

## Corrosion Resistance of Mild Steel in Simulated Concrete Pore Solution in Presence of Chloride Ions – An Overview

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### Abstract

Concrete is one of the most widely used engineering materials for construction. Its durability is a major problem affecting the service life of the engineering structures. Various technologies such as cathodic protection and the use of corrosion inhibitors are used to improve the durability of reinforced concrete. Various organic and inorganic inhibitors, and also extracts of natural products have been used as corrosion inhibitors. Corrosion resistance of rebars has been evaluated by electrochemical studies such as polarization study and AC impedance spectra. The protective films formed on the metal surface have been analyzed by NMR, FTIR spectra, SEM, AFM and XRD.

**Keywords:** Simulated concrete pore solution, concrete structure, corrosion, mild steel, inhibitors.

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### Introduction

It is generally accepted that concrete is one of the most widely used engineering materials for constructions, and its durability is the major problem affecting the service life of the engineering structures. Corrosion of the steel reinforcement is one of the main reasons causing the premature deterioration of reinforced concrete [1-2], and leading to a significant economic loss [3].

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In order to improve the durability of reinforced concrete, various technologies and methods were applied [4], e.g. patch repairs [5], coatings [6], sealing and membranes for concrete surface [7], special steel bar (stainless steel bar, epoxy coated steel reinforcement, et al.) [8-9], electrochemical protection (including cathodic protection, electrochemical realkalization and electrochemical chloride extraction (ECE) [10-14] and corrosion inhibitors [15-18]). Due to its excellent inhibition performance, low cost and labor saving, corrosion inhibitor is considered as one of the most effective, long-term corrosion protection methods for steel reinforcement [19]. Traditional corrosion inhibitors are divided into inorganic (mainly nitrites) and organic (alkanolamine and their inorganic, organic acid salt mixtures) substances. Although nitrites were widely reported as efficient corrosion inhibitors [20-21], due to their carcinogenicity and biological toxicity, they are forbidden in many European countries, i.e., Germany and Switzerland [22]. Alcoholamine [23-24] is a widely used organic corrosion inhibitor; however, there are still conflicting opinions about its effectiveness and different mechanisms were also reported: Kern and Landolt [25] suggested that organic inhibitors adsorbed on the steel surface, forming a barrier layer to prevent steel dissolution. Violetta et al. [26] revealed that these inhibitors can both halt the anodic and cathodic reactions, reducing the corrosion rate of reinforcing steel. Heiyantuduwa [27] proved that the alcoholamine presented a corrosion inhibition effect only for the chloride-induced corrosion of reinforcement. In recent years, the electrochemical migrating corrosion inhibitors were also investigated [28-30], which can be applied in the electrochemical salt extraction process. However, the available electrochemical migrating corrosion inhibitors are limited, and the related corrosion inhibition mechanism is still not clear. Therefore, it is very important to further investigate the exact mechanisms and develop a tailored type of high efficient organic corrosion inhibitor.

The corrosion inhibition performance of steel reinforcement in a simulated concrete pore solution containing 3.5 wt.% NaCl in the presence of a tailored cationic type of imidazoline quaternary ammonium salt corrosion inhibitor has been characterized by electrochemical measurements and surface analysis. The results indicate that the IQS can significantly improve the polarization resistance and pitting potential and reduce the corrosion current density of reinforcement. The main inhibition mechanism is most likely due to the adsorption of the corrosion inhibitor on the steel surface, leading to a reduced corrosion current density of the steel reinforcement [31].

The inhibition properties of aspartic and lactic acid salts are compared with nitrite ions with regard to their effect on critical chloride concentration. The tests were carried out on carbon steel specimens in simulated pore solutions with initial pH in the range of 12.6 to 13.8. The critical chloride concentrations were estimated through multiple specimen potentiostatic tests at potentials in the usual range for passive rebar in noncarbonated concrete structures. During tests, chloride ions were progressively added until all specimens showed localized attack, obtaining cumulative distribution curves reporting the fraction of corroded specimens as a function of chloride concentration. The presence of the organic inhibitors on the passivity film was detected by IR spectra. The results

confirm that 0.1 M aspartate exhibits an inhibiting effect comparable with nitrite ions of the same concentration. Calcium lactate does not increase critical chloride concentration; however it appears to promote the formation of a massive scale, reducing the corrosion propagation [32].

The corrosion inhibition effect and mechanism of D-sodium gluconate for reinforcing steel in the simulated concrete pore solution containing  $\text{Cl}^-$  were studied by electrochemical techniques, including corrosion potential, potentiodynamic polarization, and electrochemical impedance spectroscopy measurements. The results indicate that 0.01 M D-sodium gluconate showed a good corrosion inhibition effect on reinforcing steel in the simulated concrete pore solution containing 0.1 M NaCl because it strongly hindered the anodic reactions. The inhibition mechanism could be explained on the basis of the competitive adsorption between gluconate anions and chloride ions on the reinforcing steel surface. And D-sodium gluconate could eventually form a compact adsorptive film by strong chelation and effectively inhibit the initiation of reinforcing steel corrosion [33].

The inhibition of corrosion of reinforcing steel in simulated concrete pore solution (SCPS) has been studied using mass loss, gasometric measurements, potentiodynamic polarization and impedance studies using Mezlocillin (MZN) as a green inhibitor. The studies clearly revealed that MZN acted as a cathodic inhibitor. Diffused reflectance spectra confirmed the formation of an adsorbed film of the inhibitor on reinforcing steel in SCPS [34].

Novel azomethine-based polyester is synthesized and the structure of the products is confirmed by  $^1\text{H}$  NMR, FT-IR, and XRD. The as synthesized polymer is employed as inhibitor against the corrosion of rebar in artificially simulated concrete pore solution with chloride contamination (blank) by means of Tafel polarization and electrochemical impedance measurements. For the first time in literature, azomethine polyester is employed as inhibitor for rebar corrosion. Polarization studies exhibited the maximum inhibition efficiency of 98% at 1000 ppm concentration. Electrochemical studies revealed the mixed-type nature of the inhibitors. The adsorption behavior of as synthesized polymeric inhibitor obeys the Langmuir adsorption model. Mechanisms reveal the entire molecule is expected to adsorb on to the metal surface with near flat orientation and they tend to arrange themselves parallel to each other covering the entire metal surface, hence, preventing the ingress of aggressive species to the metal surface. Further, SEM and atomic force microscope have proven the presence of an adsorptive layer on the rebar under the simulated atmosphere [35]. Rajendran et al. have extensively studied the corrosion resistance of metals in simulated concrete pore solution in presence of inhibitors [36-39].

## **Conclusions**

1. Various methods are employed to prevent corrosion of rebar such as cathodic protection, electrochemical and chloride interaction, addition of inhibitors in simulated concrete pore solution in presence of chloride ions.

2. Corrosion resistance is measured by electrochemical studies such as polarization studies and AC impedance spectra.
3. The protective film is analyzed by NMR spectra, FTIR spectra, SEM, AFM and XRD.

## **References**

1. Tuutti K. Corrosion of steel in concrete. Stockholm, Sweden; 1982.
2. Vaysburd AM, Emmons PH. How to make today's repairs durable for tomorrow- corrosion protection in concrete repair. *Constr Build Mater.* 2000;14:189-197.
3. Hu J, Koleva DA, De Wit JHW, et al. Corrosion performance of carbon steel in simulated pore solution in the presence of micelles. *J Electrochem Soc.* 2011;158:76-87.
4. Emmons PH, Vaysburd AM. Factor affecting the durability of concrete repairs: the contractor's viewpoint. *Constr Build Mater.* 1994;8:5-16.
5. Pandey JL, Banerjee MK. Concrete corrosion and reference practices – an overview. *Anti-Corros Method M.* 1998;45:5-15.
6. Seneviratne AMG, Sergi G, Page CL. Performance characteristics of surface coatings applied to concrete for control of reinforcement corrosion. *Constr Build Mater.* 2000;14:55-59.
7. Srewil EY, Schorn H. Cracks of concrete and repair works & case study. Dresden. Module G-4 Dresden seminar "Rehabilitation Engineering"; 2006.
8. Assaada JJ, Issa CA. Bond strength of epoxy-coated bars in underwater concrete. *Constr Build Mater.* 2012;30:667-674.
9. Yeomans SR. Performance of black, galvanized, and epoxy-coated reinforcing steels in chloride-contaminated concrete. *Corrosion.* 1994;50:72-81.
10. Cañón A, Garcés P, Climent MA, et al. Feasibility of electrochemical chloride extraction from structural reinforced concrete using a sprayed conductive graphite powder-cement paste as anode. *Corros Sci.* 2013;77:128-134.
11. Liu Y, Shi X. Electrochemical chloride extraction and electrochemical injection of corrosion inhibitor in concrete: state of the knowledge. *Corros Rev.* 2009;27:53-82.
- [12. Sánchez M, Alonso MC. Electrochemical chloride removal in reinforced concrete structures: improvement of effectiveness by simultaneous migration of calcium nitrite. *Constr Build Mater.* 2011;25:873-878.
13. Orellan JC, Escadeillas G, Arliguie G. Electrochemical chloride extraction: efficiency and side effects. *Cem Concr Res.* 2004;34:227-234.
14. Fajardo G, Escadeillas G, Arliguie G. Electrochemical chloride extraction (ECE) from steel-reinforced concrete specimens contaminated by "artificial" sea-water. *Corros Sci.* 2006;48:110-125.
15. Söyleva TA, Richardson MG. Corrosion inhibitors for steel in concrete: state-of-the-art report. *Constr Build Mater.* 2008;22:609-622.

16. Ann KY, Jung HS, Kim HS, et al. Effect of calcium nitrite-based corrosion inhibitor in preventing corrosion of embedded steel in concrete. *Cem Concr Res.* 2006;36:530-535.
17. Hu J, Koleva DA, van Breugel K. Corrosion performance of reinforced mortar in the presence of polymeric nano-aggregates: electrochemical behavior, surface analysis, and properties of the steel/cementpaste interface. *J Mater Sci.* 2012;47:4981-4995.
18. Tritthart J. Transport of a surface-applied corrosion inhibitor in cement paste and concrete. *Cem Concr Res.* 2003;33:829-834.
19. Metha PK. Concrete durability – fifty years progress. In: *Proceedings of 2<sup>nd</sup> inter. Conf. on concrete durability.* ACI Sp 126-1; 1991. p 1-31.
20. Ngala VT, Page CL, Page MM. Corrosion inhibitor systems for remedial treatment of reinforced concrete. Part 1: Calcium nitrite. *Corros Sci.* 2002;44: 2073-2087.
21. Okeniyi JO, Omotosho OA, Ajayi OO, et al. Effect of potassium-chromate and sodium-nitrite on concrete steel-rebar degradation in sulphate and saline media. *Constr Build Mater.* 2014;50:448-456.
22. Bryan NS, Alexander DD, Coughlin JR, et al. Ingested nitrate and nitrite and stomach cancer risk: an updated review. *Food Chem Toxicol.* 2012;50:3646-3665.
23. Phanasgaonkar A, Cherry B, Forsyth M. Corrosion inhibition properties of organic amines in a simulated concrete environment: mechanism and time dependency of inhibition. In: *International conference on understanding corrosion mechanisms in concrete.* Cambridge; 1996.
24. Fedrizzi L, Azzolini F, Bonora PL. The use of migrating corrosion inhibitors to repair motorways' concrete structures contaminated by chlorides. *Cem Concr Res.* 2005;35:551-561.
25. Kern P, Landolt D. Adsorption of organic corrosion inhibitors on iron in the active and passive state. A replacement reaction between inhibitor and water studied with the rotating quartz crystal microbalance. *Electrochim Acta.* 2001;47:589.
26. Violetta F, Munteanu F, Kinney FD. Corrosion inhibition properties of a complex inhibitor – mechanism of inhibition. *Proceedings of the CANMET 2000.* American Concrete Institute; 2000.
27. Heiyantuduwa R, Alexander MG, Mackechnie JR. Performance of a penetrating corrosion inhibitor in concrete affected by carbonation-induced corrosion. *J Mater Civil Eng.* 2006;18:842-850.
28. Kubo J, Tanaka Y, Page CL, et al. Application of electrochemical organic corrosion inhibitor injection to a carbonated reinforced concrete railway viaduct. *Constr Build Mater.* 2013;39:2-8.
29. Sawada S, Kubo J, Page CL, et al. Electrochemical injection of organic corrosion inhibitors into carbonated cementitious materials: Part 1. Effects on pore solution chemistry. *Corros Sci.* 2007;49:1186-1204.
30. Pan T, Nguyen TA, Shi X. Assessment of electrical injection of corrosion inhibitor for corrosion protection of reinforced concrete. *Transport Res Rec: J Transport Res Board.* 2008;2044:51-60.

31. Fei F-L, Hu J, Wei J-X, et al. Corrosion performance of steel reinforcement in simulated concrete pore solutions in the presence of imidazoline quaternary ammonium salt corrosion inhibitor. *Construction Building Mater.* 2014;70:43-53.
32. Cabrini M, Fontana F, Lorenzi S, et al. Effect of Organic Inhibitors on Chloride Corrosion of Steel Rebars in Alkaline Pore Solution. *J Chem.* 2015;521507.
33. Li J-H, Zhao B, Hu J, et al. Corrosion inhibition effect of D-sodium gluconate on reinforcing steel in chloride-contaminated simulated concrete pore solution. *J Electrochem Sci.* 2015;10:956-968.
34. Harish EL, Karthikeyan S, Sekar SK. Corrosion inhibition of reinforcing steel in simulated concrete pore solution-An ecofriendly approach. *Int J Chem Tech Research.* 2015;7:20033-2006.
35. Bhuvaneshwari B, Selvaraj A, Iyer NR, et al. Electrochemical investigations on the performance of newly synthesized azomethine polyester on rebar corrosion. *Mater Corros.* 2015;66:387-395.
36. Pandiarajan M, Parbahakan P, Rajendran S. Corrosion Resistance of Mild Steel in Simulated Concrete Pore Solution. *Chem Sci Trans.* 2013;2:605-613.
37. Pandiarajan M, Rajendran S, Bama JS, et al. Influence of Potassium Permanganate-Zn<sup>2+</sup> System on Inhibition of Corrosion of Mild Steel in Simulated Concrete Pore Solution. *Chem Sci Rev Letters.* 2014;3:415-424.
38. Pandiarajan M, Rajendran S, Rathish RJ. Corrosion Inhibition by Potassium Chromate-Zn<sup>2+</sup> System for Mild Steel in Simulated Concrete Pore Solution. *Res J Chem Sci.* 2014;4:49-55.
39. Pandiarajan M., Rajendran S., Rathish RJ, et al. Influence of Sodium Meta Vanadate on the Corrosion Resistance of Mild Steel Immersed in Simulated Concrete Pore Solution Prepared in Well Water. *J Chem Biol Phys Sci.* 2014;4:549-557.