Electrochemical investigation of the influence of a durable exterior emulsion coating on the corrosion resistance of mild steel in simulated concrete pore solution

N. Anitha,[1] V. Velkannan,[2] K. Kavipriya,[3] K. Bhuvaneswari,[1] M. Lavanya,[1] Gurmeet Singh,[4] Abdulhameed Al-Hashem,[5] S. Rajendran[1,6]* and C. Lacnjevac[7]

[1]*Department of Chemistry, Corrosion Research Centre, St. Antony's College of Arts and Sciences for Women, Dindigul 62405, India*
[2]*Department of Chemistry, Thiagarajar College of Engineering, Thiruparankundram, Madurai Tamil Nadu, 625015, India*
[3]*Department of Chemistry, PSNA College of Engineering and Technology (Autonomous), Dindigul, India*
[4]*Vice Chancellor, Pondicherry University, Puducherry, 605014, India*
[5]*Petroleum Research Centre, Kuwait Institute for Scientific Research, Ahmadi, Kuwait*
[6]*Adjunct Professor, Centre for Nanoscience and Technology, Pondicherry University, Puducherry, 605014, India*
[7]*Faculty of Agriculture, University of Belgrade, Nemanjina 6, Beograd 11080, Serbia*
**E-mail:* susairajendran@gmail.com

Abstract

In concrete technology, rebars are used to strengthen the structure of concrete. The corrosion resistance of mild steel rebars in simulated concrete pore solution has be evaluated by electrochemical studies such as polarization study and AC impedance spectroscopy. The mild steel rebars have been coated with Nippon paint, SUMO XTRA, Durable exterior emulsion. Corrosion parameters such as linear polarization resistance (*LPR*), corrosion current density, corrosion potential, Tafel slopes, charge transfer resistance (R_t), double layer capacitance (C_{dl}), phase angle and impedance value have been derived from electrochemical studies. In the presence of emulsion coating, it was observed that, *LPR* increases, corrosion current density decreases, R_t increases, C_{dl} decreases, phase angle increases and impedance value increases. When Durable exterior emulsion coated mild steel was immersed in simulated concrete pore solution, the *LPR* value increases from 283 $Ohm \cdot cm^2$ to 1.37×10^5 $Ohm \cdot cm^2$; the corrosion current density decreases from 1.50×10^{-4} A/cm^2 to 3.323×10^{-7} A/cm^2; charge transfer resistance increases from 50.25 $Ohm \cdot cm^2$ to 64351 $Ohm \cdot cm^2$; double layer capacitance decreases from 1.01×10^{-7} F/cm^2 to 7.93×10^{-11} F/cm^2; the impedance increases from 1.81 [log(Z/Ohm)] to 4.82 [log(Z/Ohm)] and the phase angle increases from 36.27° to 51.54°. These observations confirm that the emulsion coating is stable in the presence of simulated concrete pore solution. This has controlled the corrosion of the rebars in the concrete. There will be augment in the life time of the mild steel rebars. The corrosion inhibition efficiency calculated from electrochemical studies is greater than 99%.

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Introduction

In concrete technology, rebars are used to strengthen the structure of concrete. To control the corrosion of rebars, several corrosion inhibitors have been used along with concrete admixtures. Effects of stray current and silicate ions on electrochemical behavior of a high-strength prestressing steel in simulated concrete pore solutions have been investigated by Ming *et al.*. Silicate ions were proven to be an eco-friendly corrosion inhibitor for steels subjected to coupling effects of stray current interference and chloride attack [1]. Sajid *et al.* have developed soy-protein and corn-derived polyol based coatings for corrosion mitigation in reinforced concrete. The proposed soy protein coating materials can be used for in-situ repairs of damaged rebar coatings in aggressive chloride environments and as a standalone coating in moderately corrosive environments [2]. Song *et al.* have used ultrasonic wave to trigger microcapsule inhibitor against chloride-induced corrosion of carbon steel in simulated concrete pore solution. Electrochemical results indicated that the ultrasound trigger measure could exert most of the corrosion inhibition effect of the core materials in microcapsules [3]. Kim *et al.* have reported electrochemical evaluation of epoxy-coated-rebar containing pH-responsive nanocapsules in simulated carbonated concrete pore solution. The corrosion product analysis denoted that the inhibiting action has delayed the further oxidation of the exposed surface [4]. Sreelekshmi and Kumar have studied the effect of reduced graphene oxide nanoparticles as anticorrosion material on mild steel substrate. It has been reported that epoxy coating containing 1.0 wt.% reduced graphene oxide showed better corrosion resistant behavior in concrete pore solution medium containing 0.5M NaCl solution [5]. The effect of carboxylate compounds on controlling nitrite's environmental side effects for carbon steel corrosion protection in the simulated concrete pore solution has been reported by Johari *et al.* [6]. In order to study the adsorption behavior of inhibitors and surface topography, XPS, FE-SEM and AFM analyses were utilized. XPS results showed that nitrite at low concentrations improved the adsorption of organic inhibitors and thus increased efficiency [6]. Tiwari *et al.* have evaluated the inhibition efficiency of generic compounds with additional heteroatom in simulated concrete pore solution and migration potential in concrete. The performance of two generic compounds, namely 2-aminopyridine (AP) and 4-aminobenzoic acid (ABA) at varying concentrations in carbonated pore solution contaminated by chlorides was investigated by using electrochemical measurement technique (potentiodynamic polarization curves) and surface analysis technique (optical microscope, SEM, EDX, XRD and FTIR). The migration ability of the two compounds in concrete was also investigated by using thin layer chromatography (TLC) and ultraviolet–visible spectroscopy (UV-Vis) [7]. Singh *et al.* have investigated the effect of chloride ions concentrations to breakdown the passive film on rebar surface exposed to L-arginine containing pore solution [8]. Ma *et al.* have successfully used composite organic compound as corrosion inhibitor for reinforced steel in simulated concrete pore solution or mortar specimen. It was observed that the organic amino-alcohol inhibitor can effectively delay the time for corrosion initiation of the steel bar [9]. ASTM G180-13, Standard Test Method for Corrosion Inhibiting Admixtures for Steel in Concrete by Polarization Resistance in Cementitious Slurries (Superseded), testing was used to determine the effectiveness of corrosion inhibiting admixtures by Huang *et al.* Based on the experimental data and analysis, a suggestion has been provided for specimen preparation to address the observed inconsistency in specimen preparation for ASTM G180-13 testing [10].

The rebars made of mild steel used in concrete technology may be coated with Nippon paint, SUMO XTRA, Durable exterior emulsion. This will control the corrosion of the rebars in the concrete. The life time of the mild steel rebars will increase. The present work is undertaken to find an answer to this question. Electrochemical studies such as polarization study and AC impedance spectroscopy have been employed for this purpose.

Experimental

Electrochemical studies

The corrosion resistance of mild steel in simulated concrete pore solution (SCPS-saturated solution of calcium hydroxide) has been measured by electrochemical studies such as Polarization study and AC impedance spectroscopy [11–25].

Polarization study

A CHI electrochemical work station with impedance model 660A was used for this purpose. A three-electrode cell assembly electrode was used in the present study (Figure 1). Mild steel was used as working electrode; saturated calomel electrode was used as reference electrode and Platinum electrode was used as counter electrode. From the Polarization study corrosion parameters such as corrosion potential (E_{corr}), corrosion current density (I_{corr}), Tafel slope values and Linear Polarization resistance (*LPR*) were calculated.

AC impedance spectroscopy

AC impedance spectral studies were carried out on a CHI – Electrochemical workstation with impedance, Model 660A. A three – electrode cell assembly was used. The working electrode was mild steel. A saturated calomel electrode (SCE) was the reference electrode and platinum was the counter electrode.

The real part (Z') and imaginary part ($-Z''$) of the cell impedance were measured in Ohms at various frequencies. Values of the charge transfer resistance (R_t) and the double layer capacitance (C_{dl}), impedance value and phase angle were calculated from Nyquist plots and Bode plots. The equivalent circuit diagram used in the study is shown in Figure 1.

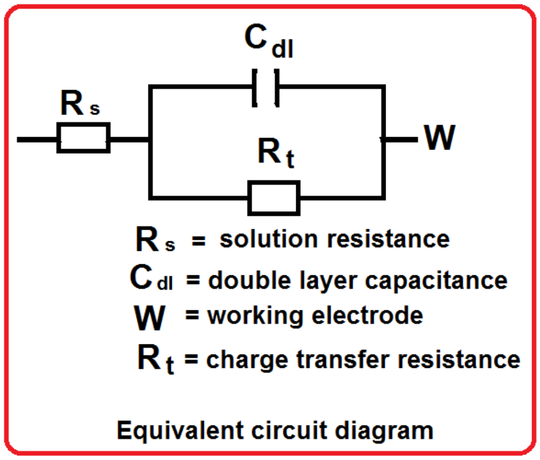

Figure 1. Equivalent circuit diagram.

The impedance values [log(Z/Ohm)] were measured in the range from 1 to 10^5 Hz.

Composition of mild steel

Mild steel with composition: C 0.101%, Si 0.055% Mn 1.629%, P 0.0087%, S 0.0028, Fe 97.74 and the rest being metals such as Cr, Ni, Cu *etc.*, was used in the present work.

Paint coating

Nippon paint SUMO XTRA is a specially formulated water based exterior emulsion with color-lock technology which ensures that the colors look bright and clean. Its unique water resistant property keeps your exterior walls protected and there is no blistering or peeling of the paint film [26].

In concrete technology, rebars are used to strengthen the concrete structures. The rebars made of mild steel used in concrete technology may be coated with Nippon paint, SUMO XTRA, Durable exterior emulsion. This will control the corrosion of mild steel immersed in simulated concrete pore solution, which consists of a saturated solution of calcium hydroxide. The solution was not deaerated. The experiment was carried out at pH=12.5.

Results and Discussion

Influence of an emulsion, namely exterior emulsion, on the corrosion resistance of mild steel in SCPS has been investigated by electrochemical methods such as polarization study and AC impedance spectroscopy. The results are presented and discussed in this section.

Analysis of results of polarization study

The polarization curves of mild steel in SCPS, in the absence and presence of exterior emulsion coating are shown in Figures 2 and 3. The corrosion parameters are given in Table 1.

According to the principles of polarization study, "when corrosion resistance increases, *LPR* increases and corrosion current density decreases".

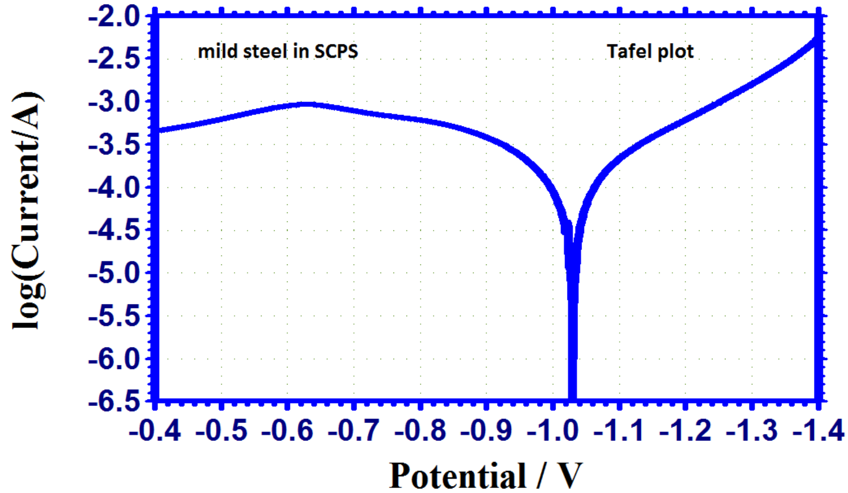

Figure 2. Polarization curve of mild steel in SCPS.

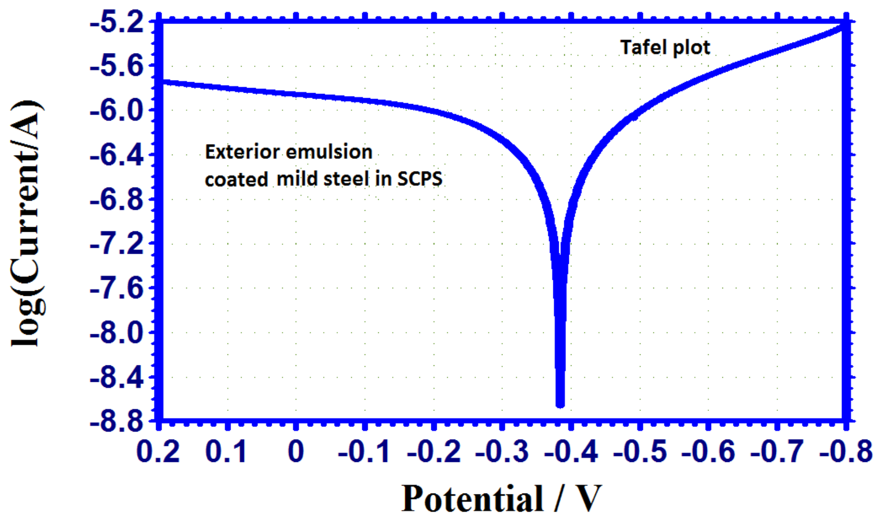

Figure 3. Polarization curve of exterior emulsion coated mild steel in SCPS.

Table 1. Corrosion parameters of mild steel immersed in SCPS obtained by polarization study.

System	E_{corr} mV/SCE	b_c mV/decade	b_a mV/decade	*LPR* Ohm·cm²	I_{corr} A/cm²
Mild steel	–1030	190	200	283	1.50×10^{-4}
Exterior emulsion coated mild steel	–384	187	238	1.37×10^{5}	3.32×10^{-7}

Based on the principles of polarization study, it is inferred from Table 1 that in the presence of *exterior emulsion* coating corrosion resistance of the rebar made of mild steel in

SCPS increases. This is due to the fact that in the presence of *exterior emulsion* coating, there in increase in *LPR* value and decrease in corrosion current density. The inhibition efficiency is 99.79%. It is also inferred that the paint coating controls the anodic reaction of metal dissolution predominantly. This is revealed by the fact in the presence of *exterior emulsion* coating corrosion potential shifts from –1030 mV *vs* SCE to –384 mV *vs* SCE (anodic shift).

Implication

The rebars made of mild steel used in concrete technology may be coated with Nippon paint, SUMO XTRA, Durable exterior emulsion. This will control the corrosion of the rebars in the concrete. There will be an increase in the life time of the mild steel rebars.

Analysis of AC impedance spectroscopy

AC impedance spectra (also known as EIS) have been used to detect the formation of the film on the metal surface.

According to the principles of AC impedance spectroscopy (also known as EIS), "when a protective film is formed, charge transfer resistance (R_t) increases, double layer capacitance (C_{dl}) decreases, phase angle increases and impedance value increases".

The AC impedance spectra of mild steel in SCPS in the absence and presence of Durable exterior emulsion coating are shown in Figures 4–9. The Nyquist plots are shown in Figures 4 and 7. The Bode plots are shown in Figures 5 and 8. The interactive 3D plots-log frequency are shown in Figures 6 and 9. The corrosion parameters are given in Table 2.

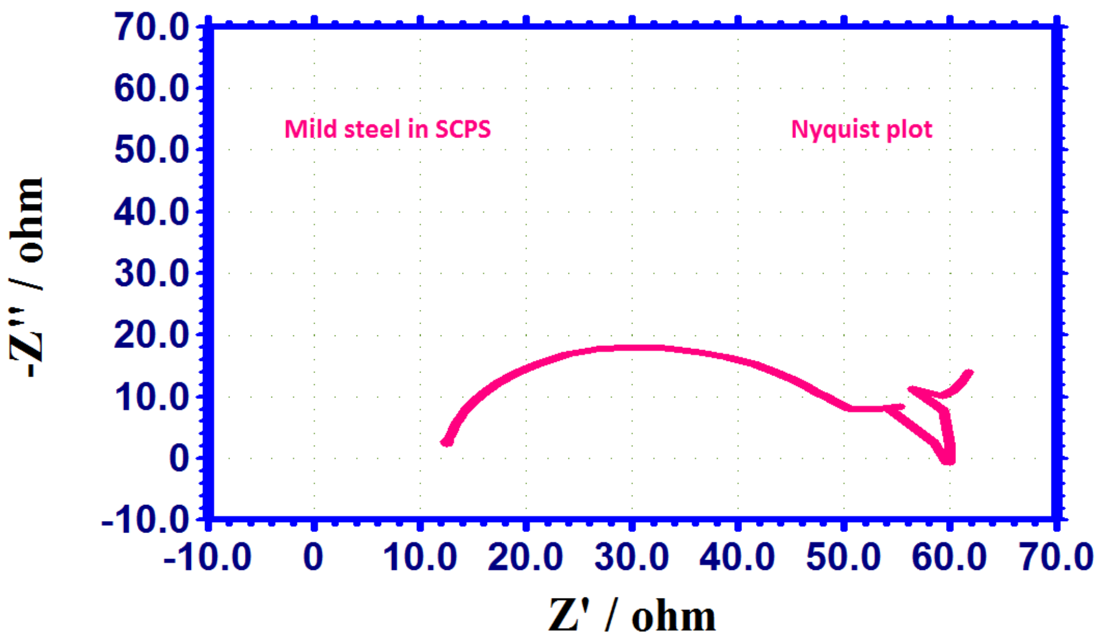

Figure 4. Nyquist plot of mild steel in SCPS.

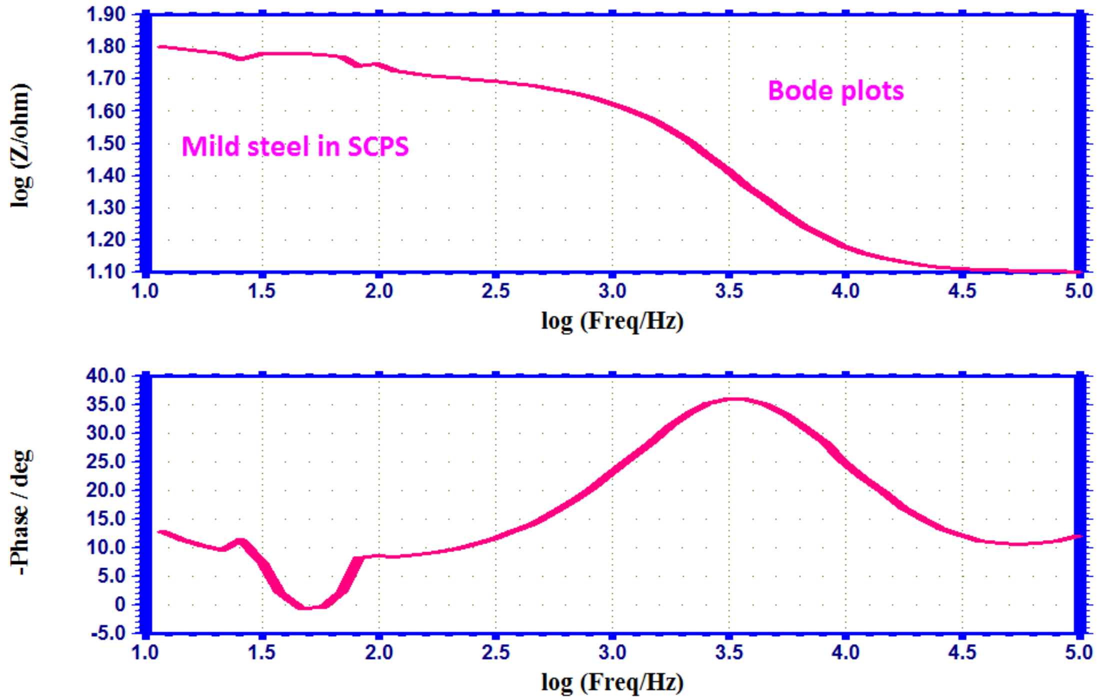

Figure 5. Bode plots of mild steel in SCPS.

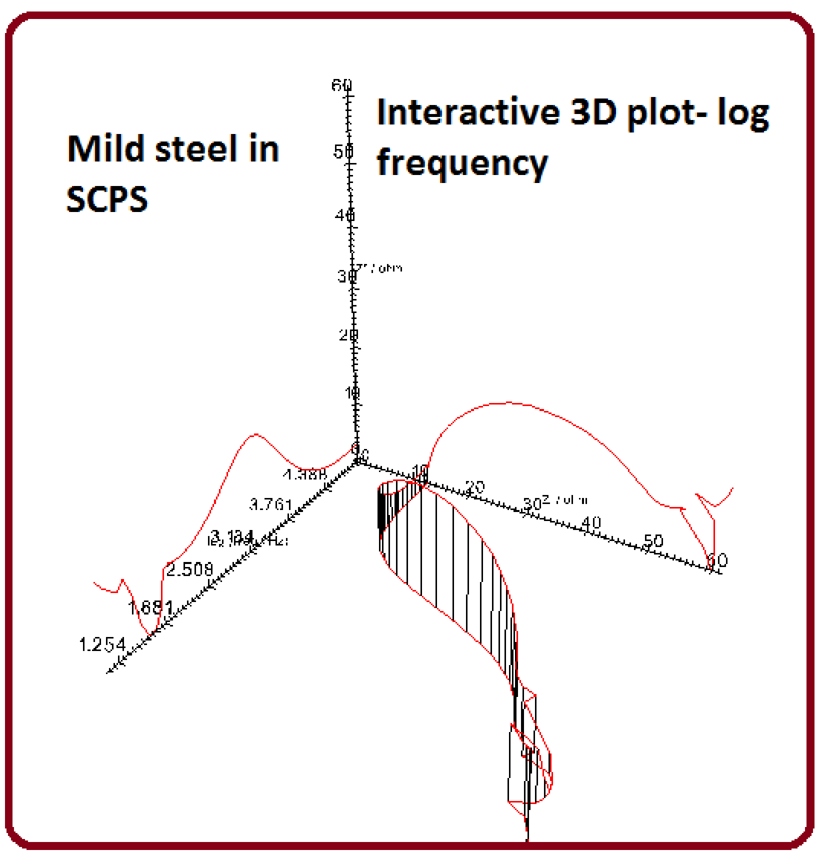

Figure 6. Interactive 3D plot of mild steel in SCPS.

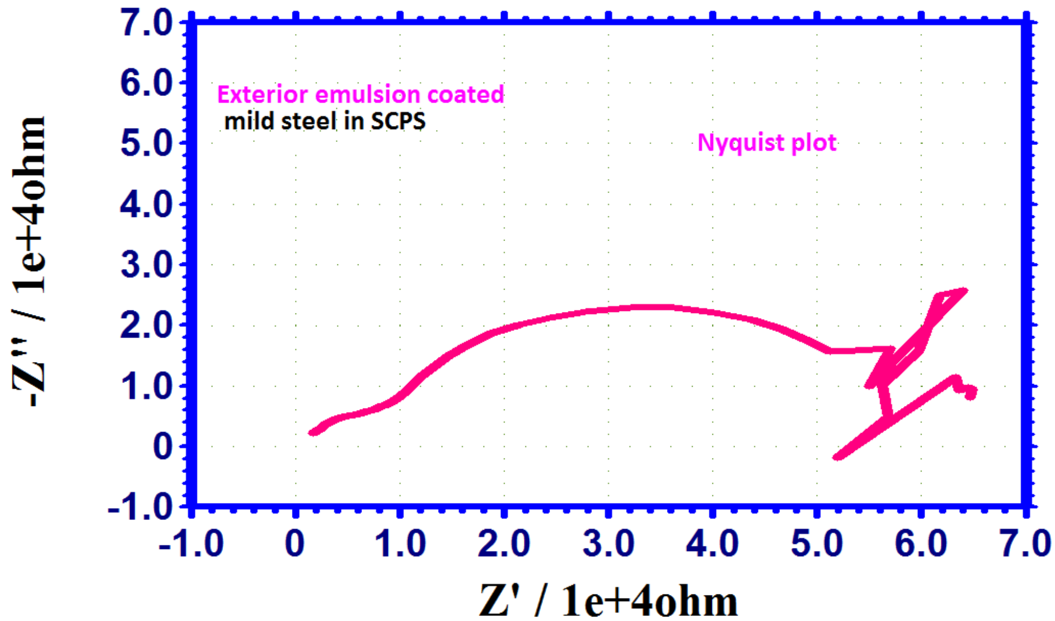

Figure 7. Nyquist plot of emulsion mild steel in SCPS.

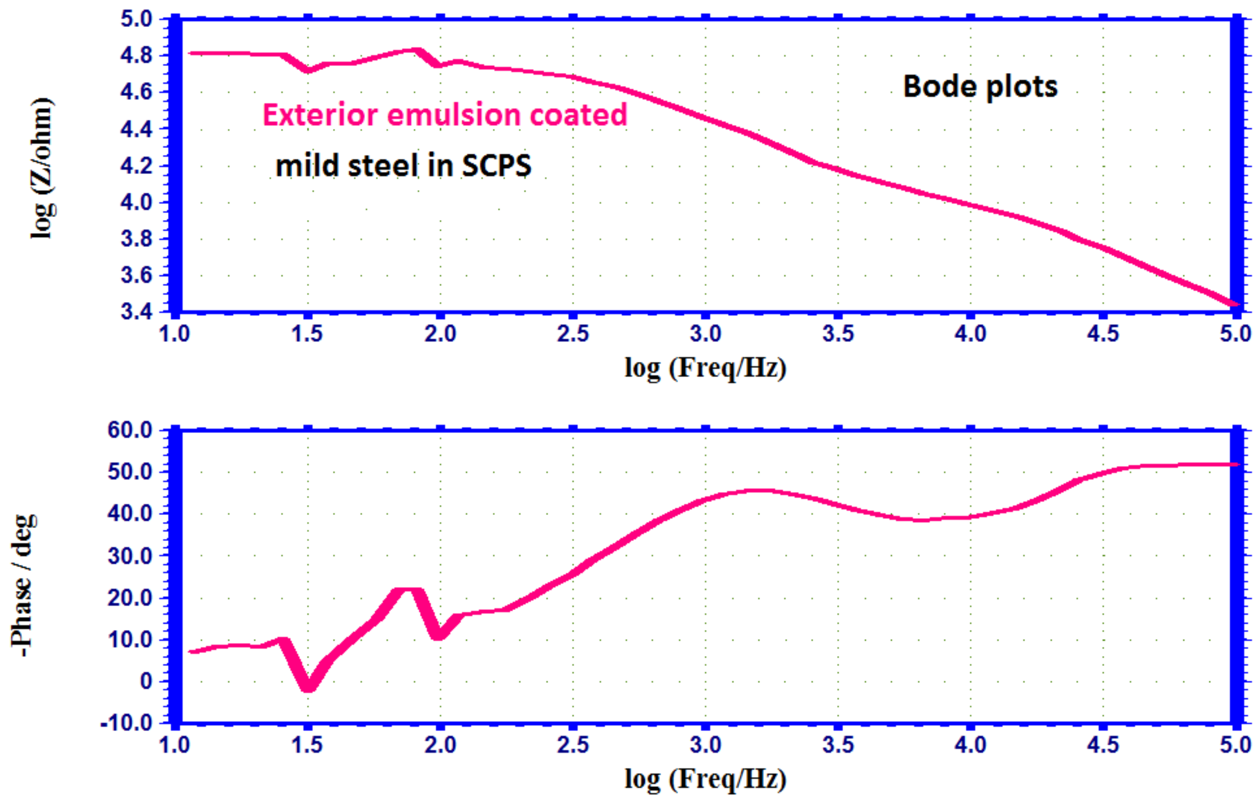

Figure 8. Bode plots of emulsion mild steel in SCPS.

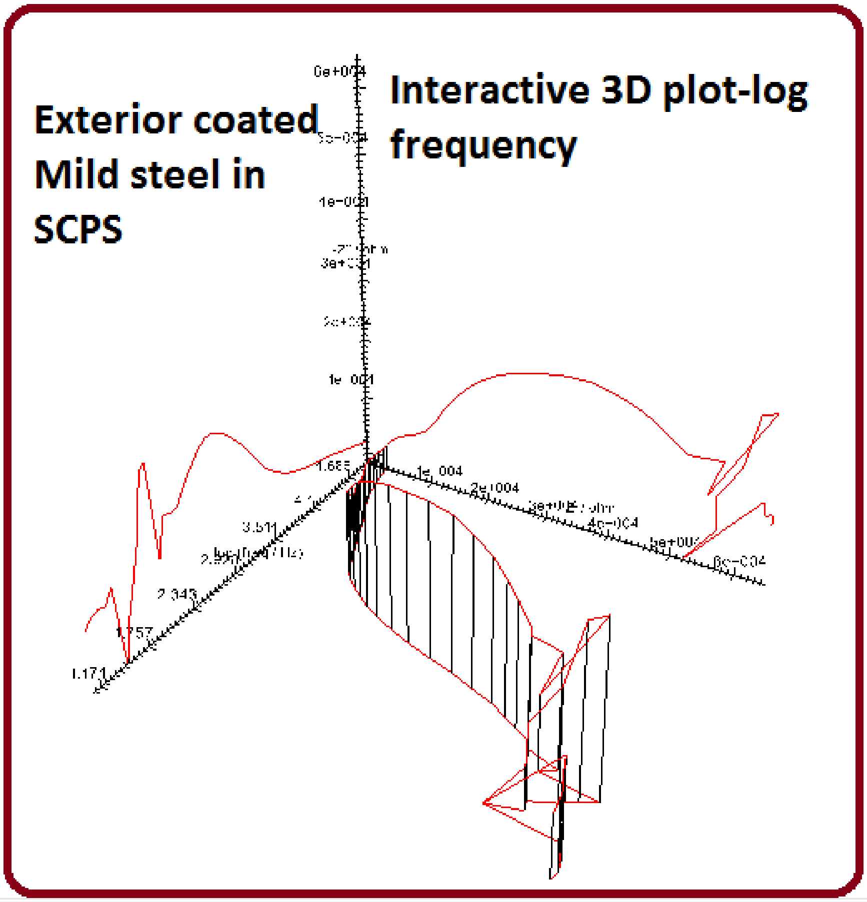

Figure 9. Interactive 3D plot of emulsion coated mild steel in SCPS.

Table 2. Corrosion Parameters of mild steel immersed in SCPS obtained by AC impedance spectroscopy.

System	R_t Ohm·cm^2	C_{dl} F/cm^2	Impedance Log(Z/Ohm)	Phase angle, deg
Mild steel	50.25	1.01×10^{-7}	1.81	36.27
Exterior emulsion coated mild steel	6.44×10^{4}	7.93×10^{-11}	4.82	51.54

Based on the principles of the AC impedance spectroscopy, it is inferred from Table 2 that in the presence of durable *exterior emulsion* coating corrosion resistance of mild steel in SCPS increases. This is due to the fact that in the presence of durable exterior emulsion coating, charge transfer resistance (R_t) increases, double layer capacitance (C_{dl}) decreases, phase angle increases and impedance value increases. The corrosion inhibition efficiency is 99.92%.

Implication

The rebars made of mild steel used in concrete technology may be coated with Nippon paint, SUMO XTRA, Durable exterior emulsion. This will control the corrosion of the rebars in the concrete, thus enhancing the life time of the mild steel rebars.

Conclusions

- In concrete technology, rebars are used to strengthen the structure of concrete.
- The corrosion resistance of mild steel rebars in simulated concrete pore solution has been evaluated by electrochemical studies such as polarization study and AC impedance spectroscopy.
- The mild steel rebars have been coated with Nippon paint, SUMO XTRA, Durable exterior emulsion.
- Corrosion parameters such as linear polarization resistance (*LPR*), corrosion current density, corrosion potential, Tafel slopes, charge transfer resistance (R_t), double layer capacitance (C_{dl}), phase angle and impedance value have been derived from electrochemical studies.
- In presence of emulsion coating, it was observed that, *LPR* increases, corrosion current density decreases, charge transfer resistance (R_t) increases, double layer capacitance (C_{dl}) decreases, phase angle increases and impedance value increases.
- These observations confirm that the emulsion coating is stable in the presence of simulated concrete pore solution.
- This has controlled the corrosion of the rebars in the concrete.
- There will be an augment in the life time of the mild steel rebars.
- The corrosion inhibition efficiency calculated from electrochemical studies is greater than 99%.

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