

Corrosion resistance of mild steel in simulated concrete pore solution before and after a paint coating

S.C. Joycee,¹ T. Vidya,¹ S.A. Rattihka,¹ B.S. Prabha,¹ R. Dorothy,²
T. Sasilatha² and S. Rajendran^{1,3} *

¹Corrosion Research Centre, Department of Chemistry, St. Antony's College of Arts and Sciences for Women Thamaraijadi, Dindigul – 624005 (Affiliated to Mother Teresa Women's University, Kodaikanal), Tamil Nadu, India

²Department of EEE, AMET University, Kanathur, East Coast Road, Chennai, India

³Adjunct Professor, Pondicherry University, Puducherry, India

*E-mail: susairajendran@gmail.com

Abstract

In reinforced concrete, mild steel can be used because, mild steel is relatively less expensive. Mild steel in concrete structures may undergo corrosion. To prevent corrosion of mild steel several inhibitors are used along with concrete admixtures. In this type of research, saturated calcium hydroxide solution, which is considered as simulated concrete pore solution (SCPS) is used. Many corrosion inhibitors have been used in this field along with organic coatings. In the present study Asian guard red paint (AGRP) coated mild steel has been used in concrete. The corrosion resistance has been measured by electrochemical studies such as polarization study and AC impedance spectra. In presence of paint coating the corrosion resistance of mild steel immersed in simulated concrete pore solution (SCPS) increases. This is confirmed by the facts that in presence of paint coating the corrosion resistance of mild steel immersed in simulated concrete pore solution (SCPS), the linear polarization resistance value increases, corrosion current value decreases, charge transfer resistance increases, double layer capacitance decreases, impedance increases, and phase angle increases. The protective layer functions as anodic inhibitor and controls the anodic reaction predominantly. It implies that the paint coated mild steel can be used in concrete technology.

Keywords: *simulated concrete pore solution, mild steel, paint coating, corrosion inhibition, electrochemical studies.*

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Introduction

Concrete is a composite material made out of fine and coarse aggregate reinforced along with a liquid (concrete glue) that solidifies (fixes) after some time. The concrete responds with the water and different fixings to frame a hard grid that ties the materials together into a tough stone-like material that has numerous employments. Reinforced concrete (RC), is a composite material wherein concrete's moderately low rigidity and malleability are made up for by the incorporation of support having higher tensile strength or ductility. The

reinforcement is ordinarily, however not really, steel bars (rebar) and is generally inserted inactively in the solid before the solid sets. Instead of steel mild steel can also be used, because mild steel is relatively less expensive.

Mild steel is a type of carbon steel with a low amount of carbon – it is actually also known as “low carbon steel”. Although ranges vary depending on the source, the amount of carbon typically found in mild steel is 0.05% to 0.25% by weight, whereas higher carbon steels are typically described as having a carbon.

Steel is less malleable and harder than mild steel. Mild steel is less brittle than steel. Steel is more resistant to corrosion. Mild steel can be further strengthened through the addition of carbon.

Mild steel is alloyed using carbon whereas stainless steel has chromium as its alloying element. The two different alloys produce very different results in corrosion resistance, malleability and ease of fabrication and cost. Mild steel (carbon steel) is preferred for reasons of weldability.

Mild steel contains carbon as the main alloy, whereas stainless steel contains a healthy dose of chromium. While these are both strong metals in their own right, stainless steel is about 200 times more resistant to corrosion than mild steel, thanks to the chromium. It will be interesting to study the corrosion resistance of mild steel in simulated concrete pore solution in the absence and presence of a paint coating.

Mild steel in concrete structures may undergo corrosion. Generally, corrosion of steel in concrete is induced by either carbonation or by chlorides. Carbonation means that carbon dioxide in air reacts with calcium within the concrete. This means that the pH of the concrete is decreasing and the steel start to corrode. To prevent corrosion several inhibitors are used along with concrete admixtures. In this type of research, saturated calcium hydroxide solution, which is considered as simulated concrete pore solution (SCPS) is used. Many corrosion inhibitors have been used in this field apart from organic coatings including painting.

The painting of metal substrates with protective paint systems is called corrosion protection painting. The purpose of corrosion protection painting is to protect the metal substrate against atmospheric corrosivity, *i.e.* rust, and to give the surface the designed appearance and texture.

Paints can inhibit corrosion by modifying the anodic reaction; for this to occur the pigment must be either metallic, or basic, or soluble. In general, paint films protect by virtue of their high electrolytic resistance; they readily acquire a charge, consequently they are relatively impermeable to ions.

Coatings can slow the rate of diffusion of water and oxygen from the environment to the metal surface. This slows the corrosion process. The paint film can slow the rate of diffusion of corrosion products from the metal surface through the paint film. This also slows the corrosion process.

Barrier coating is one of the easiest and cheapest ways to prevent corrosion.

Organic coating constituents, coating composition, surface preparation, additives and fillers, and exposure testing have been reported. Resins used in the paint industry such as vinyl resin, acrylics, alkyd, modified alkyds, chlorinated rubber, urethane, polyester, and actual service life evaluation have been explained by Branko N. Popov [1].

Most metallic alloys are susceptible to corrosion in their service environments. One of the most practical and cost-effective ways to slow or stop corrosion is by application of a protective coating or paint. Coatings and paints can be applied to large surface areas and are protective, even though they are relatively thin [2].

Paints are most common means of corrosion control and protection of metals from damages. A protective film is created on the metal surface by the paint to prevent cathodic and anodic reactions responsible for corrosion. Different types of pigments, temperature variation, concentration of electrolyte, thickness of film, and types of solvents are used to determine the resistance of the polymer films formed on the metal surface and thus it defines the performance of the paint [3].

The use of a conducting polymer coating with a superhydrophobic effect as an effective anticorrosion coating has been discussed. The use of conducting polymers as anticorrosion coatings, including the protection mechanism has been reported [4].

It has been reported that organic coatings are a complex mixture of polymers, fluid carriers, pigments, corrosion inhibitors, and additives, and represent the oldest and most widely used method for delaying the onset of corrosion [5].

More efforts have been put forward by many investigators to study the mechanisms of corrosion under coatings in different environments, and consequently predict failure modes of metals due to corrosion damage [6]. Deen *et al.* [7] investigated the corrosion protection evaluation of mild steel painted surface using electrochemical impedance spectroscopy (EIS). In the study, electrochemical behavior of painted surface was estimated by EIS parameters that contained paint film resistance, paint film capacitance and double layer capacitance. The results show that the deterioration of paint film protectiveness was due to the penetration of the electrolyte through the film which agrees with those of Durowaye *et al.* [8]. Similarly, the corrosion protection of mild steel by paint containing polyanilinehydrochloride (PANI-HCl) was investigated by Samuel *et al.* [9]. Humidity cabinet, salt spray and underwater exposure studies were adopted. The results revealed that paint containing lower PANI-HCl, protected mild steel better than that containing higher PANI-HCl Talo *et al.* [10] investigated Polyaniline epoxy blend coatings on mild steel in neutral, acidic and alkaline solutions using electrochemical methods such and potentiodynamic polarization method. The results confirmed that epoxy blend coatings containing Polyaniline was more effective in acidic solution than in neutral solution.

The present work is undertaken to study the corrosion resistance of mild steel in simulated concrete pore solution (SCPS), before paint coating and after paint coating. The paint used is Asian guard red paint (AGRP). Electrochemical studies such as polarization study and AC impedance spectra have been used in the present study, to evaluate the corrosion resistance of mild steel coated with paint and also the uncoated mild steel.

Experimental

Preparation of simulated concrete pore solution

Generally, simulated concrete pore solution (SCPS) consists mainly of saturated $\text{Ca}(\text{OH})_2$, KOH, NaOH with pH 13.5. In the present study, saturated solution of calcium hydroxide alone is used as simulated concrete pore solution (SCPS) (pH 13.5).

Electrochemical studies

The corrosion resistance of mild steel has been measured by electrochemical methods such as Polarisation study and AC impedance spectra.

Polarisation 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. Mild steel was used as a working electrode; saturated calomel electrode was used as a reference electrode and platinum electrode was used as a counter electrode. The scan rate (V/s) was 0.01. From the polarisation study corrosion parameters such as corrosion potential (E_{corr}) corrosion current (I_{corr}) and Tafel slope values (anodic= b_a and cathodic= b_c) and Linear polarisation resistance (LPR) were calculated.

AC impedance spectra

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.

Results and Discussion

Electrochemical studies

In concrete technology rebars are used to increase the strength of concrete. mild steel can be used as rebar. To protect the rebars from corrosion, corrosion inhibitors are used along with concrete. The corrosion resistance of mild steel in SCPS in the absence and presence of inhibitors can be studied. Instead of inhibitors, a protective coating of paints may be given. The paint coated mild steel can be used in concrete. To evaluate the corrosion resistance of mild steel coated with paint, the corrosion resistance can be measured electrochemical studies such as polarization study and AC impedance spectra [11–20]. In the present study, Asian guard red paint (AGRP) has been employed as protective coating.

Analysis of polarisation curves

Polarisation study has been used to detect the formation of protective film on the metal surface. When a protective film is formed on the metal surface, the linear polarisation resistance (LPR) increases and the corrosion current (I_{corr}) decreases.

The polarisation curves of mild steel immersed in various test solutions are shown in Figures 1 and 2. The corrosion parameters namely, corrosion potential (E_{corr}), Tafel slopes (b_c =cathodic; b_a =anodic) linear polarisation resistance (LPR) and the corrosion current (I_{corr}) values are given in Table 1.

Table 1. Corrosion parameters of mild steel immersed in SCPS in the absence and presence of protective coating (Asian guard red paint).

System	E_{corr} mV vs. SCE	b_c mV/decade	b_a mV/decade	LPR Ohm·cm ²	I_{corr} A/cm ²
SCPS	-923	182	226	89	$5.097 \cdot 10^{-4}$
SCPS+Asian guard red paint (AGRP)	-622	164	284	$1649 \cdot 10^2$	$2.743 \cdot 10^{-7}$

When mild steel is immersed in simulated concrete pore (SCPS) solution, the corrosion potential is -923 mV vs SCE. The LPR value is 89 Ohm·cm². The corrosion current value is $5.097 \cdot 10^{-4}$ A/cm².

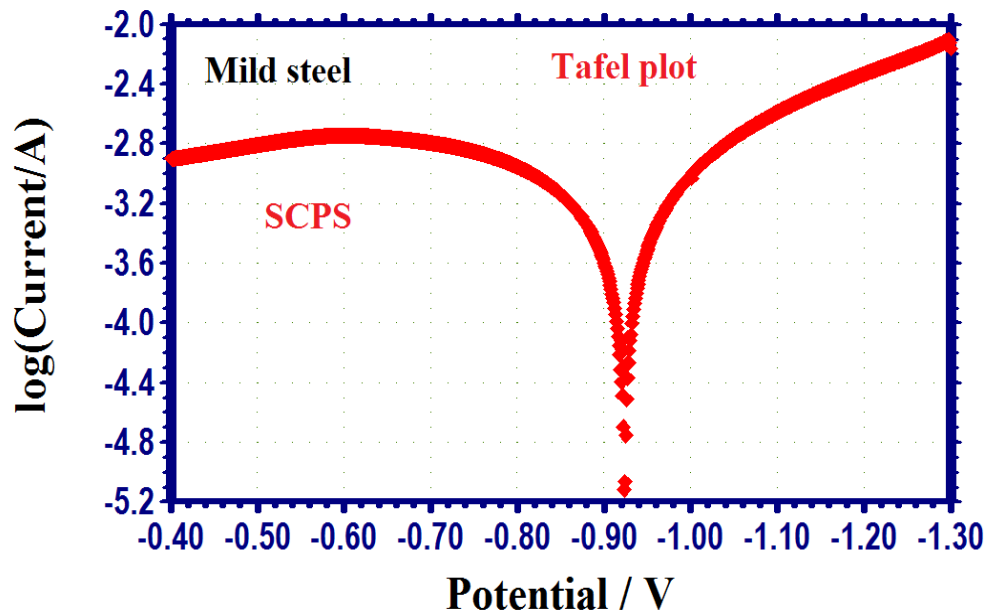


Figure 1. Polarisation curve of mild steel immersed in SCPS.

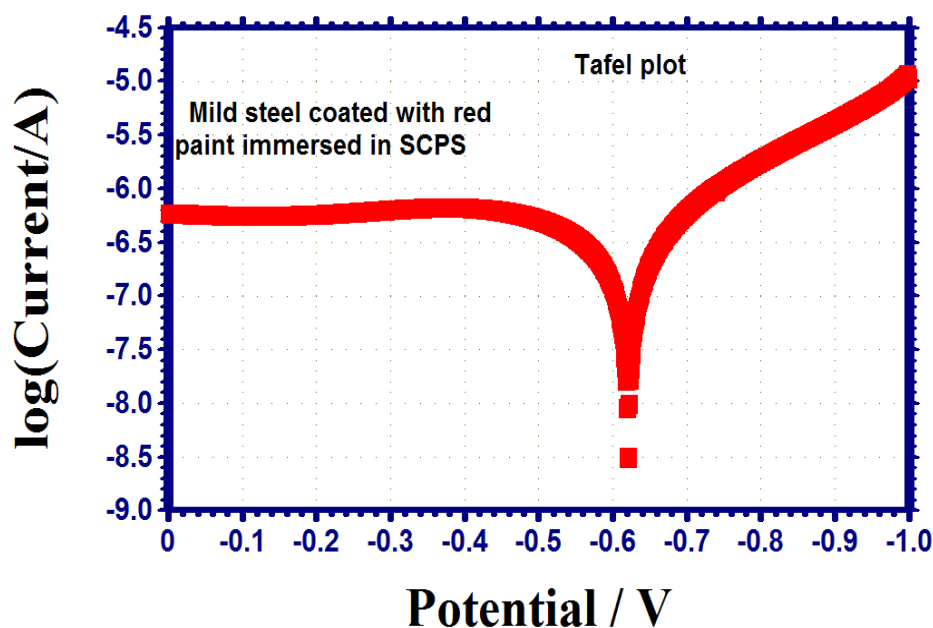


Figure 2. Polarisation curve of red paint coated mild steel immersed in SCPS.

Influence of Asian guard red paint (AGRP) on the corrosion resistance of mild steel immersed in SCPS

Coating of Asian Guard Red Paint (AGRP) shifts the corrosion potential to -0.622 V vs SCE. The corrosion potential is shifted to anodic side. This indicates that the anodic reaction is controlled predominantly. The LPR value increases from 89 to $1649 \cdot 10^2$ $\text{Ohm} \cdot \text{cm}^2$ (Figure 2), and the corrosion current decreases from $5.097 \cdot 10^{-4}$ to $2.743 \cdot 10^{-7}$ A/cm^2 . This tremendous decrease in corrosion current value suggests that a protective film is formed on the metal surface and probably the protective film consists of Fe^{2+} complex formed between Fe^{2+} and the ingredients of the Asian guard red paint (AGRP) apart from CaCO_3 and CaO . Further the decrease in corrosion current is due to the decrease of the area exposed to the solution, because the electrode is coated with the paint.

Implication

When a mild steel rebar coated with Asian guard red paint (AGRP) is immersed SCPS, the corrosion resistance of the rebar increases. This is due to the fact, the coating of the film prevents the corrosion of mild steel SCPS. Hence, it is recommended that the mild steel rebars used in concrete technology may be coated with the Asian guard red paint (AGRP).

Analysis of AC Impedance spectra

AC impedance spectra have been used to detect the formation of the film on the metal surface. If the protective film is formed, the charges transfer resistance (R_t) increases and double layer capacitance (C_{dl}) value decreases. The impedance value increases and phase angle increases.

The AC Impedance spectra of mild steel immersed in various solutions are shown in Figures 3 and 5 (Nyquist) and Figures 4 and 6 (Bode plots). The AC impedance parameters, namely charge transfer resistance (R_t) and double layer capacitance (C_{dl}) are given in Table 2. When mild steel is immersed in simulated concrete pore (SCPS) solution, the R_t value is $90.13 \text{ Ohm}\cdot\text{cm}^2$ and C_{dl} value is $5.65 \cdot 10^{-8} \text{ F/cm}^2$. The impedance value is 2.251. The phase angle value is 32 degree.

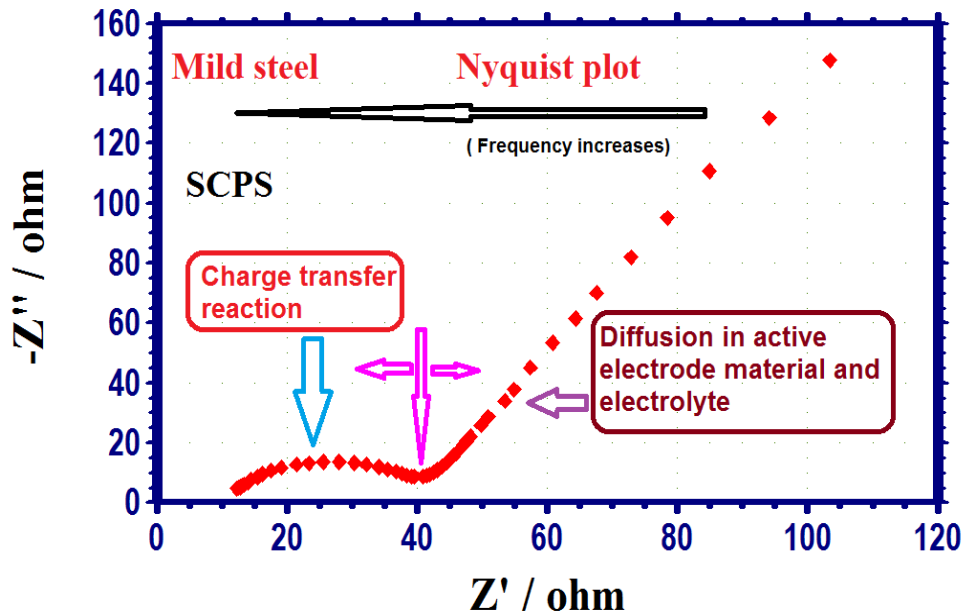


Figure 3. Nyquist plot of mild steel in SCPS.

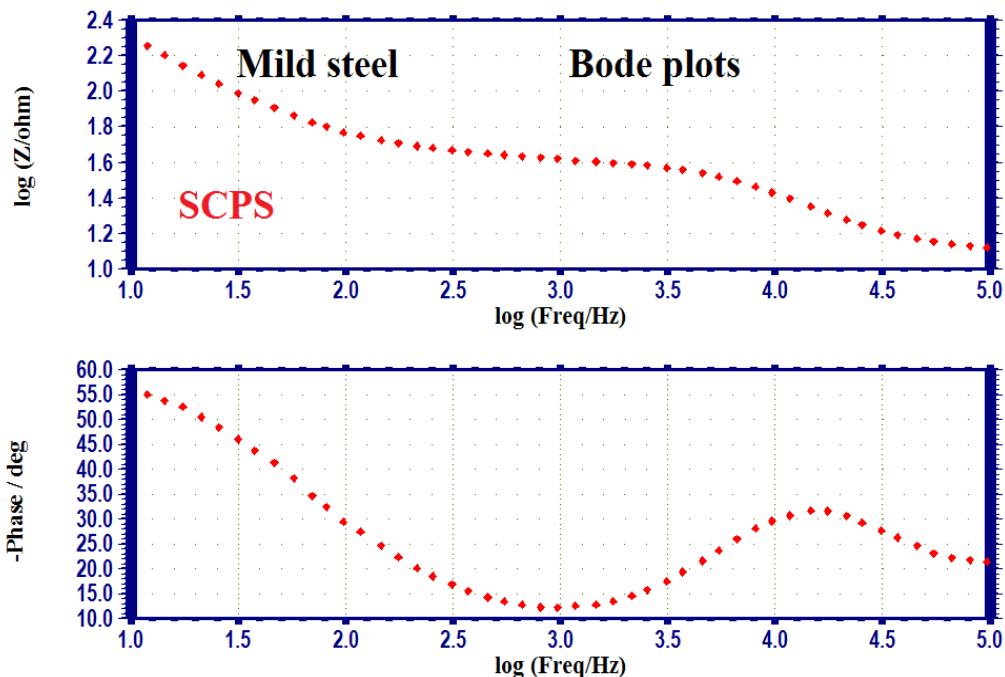


Figure 4. Bode plots of mild steel in SCPS.

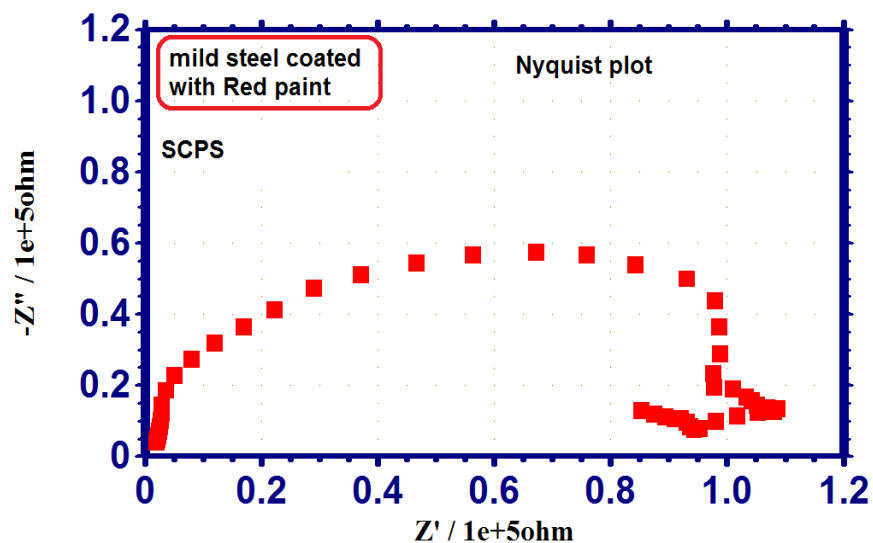


Figure 5. Nyquist plot of paint coated mild steel in SCPS.

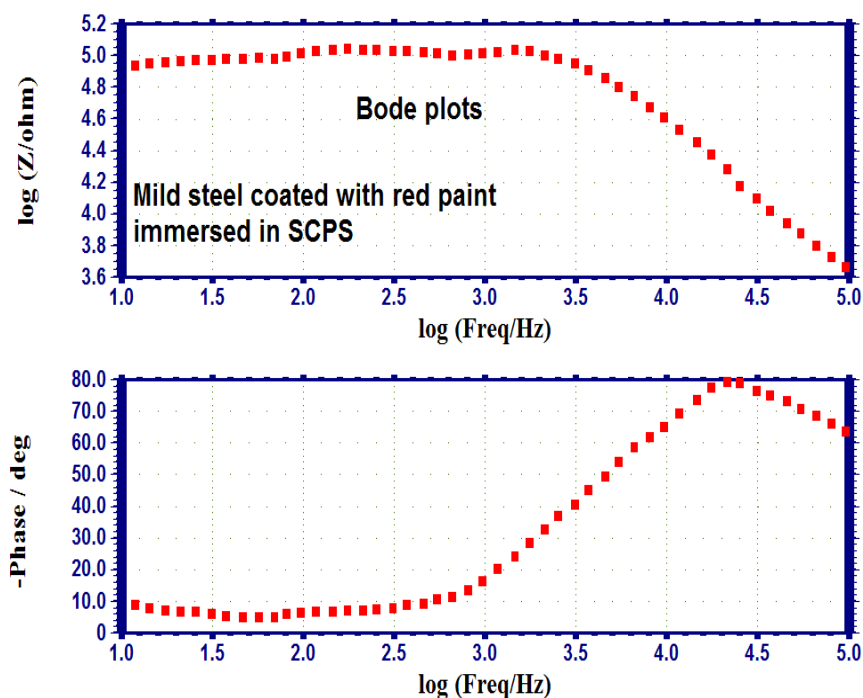


Figure 6. Bode plots of paint coated mild steel in SCPS.

When the paint coated electrode is immersed in SCPS, the R_t value increases from 90.13 to $1.058 \cdot 10^5 \text{ Ohm} \cdot \text{cm}^2$ and C_{dl} value decreases from $5.65 \cdot 10^{-8}$ to $4.81 \cdot 10^{-11} \text{ F/cm}^2$. The impedance value increases from 2.251 to 4.939. The phase angle increases 32 to 79 degrees. These values indicate that the coated film is very strong and it is not broken by the ions present in SCPS medium.

Table 2. AC Impedance parameters of mild steel immersed in various solutions obtained from AC impedance spectra.

System	R_t Ohm·cm ²	C_{dl} F/cm ²	Impedance, (log Z/Ohm)	Phase angle, degrees
SCPS	90.13	$5.65 \cdot 10^{-8}$	2.251	32
SCPS + Asian guard red paint (AGRP)	$1.058 \cdot 10^5$	$4.81 \cdot 10^{-11}$	4.939	79

Implication

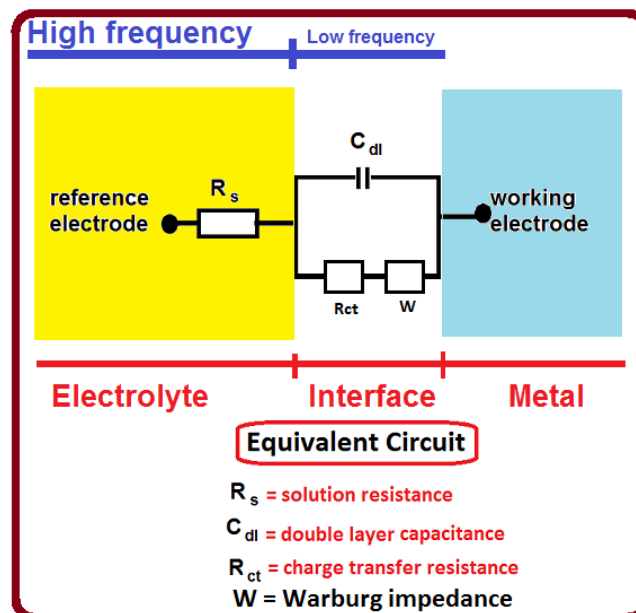
When a mild steel rebar coated with Asian guard red paint (AGRP) is immersed SCPS, the corrosion resistance of the rebar increases. This is due to the fact; the coating of the film prevents the corrosion of mild steel SCPS. Hence, it is recommended that the mild steel rebars used in concrete technology may be coated with the Asian guard red paint (AGRP).

Equivalent circuit diagrams

In the present study the AC impedance spectra of mild steel immersed in SCPS before and after paint coating were recorded. The equivalent circuit diagrams are assigned based on their Nyquist plots.

The equivalent circuit for mild steel immersed in SCPS

The shape of the Nyquist plot indicates that this system consists of two process namely, charge transfer process and diffusion controlled process. The equivalent circuit for this system is shown in Figure 7.

**Figure 7.** Equivalent circuit for kinetic and diffusion processes.

Equivalent circuit for paint coated mild steel immersed in SCPS

The equivalent circuit for paint coated mild steel immersed in SCPS is shown in Figure 8. This is in accordance with the shape of the corresponding Nyquist plot, wherein two time constants are noticed. The one in the high frequency region is obvious. The one in the low frequency region is less obvious. This type of Nyquist plot is characteristic of film formation and film breaking.

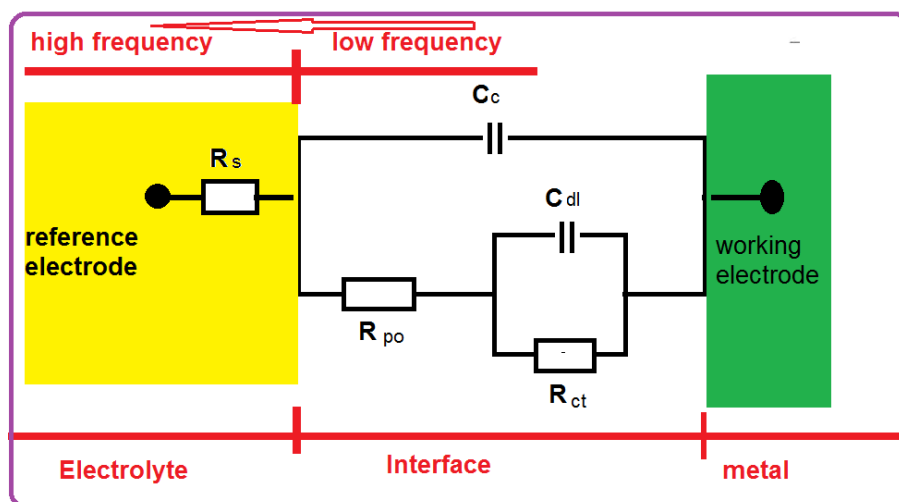


Figure 8. Equivalent circuit diagram for failed coating (Film formation and film breaking).

Summary of the main results are given in Figure 9 and Table 3.

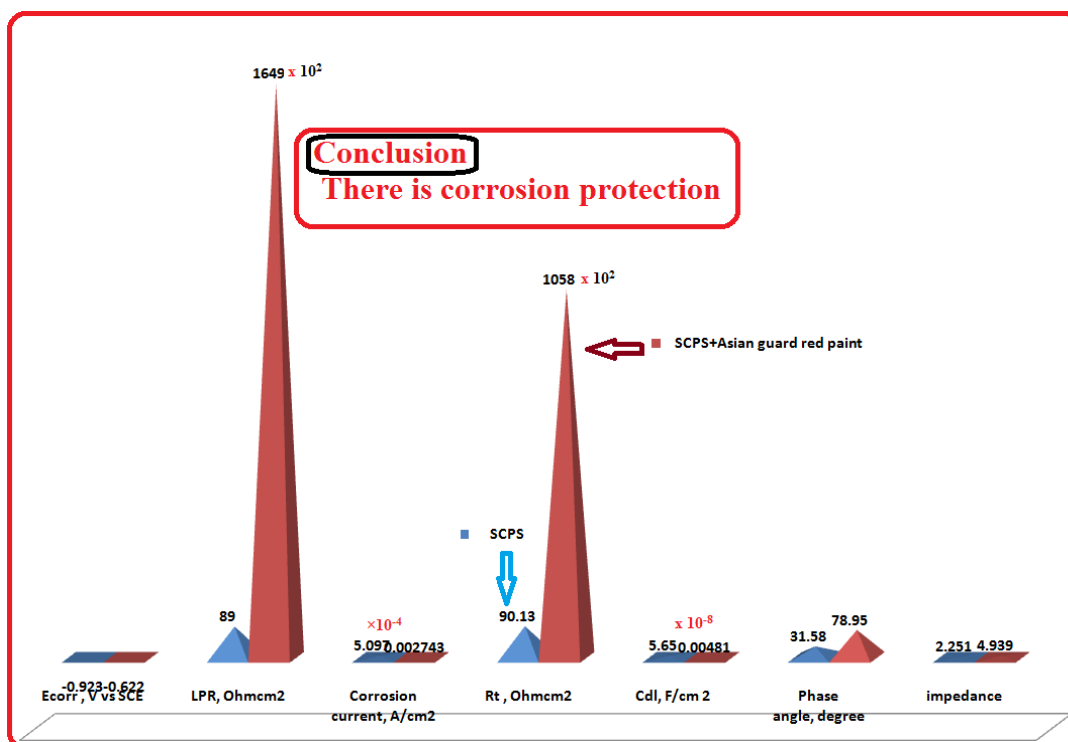


Figure 9. Summary of the main results.

Table 3. Summary of the main results.

Parameters	SCPS	SCPS + Asian guard red paint	Inference
E_{corr} , V vs. SCE	-0.923	-0.622	anodic
LPR , $\text{Ohm} \cdot \text{cm}^2$	89	1649	increases
Corrosion current, A/cm^2	$5.097 \cdot 10^{-4}$	$0.002743 \cdot 10^{-4}$	decreases
R_t , $\text{Ohm} \cdot \text{cm}^2$	90.13	$1058 \cdot 10^2$	increases
C_{dl} , F/cm^2	$5.65 \cdot 10^{-8}$	$0.00481 \cdot 10^{-8}$	decreases
Phase angle, degree	32	79	increases
impedance	2.251	4.939	increases

Conclusions

In reinforced cement concrete (RCC), mild steel can be used because, mild steel is relatively less expensive. Mild steel in concrete structures may undergo corrosion. To prevent corrosion of mild steel several inhibitors are used along with concrete admixtures. In this type of research, saturated calcium hydroxide solution, which is considered as simulated concrete pore solution (SCPS) is used. Many corrosion inhibitors have been used in this field along with organic coatings.

- In the present study Asian guard red paint (AGRP) coated mild steel has been used in concrete. Instead of concrete, simulated concrete pore solution (SCPS) has been used.
- The corrosion resistance has been measured by electrochemical studies such as polarization study and AC impedance spectra.
- In presence of paint coating the corrosion resistance of mild steel immersed in simulated concrete pore solution (SCPS) increases. This is confirmed by the facts that in presence of paint coating the linear polarization resistance value increases, corrosion current value decreases, charge transfer resistance increases, double layer capacitance decreases, impedance increases, and phase angle increases.
- The protective layer functions as anodic inhibitor and controls the anodic reaction predominantly.

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