Corrosion Resisting Performance of Epoxy Coated Rebars in accelerated aging environment simulating the tidal zone and concrete submerged in sea water in comparison to and Mild Steel rebars

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Introduction

The infrastructure in Qatar and the Persian Gulf suffers sever environment of Cl⁻ ions in atmosphere especially near sea shores. When ingressed in concrete pores the Cl⁻ ions destroy the passive layer at steel surface and corrosion process starts. The remaining structural life of concrete structures are drastically reduced when there is sever corrosion of steel rebars. Figure-1 shows some examples of damages caused by corrosion.

The Epoxy Coated Rebars (ECR) is one established solution to avoid such degradation of important structures like bridges and marine structures. These ECR are in use since 1970's. *Although their use is not very common in Qatar due the no local production and design standards.* (This sentence to be deleted as Q-Coat was established in 1990 and ECR is included in QCS 2014)

Figure-1 Damage caused by steel corrosion to reinforced concrete structure

Corrosion Mechanism

The corrosion of steel in concrete is essentially an electrochemical process involving two half-cell reactions occurring simultaneously at steel surface (Figure 2). The anodic reaction is the oxidation of iron in aqueous environment, represented by the following half-cell reaction (Eq.1) (Ahmad, 2009; Elsener et al., 2003).

$$Fe \leftrightarrow Fe^{2+} + 2e^- \qquad \text{Eq. 1}$$

To preserve electro-neutrality, electrons produced by this anodic reaction are consumed by oxygen reduction reaction at cathodic sites on the steel surface Eq.2 (Andrade and Alonso, 2004).

$$1/2O_2 + H_2O + 2e^- \leftrightarrow 2OH^- \qquad \text{Eq.2}$$

The resulting corrosion products cause distress to concrete cover and tends to spall it. Further loss in cross sectional area of steel rebars could reduce the service life or in some cases collapse the structures.

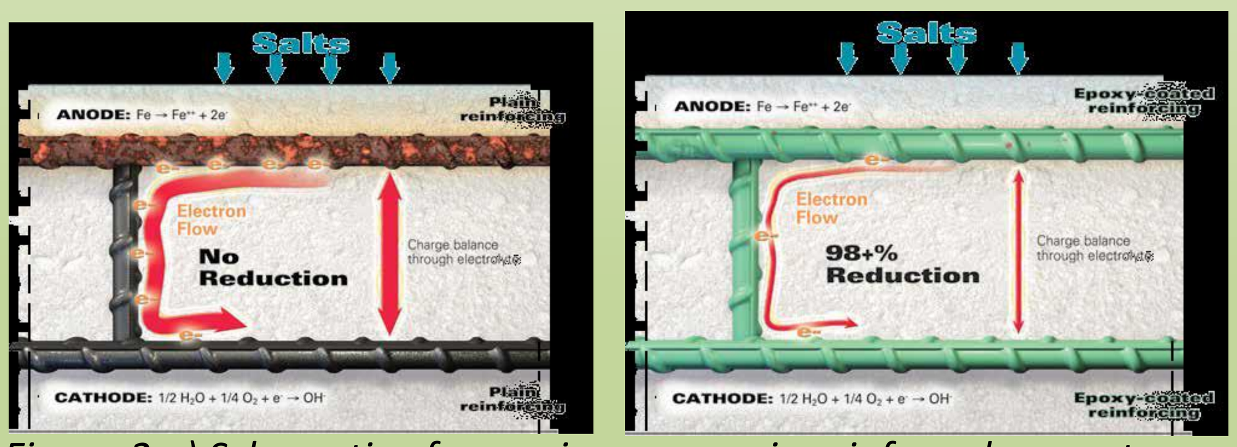

Figure-2 a) Schematic of corrosion process in reinforced concrete. b) Epoxy coated rebars do not allow such reaction to occur even with Cl- present in concrete.

Advantages of epoxy coating

· Protection: Epoxy coated rebar is designed to protect the rebar against rust and corrosion. Applying an epoxy coating to steel rebar prevents oxygen and chlorides from reaching the steel surface reducing corrosion.

· Environmentally friendly materials Unlike many paints, the fusion-bonded epoxy coatings used for steel reinforcement do not contain appreciable solvents or other environmentally hazardous substances

Figure-3 a) 90 degree bent with epoxy coated rebars. b) mesh of epoxy rebars in a bridge deck.

Objective of Study

Qatar Steel as the major producer of steel rebars in Qatar, has responded to the need of durable and corrosion free reinforcing bars in concrete by producing the epoxy coated rebars [ECR] through its joint venture company named Qatar Metal Coating (Q-Coat). The purpose of this study was to evaluate the corrosion performance of these ECR's and bared black rebars under sever corroding sea environment of Qatar shores. The sturdy was carried out at Center for Advance Materials (CAM) at Qatar University.

Experimental plan & Materials

Nine (09) concrete block samples of 300 mm x 230 mm x 70 mm were prepared with a U shaped bended steel bar in it. The schematic of samples geometry is given in Figure 4. Three samples were cast for ECR, ECR with controlled damage and black rebars each for comparison purposes by maintaining concrete cover thickness of 25mm. The forming of U shape bent was provided to observe the effect of induced stress on corrosion behaviors.

Figure-4 Sample geometry with steel bars of U shaped bent. All dimensions are in mm

After curing by submerging in water for 28 days, the samples were placed in to the simulated Qatar and GCC corrosive environment of sea water solution in a salt spray chamber, as shown in Figure 4. The cycles of three (3) days heating and drying at a target temperature of 52ºC was applied. This was followed by fours (4) days of ponding under sea water at 16 - 27oC, these cycles continued for twelve (12) weeks. After initial cycles the samples were then submerged for continuous ponding under sea water at target of 32ºC for next 12 weeks. This 24 weeks cycle is repeated 4 times for a total test period of 96 weeks. (i.e.2 years)

With wetting and drying cycles the chloride penetration in concrete is ensured. The water penetrates into the concrete pores transporting Cl- ions with it during ponding of four days. It evaporates during drying periods leaving behind the Cl- ions. This increases the chloride ions concentration at concrete surface. The diffusion process would help these ions to reach the steel concrete interface.

Results

The chloride contents were measure at different depths till steel surface according to BS 1881 part 124. The chloride profile as shown in Figure-5, the threshold of corrosion initiation for mild steel bars is mostly surpassed. Table-1 shows the accepted threshold values for corrosion initiations in reinforced concrete.

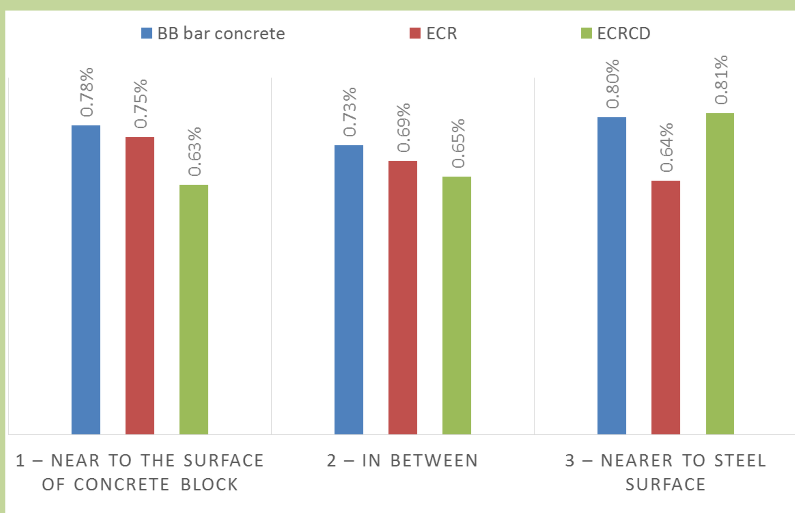

Figure-5 Chloride contents at different depths till steel surface after 2 years of submergence in Sea Water.

Table-1 Chloride threshold for corrosion initiation for mild steel bars

% Chloride by mass of cement	% Chloride by mass of sample (concrete)	Risk
<0.2	<0.03	Negligible
0.2–0.4	0.03–0.06	Low
0.4–1.0	0.06–0.14	Moderate
>1.0	>0.14	High

The half cell potential of steel bars were measure using Giatec Half-cell equipment. It was observed that potentials for mild steel rebars were much more electronegative. And were in range were probability of corrosion is above 90 %. While the potentials measured in concrete blocks with epoxy coated rebars were less than -300 mV/SCE. Which shows no corrosion.

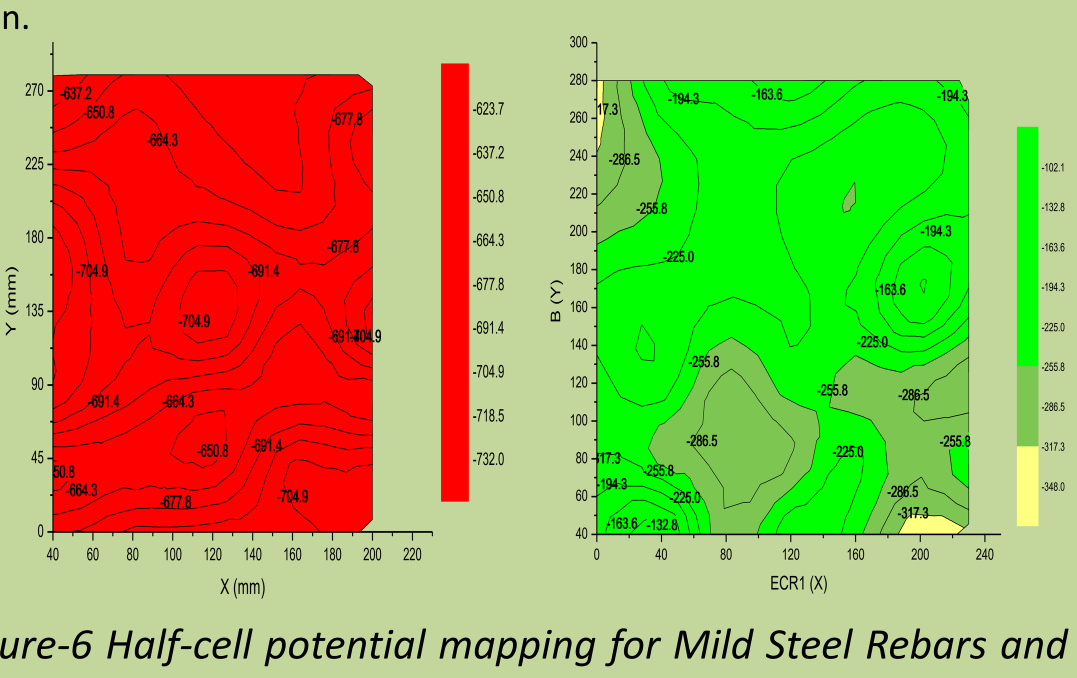

Figure-6 Half-cell potential mapping for Mild Steel Rebars and Epoxy Coated Rebars. Mild steel rebars have corrosion potential above -550 mV/SCE while epoxy coated rebars have potential less than -300mV/SCE means no corrosion.

Electrochemical Experiments

Figure-7 shows Tafel polarization curves. This polarizations show that the mild steel rebars are in active state and have higher corrosion current values. The results of Tafel slope constants and corrosion current densities are shown in Table-2. From these corrosion current values it is inferred that black steel rebars would loss the cross sectional area and hence will reduce the remaining structural life. While no such current is present in case of epoxy coated rebars.

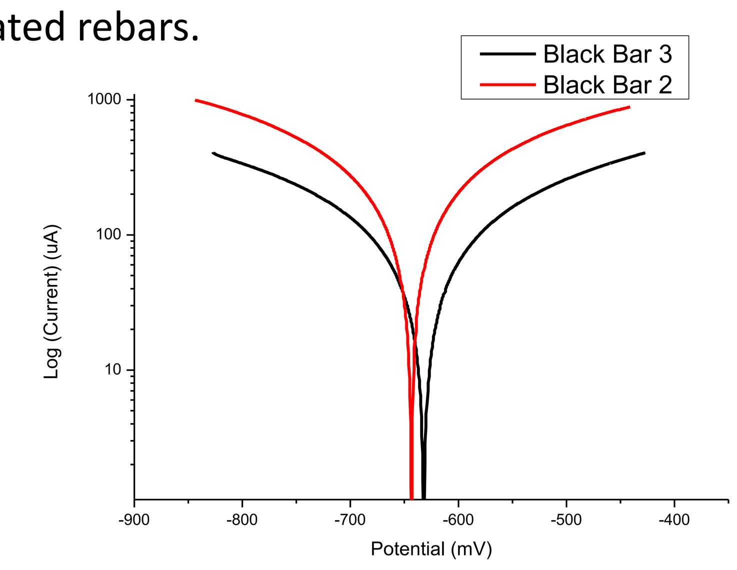

Figure-7 Tafel polarization curve for mild steel rebars. For Epoxy Coated rebars these curve were not possible to attain as epoxy was not broken and no current could be passed through to polarize the steel bars.

Table -2 Corrosion current values at mild steel rebars. No such currents were observed at epoxy coted rebars.

	Tafel		Tafel Slope		LPR		Corrosion rate	
Sample	I_{corr}		β_a	β_c	R_p	i_{corr}		
	μA	μA/cm²	mV/dec	mV/dec	Ω.cm²	μA/cm²	μm/year	mm/year
BB 2	369	2.94	450	420	26603.07	0.98	0.6854	0.00068540
BB 3	124	0.99	440	415	8851.77	2.94	0.2303	0.00023033

Figure- 8 The extracted steel bars from samples after 2 years of submergence in sea water. Sever corrosion was present at mild steel while no corrosion was found at epoxy coated rebars.

Figure-8 shows that the ECR were undamaged under very high concentration of chloride ions. While sever corrosion products are visible at mild steel black bars. .

Conclusion

The high corrosion rate in black bar will reduce the cross sectional area of the bar and rust formed is up to 10 times more voluminous than steel itself which will cause the delamination of the concrete cover. The research conducted by Qatar University proves that such problem would not exist in Epoxy Coated Rebar. Hence, as far as durability is concerned Epoxy Coated Rebars performs exceptionally well in aggressive marine environment than black bars. Since durability due to corrosion is main degrading phenomena in Qatari Infrastructure, use of epoxy could enhance the service life and reduce the repair cost of reinforced concrete structure, hence will have a direct bearing on the economy of country.

REFERENCES

Ahmad, S., 2009. Techniques for inducing accelerated corrosion of steel in concrete. The Arabian Journal for Science and Engineering 95–104.

Andrade, C., Alonso, C., 2004. Test methods for on-site corrosion rate measurement of steel reinforcement in concrete by means of the polarization resistance method. Mat. Struct. 37, 623–643

Elsener, B., Andrade, C., Gulikers, J., Polder, R., Raupach, M., 2003. Hall-cell potential measurements—Potential mapping on reinforced concrete structures. Mat. Struct. 36, 461–471

Darwin, D., Browning, J., O'Reilly, M., Xing, L., and Ji, J. (2009). "Critical chloride corrosion threshold of galvanized reinforcing bars." ACI Materials Journal, 106(2), 176–183

Glass, G. K., and Buenfeld, N. R. (1997). "The presentation of the chloride threshold level for corrosion of steel in concrete." Corrosion Science, Pergamon, 39(5), 1001–1013.

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