accelerated Corrosion Test Setup with Constant Voltage

Figure 2. (a) Experimental setup- Half cell potential (b) Half-cell Potentiostat

Table 1. shows the mix design propositions

| S. No. | Mix ID | Cement Kg/m <sup>3</sup> | GGBS Kg/m <sup>3</sup> | Fine Aggregate Kg/m <sup>3</sup> | Coarse Aggregate Kg/m <sup>3</sup> | Corrosion Inhibitors Kg/m <sup>3</sup> |
|--------|--------|--------------------------|------------------------|----------------------------------|------------------------------------|----------------------------------------|
| 1      | M1     | 259                      | 172                    | 770                              | 1099                               | -                                      |
| 2      | M2     | 259                      | 172                    | 770                              | 1099                               | 7.77 Calcium Nitrate                   |
| 3      | M3     | 259                      | 172                    | 770                              | 1099                               | 7.77 Sodium Nitrate                    |
| 4      | M4     | 259                      | 172                    | 770                              | 1099                               | 7.77 Diethanol Amine                   |

**Table 2. Potential range classification for various stages of corrosion (ASTM C876)**

| Potential Range (mV) | Probability of Corrosion             | Number of Grid Points |
|----------------------|--------------------------------------|-----------------------|
| > -200               | Low probability of corrosion         | 3                     |
| -200 to -350         | Uncertain/moderate probability       | 4                     |
| < -350               | High probability of active corrosion | 2                     |

## Results and Discussion

Corrosion resistance was measured through a series of electrochemical studies, including Half cell potential (OCP) monitoring, accelerated corrosion test and its structural response. In this section, the performance of the various concrete mixes is discussed, with particular focus on potential time behavior, electrochemical properties, steel loss, cracking, and the structural integrity of the specimens. The mixes evaluated include a control (M1) without inhibitors, and three mixes with 3% by weight of cement added as calcium nitrate (M2), sodium nitrate (M3), and diethanolamine (M4). Additionally, 40% of the cement in all mixes was replaced with GGBS.

### Accelerated corrosion

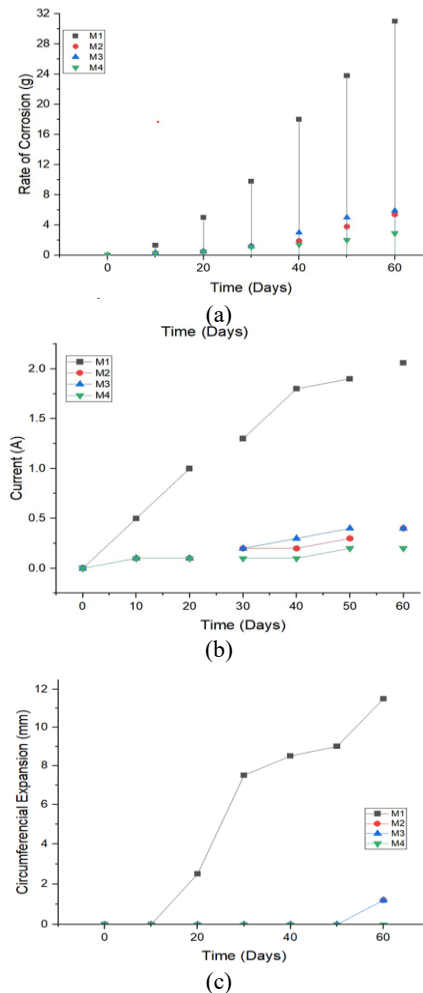
The half-cell potential measurements revealed significant differences in the corrosion rates of the specimens. The control mix (M1), which contained no inhibitors, exhibited a rapid rise in corrosion activity within the first few days of testing. By contrast, the mixes with corrosion inhibitors (M2, M3, and M4) demonstrated reduced corrosion rates throughout the experimental period, with diethanolamine (M4) showing the greatest inhibition of corrosion.

The accelerated corrosion test results, as shown in Figure 3(a) and Figure 3b, provide clear evidence of the superior performance of the diethanolamine-treated specimens. Over the course of 48 days, the steel loss in the control specimens (M1) reached an average of 37%, indicating a high degree of corrosion and subsequent diameter loss is observed from Fig. 3d. Among the inorganic inhibitors, calcium nitrate (M2) was more effective than sodium nitrate (M3), as evidenced by the lower steel loss (6% vs. 7%) and lower current values during the corrosion process. This supports the superior corrosion inhibition performance of M2 compared to M3, while diethanolamine (M4) remained the most effective overall.

Figure 3(b) (current vs. time) further reinforces the findings, where the current flow in

the control specimens surged during the first few days, corresponding to rapid corrosion onset. In contrast, the specimens with inhibitors maintained low and steady current readings, particularly M4, which recorded the lowest values, indicating suppressed corrosion reactions.

The circumferential expansion and cracking patterns in the concrete specimens also reflect the varying degrees of corrosion. As shown in Figure 3(c), the control specimens (M1) exhibited significant circumferential expansion due to the formation of corrosion products, which led to visible cracks within 15 days of testing. In contrast, specimens with inhibitors delayed the onset of cracking, with M4 (diethanolamine) showing the least amount of expansion and delayed cracking, supporting its superior performance in preventing corrosion-induced damage.



**Figure 3. (a). Rate of steel loss over time (b). Current Vs. Time (c). Variation of the circumferential expansion**

### Half Cell Potential Studies

The control mix (M1), which lacks any corrosion inhibitors, shows a significant shift in half-cell potential over time. Initially, M1 starts with a potential of approximately -100 mV, which decreases to -450 mV after 60 days of exposure. According to ASTM C876, a potential more negative than -350 mV indicates a high probability of corrosion activity. This suggests that the control specimen experienced active corrosion, with potential values crossing the critical threshold after approximately 30 days. The sharp decrease in half-cell potential after 30 days highlights the onset and rapid progression of corrosion in M1. It should be noted that the potential values presented in the figure are assumed to follow ASTM C876 conventions, and thus should be interpreted as negative values unless otherwise specified.

The mix containing calcium nitrate (M2) showed a more stable performance compared to the control. The initial potential values were around 100 mV, and after 60 days of exposure, the potential remained below 150 mV. These values fall under the category of low to moderate corrosion risk according to ASTM standards. Calcium nitrate is known to function as a corrosion inhibitor by forming a passive layer on the steel surface, preventing the ingress of chloride ions and thus delaying corrosion initiation. The relatively stable half-cell potentials of M2 demonstrate the effectiveness of calcium nitrate in mitigating corrosion.

The mix with sodium nitrate (M3) performed similarly to M2, with potential values starting at around 100 mV and rising to 200 mV after 60 days. The gradual increase in half-cell potential suggests that while some corrosion may have initiated, the sodium nitrate significantly delayed the progression of corrosion. The half-cell potential values remained well below the critical threshold of -350 mV, indicating a low probability of active corrosion throughout the exposure period. Sodium nitrate acts by inhibiting the anodic reaction of corrosion, effectively reducing steel dissolution and prolonging the service life of reinforced concrete.

The mix containing diethanolamine (M4) exhibited the most consistent half-cell potential values over time, remaining around 100 mV throughout the exposure period. Diethanolamine, as an organic inhibitor, prevents chloride-induced corrosion by adsorbing onto the steel surface, forming a protective layer. The very minimal increase in potential observed for M4 indicates that the diethanolamine provided strong protection against corrosion, even after prolonged exposure to NaCl. Based on the half-cell potential readings, M4

demonstrated the highest resistance to corrosion, maintaining a low corrosion probability throughout the study.

The partial replacement of cement with GGBS (40%) likely contributed to the improved durability of the mixes, as GGBS is known to reduce permeability and enhance the resistance of concrete to chloride ingress. The half-cell potential readings clearly demonstrate that the control mix (M1) experienced the highest level of corrosion, while the mixes with inhibitors (M2, M3, and M4) showed significantly better resistance to chloride-induced corrosion. Among the inhibitors, diethanolamine (M4) proved to be the most effective in maintaining low corrosion potential values, followed by calcium nitrate (M2) and sodium nitrate (M3). The half-cell potential results for different concrete mixes exposed to NaCl over a period of 60 days are shown in Figure 4.

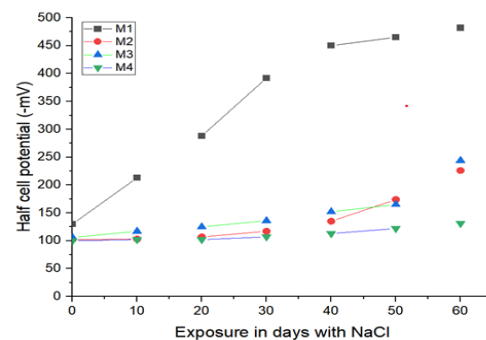


Figure 4. Potential time behavior

The compressive strength of the concrete specimens was tested both before and after the corrosion tests to assess the impact of corrosion on the structural integrity of the RC. The results are summarized in Table 3, which compares the compressive strength reduction due to corrosion across all mixes.

Table 3. Structural Response of the specimens subjected to corrosion

| Specimen | Compressive Strength (MPa) | Strength Reduction (%) | Steel Loss (%) |
|----------|----------------------------|------------------------|----------------|
| M1       | 15.47                      | 61.32                  | 37             |
| M2       | 35.35                      | 11.63                  | 6              |
| M3       | 35.87                      | 10.32                  | 7              |
| M4       | 36.97                      | 7.58                   | 3              |

The control mix (M1) experienced a substantial 61.32% reduction in compressive strength after the corrosion testing, reflecting the severe deterioration caused by the high levels of steel corrosion. The cracks induced by corrosion significantly weakened the structural capacity of the specimens, making them prone to failure under compressive loads.

In comparison, the specimens treated with calcium nitrate (M2) and sodium nitrate (M3) experienced compressive strength reductions of 11.63% and 10.32%, respectively. While these results indicate significant improvements over the control mix, they still reveal some vulnerability to corrosion-related strength degradation. This is consistent with the electrochemical test results, where these inhibitors were effective in reducing corrosion but not to the same extent as diethanolamine.

The diethanolamine-treated specimens (M4) exhibited the least compressive strength reduction of just 7.58%, indicating that the concrete maintained much of its structural integrity despite exposure to corrosive conditions. This is consistent with the electrochemical results, where M4 demonstrated the lowest corrosion rates and minimal steel loss. The superior performance of diethanolamine is attributed to its strong inhibition of electrochemical reactions, as well as its ability to protect the steel reinforcement from aggressive chloride ions.

## Conclusions

The findings of this study align with previous research on the use of corrosion inhibitors and supplementary cementitious materials in RC structures. The superior performance of diethanolamine is consistent, which highlighted the effectiveness of organic inhibitors in protecting steel reinforcement in chloride-rich environments. Similarly, the benefits of GGBS in improving durability are well-documented in studies, confirming that the inclusion of SCMs enhances the long-term performance of RC structures.

This study underscores the importance of using a combination of corrosion inhibitors and SCMs in concrete mixes to improve the durability and longevity of RC structures exposed to harsh environments. The results demonstrate that diethanolamine, when used in conjunction with GGBS, offers the most effective solution for mitigating chloride-induced corrosion and maintaining the structural integrity of RC structures over time.

Diethanolamine was the most effective corrosion inhibitor tested, providing superior corrosion resistance and structural integrity in RC structures exposed to chloride-rich environments. The combination of GGBS and diethanolamine significantly improves the durability of RC structures, offering an effective solution for extending service life in corrosive conditions.

## Acknowledgment

The authors acknowledge the support of Karpagam Academy of Higher Education in facilitating the experimental work.

## References

- Ahmed, E.S., Junaid, and Ganesh, G.M. (2022). A comprehensive overview on corrosion in RCC and its prevention using various green corrosion inhibitors. *Buildings*, 12(10):1682. <https://doi.org/10.3390/buildings12101682>
- Akpan, E.D., Singh, A.K., Lgaz, H., Quadri, T.W., Shukla, S.K., Mangla, B., Dwivedi, A., Dagdag, O., Inyang, E.E., and Ebenso, E.E. (2024). Coordination compounds as corrosion inhibitors of metals: A review. *Coordination Chemistry Reviews*, 499:215503. <https://doi.org/10.1016/j.ccr.2023.215503>
- Al-Amiery, A., Wan Isahak, W.N.R., and Al-Azzawi, W.K. (2024). Sustainable corrosion inhibitors: A key step towards environmentally responsible corrosion control. *Ain Shams Engineering Journal*, 15:102672. <https://doi.org/10.1016/j.asej.2023.102672>
- Anbarasu, N.A., Keshav, L., Polichetty Raja, K.C., and Sivakumar, V. (2024). Unraveling the flexural behavior of concrete and compare with innovative FEA investigations. *Matéria (Rio de Janeiro)*, 29(4):e20240656. <https://doi.org/10.1590/1517-7076-rmat-2024-0656>
- Aslam, R., Mobin, M., Zehra, S., and Aslam, J. (2022). A comprehensive review of corrosion inhibitors employed to mitigate stainless steel corrosion in different environments. *Journal of Molecular Liquids*, 364:119992. <https://doi.org/10.1016/j.molliq.2022.119992>
- Ayano, T. and Fujii, T. (2021). Improvement of concrete properties using granulated blast furnace slag sand. *Journal of Advanced Concrete Technology*, 19(2):118-132. <https://doi.org/10.3151/jact.19.118>
- Bodian, M., Keinde, D., Hannawi, K., Fall, M., Darquennes, A., and Agbodjan, P. W. (2024). Evaluation of the inhibitory gel Aloe vera against corrosion of reinforcement concrete in NaCl medium. *Materials Sciences and Applications*, 15(5):101-112. <https://doi.org/10.4236/msa.2024.155008>
- Chithra, N.V., Karuppasamy, R., Manickaraj, K., and Ramakrishnan, T. (2024). Effect of reinforcement addition on mechanical behavior of Al MMC - A critical review. *Journal of Environmental Nanotechnology*, 13(2):65-79. <https://doi.org/10.13074/jent.2024.06.242632>

- Elsa, T., Geethu, A.S., Sajith, and Indira, P.V. (2023). Investigations on Ni-Ti shape-memory alloy fiber-reinforced GGBS mortar in aggressive environment. *Journal of Materials in Civil Engineering*, 35(10). <https://doi.org/10.1061/JMCEE7.MTENG-15355>
- Ghazae, A., Pour-Ali, S., Mahdavi, S., Tavangar, R., and Khalili, M. (2024). Corrosion inhibition of steel rebar in chloride-contaminated concrete pore solution: Ecofriendly glutamic acid inhibitor and its synergy with galvanized coating. *Inorganic Chemistry Communications*, 167:112832. <https://doi.org/10.1016/j.inoche.2023.112832>
- Gurusamy, M., Soundararajan, S., Karuppusamy, M., and Ramasamy, K. (2024). Exploring the mechanical impact of fine powder integration from ironwood sawdust and COCO dust particles in epoxy composites. *Matéria (Rio de Janeiro)*, 29(3). <https://doi.org/10.1590/1517-7076-rmat-2024-0216>
- Hoy, M., Chutichai, T., Horpibulsuk, S., Suddeepong, A., Buritatum, A., Yaowarat, T., and Arulrajah, A. (2024a). Enhancing concrete pavement performance using refuse-derived fuel fly ash as a sustainable cementitious material. *International Journal of Pavement Engineering*, 25(1). <https://doi.org/10.1080/10298436.2024.2431601>
- Hoy, M., Horpibulsuk, S., Chinkulkijniwat, A., Suddeepong, A., Buritatum, A., Yaowarat, T., Choenklang, P., Udomchai, A., and Kantatham, K. (2024b). Innovations in recycled construction materials: Paving the way towards sustainable road infrastructure. *Frontiers in Built Environment*, 10:1449970. <https://doi.org/10.3389/fbuil.2024.1449970>
- Kanwal, M., Adnan, F., Khushnood, R.A., Jalil, A., Khan, H.A., Wattoo, A.G., and Rasheed, S. (2024). Biomimetic self-healing concrete: Journal of Building Engineering, 82:108224. <https://doi.org/10.1016/j.job.2024.108224>
- Kiran, T., Anand, N., Kumar, S.N., Andrushia, D., Singh, S.K., and Arulraj, P. (2021). Influence of nano-cementitious materials on improving the corrosion resistance and microstructure characteristics of concrete. *Journal of Adhesion Science and Technology*, 35(18):1,995-2,022. <https://doi.org/10.1080/01694243.2020.1870083>
- Krishnadas, G., Karuppusamy, R., Selvam, S., and Manickaraj, K. (2024). Evolving sandwich composites through structural modifications with polyurethane foam and glass fiber. *Matéria (Rio de Janeiro)*, 29(4). <https://doi.org/10.1590/1517-7076-rmat-2024-0507>
- Li, J., Wu, T., Zhuang, E., Cao, W., and Chen, Z. (2024). The use of LDHs-NO<sub>3</sub><sup>-</sup> and LDHs-NO<sub>2</sub><sup>-</sup> as corrosion inhibitors in simulated concrete pore solution: An experimental and theoretical study. *Construction and Building Materials*, 411:134779. <https://doi.org/10.1016/j.conbuildmat.2024.134779>
- Liu, Q., Yuan, M., Zhang, J., and Qiang, S. (2024b). Research on the corrosion inhibition effect of Xanthium sibiricum on reinforced steel and the prediction of reinforced concrete performance under a stray current and chloride environment. *Applied Sciences*, 14(16):6986. <https://doi.org/10.3390/app14166986>
- Liu, S., Zhu, M., Ding, X., Ren, Z., Zhao, S., Zhao, M., and Dang, J. (2021). High-durability concrete with supplementary cementitious admixtures used in corrosive environments. *Crystals*, 11(2):196. <https://doi.org/10.3390/cryst11020196>
- Liu, Y. and Shi, J. (2024a). Recent progress and challenges of using smart corrosion inhibitors in reinforced concrete structures. *Construction and Building Materials*, 411:134595. <https://doi.org/10.1016/j.conbuildmat.2024.134595>
- Manickaraj, K., Ramamoorthi, R., Karuppusamy, R., Sakthivel, K. R., and Vijayaprakash, B. (2024). A review of natural biofiber-reinforced polymer matrix composites. In *Evolutionary manufacturing, design and operational practices for resource and environmental sustainability* (pp. 135-141). CRC Press. <https://doi.org/10.1002/9781394198221.ch11>
- Min, S.H., Lee, H.S., and Singh, J.K. (2024). Effects of different inhibitors on the corrosion mitigation of steel rebar immersed in NaCl-contaminated concrete pore solution. *Buildings*, 14(11):3559. <https://doi.org/10.3390/buildings14113559>
- Mohamed, O.A., Al Khattab, R., and Al Hawat, W. (2022). Effect of relative GGBS/fly contents and alkaline solution concentration on compressive strength development of geopolymer mortars subjected to sulfuric acid. *Scientific Reports*, 12(1):5634.
- Owamah, H.I., Ikpeseni, S.C., Dharmaraj, R., Gopikumar, S., Malathy, R., Uma, S., Sada, S.O., and Oyeibisi, S.O. (2021). Influence of diethanolamine on the properties of concrete, corrosion rate of rebar and renewable energy generation. *Arabian Journal for Science and Engineering*, 46:11,487-11,496. <https://doi.org/10.1007/s13369-021-05974-0>
- Parthasaarathi, R., Balasundaram, N., and Arasu, N. (2024). The experimental investigation on coconut shell fibre reinforced concrete (CSFRC) based on different loading condition. *Journal of Advanced Research in Applied Sciences and Engineering Technology*, 35(1):106-120. <https://doi.org/10.37934/ARASET>
- Prusty, J.K. and Pradhan, B. (2020). Effect of GGBS and chloride on compressive strength and corrosion performance of steel in fly ash-GGBS based geopolymer concrete. *Materials Today: Proceedings*, 32(4):850-855. <https://doi.org/10.1016/j.matpr.2020.04.210>
- Purnima, S., Goyal, S., and Luxami, V. (2024). Corrosion inhibition mechanism of aromatic amino acids for steel in alkaline pore solution simulating carbonated concrete environment. *Materials and Corrosion*, 75(1):39-60. <https://doi.org/10.1002/maco.202313949>
- Qasim, I. and Singh, K. (2022). The inhibitive effect of vitamin-C on the corrosive performance of mild steel in ground granulated blast furnace slag-based concrete. In *Advances in construction materials and sustainable environment: Select proceedings of ICCME 2020* (pp. 675-685). Springer. [https://doi.org/10.1007/978-981-16-6557-8\\_55](https://doi.org/10.1007/978-981-16-6557-8_55)
- Ramakrishnan, T., Manickaraj, K., Prithiv, S.P., Aditya, S.L., Rajanarayanan, N., and Gopalsamy, S. (2024). Advancements in aluminum metal matrix composites: Reinforcement, manufacturing, and applications. In *AIP Conference Proceedings*, 3221(1). AIP Publishing. <https://doi.org/10.1063/5.0235881>
- Ramshankar, P., Ganeshan, P., Raja, K., and NagarajaGanesh, B. (2024). Experimental investigation of the structural performance of concrete containing cellulose fibers and the anti-corrosive effect of green corrosion inhibitors. *Civil and Environmental Engineering Reports*, 34(2):22-44. <https://doi.org/10.59440/ceer/187189>
- Shankar, S.S., Natarajan, M., and Arasu, A.N. (2024). Exploring the strength and durability characteristics of high-performance fibre reinforced concrete containing nanosilica. *Journal of the Balkan Tribological Association*, 30(1):45-56.
- Shwetha, K.M., Praveen, B.M., and Devendra, B.K. (2024). A review on corrosion inhibitors: Types, mechanisms, electrochemical analysis, corrosion rate and efficiency of corrosion inhibitors on mild steel in an acidic environment. *Results in Surfaces and Interfaces*, 16:100258. <https://doi.org/10.1016/j.rsufi.2024.100258>

- Taheri, S., Pareja Delgado, G., Agbaje, O.B.A., Giri, P., and Clark, S.M. (2020). Corrosion inhibitory effects of mullite in concrete exposed to sulfuric acid attack. *Corrosion and Materials Degradation*, 1(2):14. <https://doi.org/10.3390/cmd1020014>
- Tan, B., Ren, H., Liu, Y., Li, X., Wang, R., Sun, J., Cao, X., Dai, Q., Guo, L., Liu, H., Al-Sadoon, M.K. (2024). Insight into the anti-corrosion performance of crop waste as a degradable corrosion inhibitor for copper in sulfuric acid medium. *Industrial Crops and Products*, 222(2):119654. <https://doi.org/10.1016/j.indcrop.2024.119654>
- Teklegiorgis, N.S., Pradhan, B., Prusty, J.K., and Das, J.K. (2022). Effect of sodium nitrite as corrosion inhibitor against chloride-induced corrosion of steel rebar in geopolymer concrete containing fly ash and GGBS. *Journal of Materials in Civil Engineering*, 34(4):04022007. [https://doi.org/10.1061/\(ASCE\)MT.1943-5533.0004190](https://doi.org/10.1061/(ASCE)MT.1943-5533.0004190)
- Thangavel, N., Shanmugavel, N.K., Karuppusamy, M., and Thirumalaisamy, R. (2024). Friction and wear behavior of premixed reinforcement hybrid composite materials. *Matéria (Rio de Janeiro)*, 29(4):e20240552. <https://doi.org/10.1590/1517-7076-RMAT-2024-0552>
- Tian, Z., Chen, Z., and Ye, H. (2023). Relationship of electrical resistivity and corrosion rate in alkali-activated mortars with varying alkalinity and nitrite inhibitor. *Construction and Building Materials*, 409:134211. <https://doi.org/10.1016/j.conbuildmat.2023.134211>
- Yang, W., Zhu, P., Liu, H., Wang, X., Ge, W., and Hua, M. (2021a). Resistance to sulfuric acid corrosion of geopolymer concrete based on different binding materials and alkali concentrations. *Materials*, 14(23):7109. <https://doi.org/10.3390/ma14237109>
- Yang, W., Zhu, P., Liu, H., Wang, X., Ge, W., and Hua, M. (2021b). Resistance to sulfuric acid corrosion of geopolymer concrete based on different binding materials and alkali concentrations. *Materials*, 14(23):7109. <https://doi.org/10.3390/ma14237109>