



CORROSION RESISTANCE OF MILD STEEL IN SIMULATED CONCRETE PORE SOLUTION IN PRESENCE OF SIMULATED URINE, TARTARIC ACID AND LACTIC ACID

P. Nithya Devi ^[a], S Rajendran ^{[b]*}, J.Sathiyabam ^[a], M. Pandiarajan ^[a], R. Joseph Rathish ^[c] and S. Santhana Prabha ^[c]

Keywords: Concrete corrosion, mild steel, urine corrosion, lactic acid, tartaric acid

Corrosion resistance of mild steel in simulated concrete pore solution (SCPS) in presence of simulated urine (SU), tartaric acid and lactic acid has been evaluated by electrochemical studies such as polarization study and AC impedance spectra. These studies lead to the conclusion that, the corrosion resistance of mild steel in various test solutions is as follows. Lactic acid+ SCPS+ urine > tartaric acid+ SCPS+ urine > SCPS > SCPS+ urine > urine. This leads to the conclusion that urination on the concrete structures such as bridges and building should be discouraged. Otherwise, the structure may collapse one day without prior information. However, the inclusion of tartaric acid or better lactic acid during the preparation of concrete admixtures strengthens the structures and should be encouraged

Corresponding author

Fax: +91 451 2424114

E-Mail: susairajendran@gmail.com.

[a] PG and Research Department of Chemistry, G.T.N. Arts College, Dindigul- 624005, India.
E-mail: nithichem7@gmail.com.

[b] Corrosion Research Centre, Department of Chemistry, RVS School of Engineering and Technology, Dindigul-624005, India. E-mail: susairajendran@gmail.com.

[c] PSNACollege of Engineering and Technology, Dindigul, India. Email:rathishjosoph@gmail.com.

to SCC was very effective in terms of increasing the post-cracking flexural resistance and the energy absorption, and did not affect significantly the self-compacting requisites and the durability indicators of SCC.³ Similarly, it has been observed that fibres, when provided in sufficient amount to guarantee an adequate toughness to Fibre Reinforced Concrete (FRC), are significantly effective as shear reinforcement.⁴ Ji et al.⁵ have investigated the effect of degree of pore saturation (PS) in concrete on corrosion current. They showed that the maximum of corrosion current appeared in the water-saturated concrete and it decreased in dried concrete. This due to FeOOH in corrosion layer acting as a depolarizer instead of oxygen.

Introduction

Reinforced concrete (RC) is a composite material. The reinforcement is usually steel reinforcing bars (rebar) and is usually embedded passively in the concrete before the concrete sets. Concrete is one of the most widely used engineering materials for constructions. 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 and leading to a significant economic loss. In order to improve the durability of reinforced concrete, various technologies and methods have been applied. Shrinkage of concrete under restricted conditions leads to cracking in concrete structural members, such as beams, decks, and slabs on grade. One possible method of decreasing and delaying the cracking is to use expansive cement concrete known as shrinkage-compensating concrete (SHCC). Hybrid fiber-reinforced polymer reinforced SHCC structural system shows a good potential for delaying concrete cracking and eliminating steel corrosion.¹

Durability of RC corroded shear-critical deep beams with near surface mounted carbon fiber-reinforced polymer rods has been examined.² Durability is one of the most important aspects of concrete due to its fundamental incidence on the serviceability working conditions of concrete structures. Research on the durability of steel fiber reinforced self-compacting concrete showed that the addition of steel fibers

The corrosion resistance of metals has been tested in simulated concrete pore solution (SCPS), which consists of saturated calcium hydroxide [Ca(OH)₂], with the pH ~13.5. Rajendran et al., have investigated corrosion resistance of SS316L in simulated concrete pore solution in presence of trisodium citrate (TSC). The polarization study and AC impedance spectra lead to the conclusion that in presence of TSC, the corrosion resistance of SS 316L simulated concrete pore solution decreases.⁶ Pandiarajan et al., have studied the corrosion behaviour of mild steel in simulated concrete pore solution prepared in rain water, well water and sea water.⁷ The mechanistic aspects of corrosion inhibition have been studied using polarization study and AC impedance spectra. The scanning electron microscopy study confirms the protection of carbon steel surface by strong adsorption of PVP.⁸ Influence of sodium metavanadate on the corrosion resistance of mild steel immersed in simulated concrete pore solution prepared in well water has been investigated by Pandiarajan et al.⁹

Urine is a sterile liquid by-product of the body secreted by the kidneys through a process called urination and excreted through the urethra. Cellular metabolism generates numerous by-products, rich in nitrogen. In some countries, people have the habit of urinating in public places especially on the concrete structures such as bridges and buildings.

This may affect the life time of the bridges and rebars because urine contains corrosive ions such as chlorides.

The present study is undertaken to investigate the corrosion resistance mild steel, in SCPS in the absence and presence of SU, tartaric acid and lactic acid. A saturated solution of calcium hydroxide is used as SCPS.¹⁰ Electrochemical studies such as polarization study and AC impedance spectra have been used to evaluate the corrosion resistance of the mild steel under investigation.

Experimental

Simulated Concrete Pore solution

A saturated calcium hydroxide solution is used in present study, as SCPS solution with the pH-12.5.¹⁰

Metal specimens

Mild steel specimens (0.0267% S, 0.06% P, 0.4% Mn, 0.1% C and the rest iron) were used in the present study.

Artificial urine

Two solutions A and B are prepared. Just before the experiment they are mixed in 1:1 ratio to create artificial urine.¹¹ The compositions of A and B are given in Table 1.

Table 1. Constituent of artificial urine.

Solution A		Solution B	
Compounds	Weight g L ⁻¹	Compounds	Weight g L ⁻¹
CaCl ₂ .H ₂ O	1.765	NaH ₂ PO ₄ .2H ₂ O	2.660
Na ₂ SO ₄	4.862	Na ₂ HPO ₄	0.869
MgSO ₄ .7H ₂ O	1.462	C ₆ H ₅ Na ₃ O ₇ .2H ₂ O	1.168
NH ₄ Cl	4.643	NaCl	13.545
KCl	2.130		

Potentiodynamic polarization

Polarization studies were carried out in a CHI–Electrochemical workstation with impedance, Model 660A. The working electrode was mild steel. A saturated calomel electrode (SCE) was the reference electrode and platinum was the counter electrode. From the polarization study, corrosion parameters such as corrosion potential (E_{corr}), corrosion current (I_{corr}) and Tafel slopes (anodic = b_a and cathodic = b_c) were calculated.

AC impedance spectra

The instrument used for polarization study was used to record AC impedance spectra also. The cell setup was also the same. 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}) were calculated.

Results and Discussion

Corrosion behavior of mild steel, immersed in SCPS, (saturated calcium hydroxide solution) in presence of SU, tartaric acid, and lactic acid has been investigated by polarization study and AC impedance spectra.

Polarization Study

Polarization study has been used to evaluate the corrosion resistance of metals.¹²⁻¹⁴

When mild steel is immersed in simulated urine (SU), the corrosion potential is -859 mV vs SCE. Linear polarization resistance (LPR) is 4737 ohm cm² and the corrosion current (I_{corr}) is 8.349 x 10⁻⁶ A cm⁻². When mild steel is immersed in simulated concrete pore solution (SCP), the corrosion potential is -668; mV vs SCE. Linear polarization resistance (LPR) is 10991ohm cm² and the corrosion current (I_{corr}) is 5.183x10⁻⁶ A cm⁻². This indicates that the corrosion resistance of mild steel decreases in urine solution. This is due to the presence of corrosive ions present in urine.

When mild steel is immersed in a solution containing simulated urine and SCPS, the corrosion potential is -726 mV vs SCE, linear polarization resistance (LPR) is 9593 ohm cm² and the corrosion current (I_{corr}) is 7.680 x 10⁻⁶ A cm⁻². This indicates that the corrosion resistance of mild steel decreases in this solution when compared with the corrosion resistance in SCPS. This is due to the presence of corrosive ions in urine. However, this corrosion resistance is better than that when mild steel is immersed in urine solution only.

When mild steel is immersed in a solution containing simulated urine solution, SCPS and 250 ppm of tartaric acid and 50 ppm of Zn²⁺ ions, the corrosion potential is 740 mV vs SCE. Linear polarization resistance (LPR) is 17075 ohm cm² and the corrosion current (I_{corr}) is 3.614 x 10⁻⁶ A cm⁻². This indicates that the corrosion resistance of mild steel increases in this solution when compared with the corrosion resistance in SCPS. This is due to the formation of a protective film in presence of tartaric acid. This protective film is more stable. This consists probably of calcium hydroxide, calcium oxide and iron tartrate complex. There is also a probability of anchoring of tartaric acid molecule on the surface film of calcium oxide and calcium hydroxide.

When mild steel is immersed in a solution containing simulated urine solution, SCPS and 250 ppm of lactic acid and 50 ppm of Zn²⁺ ion the corrosion potential is -748; mV vs SCE. Linear polarization resistance (LPR) is 17110 ohm cm² and the corrosion current (I_{corr}) is 1.860 x 10⁻⁶ A cm⁻². This indicates that the corrosion resistance of mild steel increases in this solution when compared with the corrosion resistance in SCPS and also in presence of a solution containing simulated urine solution, SCPS and 250 ppm of lactic acid. This is due to the formation of a protective film in presence of lactic acid. This protective film is more stable. This consists probably of calcium hydroxide, calcium oxide and iron lactate complex. There is also a probability of anchoring of lactic acid molecule on the surface film of calcium oxide and calcium hydroxide.

Table 2. Corrosion parameters of mild steel immersed in different solutions obtained by polarization study.

System	E_{corr} , mV vs SCE	b_c , mV decade ⁻¹	b_a , mV decade ⁻¹	LPR, ohm cm ²	I_{corr} , A cm ⁻²
SU	-859	144	246	4737	8.349 x 10 ⁻⁶
SCPS	-668	283	243	10991	5.183 x 10 ⁻⁶
SCPS + SU	-726	763	217	9593	7.680 x 10 ⁻⁶
SCPS + SU+ TA 250 ppm + Zn ²⁺ 50 ppm	-740	862	169	17075	3.614 x 10 ⁻⁶
SCPS +SU + LA2 50 ppm + Zn ²⁺ 50 ppm	-748	134	160	17110	1.860 x 10 ⁻⁶

Table 3. Corrosion parameters of mild steel immersed in different solutions obtained by AC impedance spectra.

System	R_i ohm cm ²	C_{dl} F cm ⁻²	Impedance Log(z/ohm)
SU	47.78	1.067 x 10 ⁻⁷	2.008
SCPS	126.7	4.025 x 10 ⁻⁸	2.417
SCPS + SU	69.1	7.381 x 10 ⁻⁸	2.242
SCPS + SU + TA + Zn ²⁺	134.6	3.788 x 10 ⁻⁸	2.187
SCPS + SU + LA + Zn ²⁺	231.3	2.205 x 10 ⁻⁸	2.446

Thus, polarization study (Table 2) leads to the conclusion that, the corrosion resistance of mild steel in various test solutions is as follows.

Lactic acid + SCPS + urine > tartaric acid + SCPS +urine > SCPS +urine > SCPS > urine

AC impedance Spectra

Electrochemical studies such as AC impedance spectra have been used to investigate the corrosion resistance of metals.¹⁵⁻²⁵

The results of AC impedance spectral study of mild steel immersed in various test solutions are shown in Table 3. When corrosion rate decreases, due to formation of protective film, the charge transfer resistance value increases and double layer capacitance value decreases the impedance value log (Z/ohm) increases and phase angle value increases. Conversely, when corrosion rate increases, R_i value decreases and C_{dl} value increases. Based on these principles and looking at the Table 3, it is inferred that corrosion resistance of mild steel immersed in various test solutions can be arranged in the decreasing order:

Lactic acid+ SCPS+urine > tartaric acid+ SCPS+urine > SCPS > SCPS+urine > urine

Increase in charge transfer resistance and impedance value of mild steel also follows the same sequence. Decrease in double layer capacitance of mild steel follows the same sequence.

These results are in agreement with that derived from polarization study. This leads to the conclusion that urination on the concrete structures such as bridges and building should be discouraged as this induces faster corrosion and may hasten the collapse of the structure. Inclusion of lactic and tartaric acids during the preparation of concrete admixtures is likely to strengthen the structure and increase its life.

Conclusion

Corrosion resistance of mild steel in SCPS in presence of simulated urine, tartaric acid and lactic acid has been evaluated by electrochemical studies such as polarization study and AC impedance spectra. These studies lead to the conclusion that, the corrosion resistance of mild steel in various test solutions is as follows.

Lactic acid + SCPS + urine > tartaric acid + SCPS +urine > SCPS > SCPS + urine > urine.

References

- Cao, Q., Ma Z. J., *Constr.Build. Mater.*, **2015**, 75, 450–457
- Almassri, B., Kreit, A., Al Mahmoud, F., Francois, R., *Compos.Struct.*, **2015**,123204– 215.
- Frazao, C., Camoes, A., Barros, J., Gonçalves, D., *Constr.Build. Mater.*,**2015**, 80,55–166.
- Conforti, A., Minelli, F., Tinini, A., Plizzari,G.A., *Eng.Struct*, **2015**, 88,12–21.
- Ji, Y-S., Zhan,G., Tan, Z., Hu, Y., Gao, F.,*Constr.Build. Mater.*, **2015**, 79, 214–222.
- Rajendran, S., Muthumegala, T.S., Pandiarajan, M., Nithya Devi, P., Krishnaveni, A., Jeyasundari, J., Narayana Samy, B., Hajara Beevi, N., *Zastit. mater.* **2011**, 52, 85-89.
- Pandiarajan.M., Prabhakar, P., Rajendran,S., *Eur.Chem.Bull.*, **2012**, 1(7),238-240.
- Shanthi, T., Rajendran, S., *Res. J. Chem. Sci.*, **2013**, 3(9), 39-44.
- Pandiarajan, M., Rajendran, S., Joseph Rathish, R., Saravanan, R., *J. Chem. Bio.Phy.Sci.Sec.C* **2014** , 4(1), 549-557.
- Pandiarajan, M., Prabakaran, P., Rajendran S., *Chem. Sci.Trans*, **2013**, 2, 605- 613.
- Nagalakshmi, R., Rajendran, S., Sathiyabama, J., Pandiarajan, M and Lydia Christy, J., *Eur.Chem. Bull.*, **2013**, 2(4), 150 -153.
- Pandiarajan M, Rajendran S, Sathiya bama, J., Vijaya, N., Shanthi, P., *Chem. Sci. Rev.Lett*, **2014**, 3 , 415-424.
- Pandiarajan, M., Rajendran. S., Joseph Rathish, R.,*Res. J. Chem. Sci.*, **2014** , 4, 49-55.
- Shanthi, T., Rajendran, S., *J. Chem, Bio. Phy. Scis*, **2013**, 3, 2550-2556.
- Nithya Dvi, P., Sathiya bama, J., Rajendan, S., Joeph rathish, R., Santanaprabha, S., *J.Chem. Pharm. Res.*, **2015**, 7(10S), 133-140.
- Nagalakshmi, R., Rajendran, S., Sathiyabama, J., *Int. J. Innov. Res. Sci. Eng. Technol*,**2013**, 2, 420-427
- Muthumani. N., Susai Rajendran., Pandiarajan M., Lidia Christ J.,Nagalakshmi, R., *Port. Electrochem. Acta*, **2012**, 30(5), 307-315.

- ¹⁸Pandiarajan, M., Prabhakar, P., Rajendran, S., *Eur. Chem. Bull*, **2012**, *1*(7), 238.
- ¹⁹Nagalakshmi, R., Rajendran, S., Sathiyabama, J., Pandiarajan, M., Lydia Christy, *Eur. Chem. Bull*, **2013**, *2*(4), 150.
- ²⁰Gowri, S., Sathiyabama, J., Rajendran, S., and Angelin Thangakani, J, *Eur. Chem. Bull*, **2013**, *2*(4), 214-219.
- ²¹Nagalakshmi, R., Nagarajan, L., Joseph Rathish, R., Santhana Prabha, S., Vijaya, N., Jeyasundari, J., Rajendran, S., *Int. J. Nano. Corr. Sci. Engg*, **2014**, *1*, 39-49.
- ²²Nithya Devi, P., Sathiyabama, J., Rajendran, S., Joseph Rathish, R., Santhana Prabha, S, *Int. J. Nano. Corr. Sci. Engg*, **2015**, *2*(3), 1-13.

Received: 10.05.2016

Accepted: 29.06.2016.