स्टील अथॉरिटी ऑफ इण्डिया लि०
(भारत सरकार का संस्थान)
रिसर्च एण्ड डेवलपमेन्ट सेंटर
फॉर आईरन एण्ड स्टील
आई. एस. ओ. 9001 प्रमाणित
पोस्ट : डोरण्डा, रॉची - 834 002

STEEL AUTHORITY OF INDIA LTD.
(A Govt. of India Enterprise)
RESEARCH AND DEVELOPMENT CENTRE
FOR IRON AND STEEL
"I.S.O. 9001 Certified"
P.O. DORANDA, RANCHI - 834 002

Ranch
May 31, 200

M/s SRMB Udyog Limited
46, B. B. Ganguly Street,
Kolkata- 700012

Sub: Comparative evaluation of corrosion performance of coated and uncoated steel reinforcement bar from M/s SRMB Udyog Limited, Kolkata (Ref : Our Final Study Report No. RD/CACE/SRMB-06)

Dear Sir
This has the reference to your letter dated 20-07-2005 (Ref: SRMB/05-06/070168/SAIL) on the above subject. W have conducted tests for five types of rebars supplied by M/s SRMB Udyog Limited, Kolkata for comparativ evaluation of their corrosion performance under controlled laboratory conditions. The results are summarize below:

Table 1 Corrosion rates for various types of rebars evaluated under different test conditions as pe relevant ASTM standards (Test duration: 90 days, Temperature: 30°C)

Type of Test	Type of rebars				
	Corrosion rate (µmpy)				
	Zinga-coated SRMB steel rebar	Galvanized SRMB steel rebar	Fusion bonded epoxy-coated SRMB steel rebar	Uncoated corrosion resistant low alloy steel rebar	Uncoated plain carbon SRMB steel rebar
Static immersion (3.5% NaCl solution)	6.35	25.52	10.90	87.98	140.62
Salt spray (5% NaCl solution)	15.76	274.43	41.23	506.35	549.38
Galvanic Protection	Present	Present	Absent	Absent	Absent

Findings: The above results demonstrate the superior corrosion performance of Zinga-coated rebars over oth coated rebar varieties for short-term exposure of 3 months under controlled laboratory test conditions. The superi corrosion resistance may be attributable in part to: (i) greater degree of galvanic protection afforded by the Z based coating (ii) lower sacrificial consumption of Zn due to discrete dispersion of Zn dust within the binder materi and (iii) barrier protection afforded by the organic binder material itself. However, it is imperative to add that th corrosion performance of coated steel rebars like Zinga-coated rebar cannot be compared with the corrosic performance of uncoated corrosion resistant low alloy steel rebars which rely on corrosion resistance derived fro a protective rust layer formation under long-term exposures in corrosive environments.

Thanking you

Yours faithfull

Dr A Bhattachary
DGM & I
CA & CE Grou

Comparative evaluation of corrosion performance of coated and uncoated steel reinforcement bars from M/s SRMB Udyog Limited, Kolkata

Final Study Report

R&D Centre for Iron and Steel
STEEL AUTHORITY OF INDIA LIMITED
Ranchi- 834 002

April 2006

Report No. RD/CACE/SRMB-06

Table of contents

(i)

List of tables, figures and annexures

Tables

Figures

Summary

The relative corrosion performance of zinga-coated, galvanized, epoxy-coated and plain SRMB steel rebars was evaluated by static immersion and salt fog corrosion testing in chloride-laden aqueous environments. The galvanic protection provided by the zinc-based Zinga and galvanized coatings was studied using galvanic corrosion measurements made with a potentiostat. Static immersion testing in 3.5% NaCl solution and salt fog test with 5% NaCl fog revealed highest corrosion resistance for zinga-coated SRMB steel rebars. Galvanic corrosion measurements in 3.5% NaCl solution and artificial concrete pore solution with 0.1M NaCl also confirmed greater degree of galvanic protection afforded by the Zinga-coating to the underlying steel rebar. The superior corrosion performance of Zinga-coated rebars has been attributed to: (i) galvanic protection afforded by the Zn-based coating (ii) lower sacrificial consumption of Zn due to discrete dispersion of Zn dust within the binder material and (iii) barrier protection afforded by the organic binder in the coating.

1 Introduction

Coated and uncoated varieties of steel reinforcement bars (rebars) were supplied by M/s SRMB Udyog Limited, Kolkata for comparative evaluation of their corrosion performance under controlled laboratory conditions. In all, five types of rebars were studied.

1. Zinga-coated SRMB steel rebar
2. Galvanized SRMB steel rebar
3. Epoxy-coated SRMB steel rebar
4. Uncoated plain carbon SRMB rebar
5. Uncoated corrosion resistant low alloy steel rebar

The corrosion performance of the rebars was evaluated using two standard corrosion test procedures: static immersion corrosion testing and salt fog testing. In addition, the sacrificial, protective nature (galvanic protection) of the zinc-based Zinga and galvanized coatings was studied and compared with galvanic corrosion measurement technique using a computer-controlled potentiostat/ galvanostat.

The present report describes the experimental procedures adopted for the laboratory studies including the test conditions and test environments employed. The report also summarizes the results of experimentation and the conclusions inferred thereof on the corrosion behaviour of coated and uncoated SRMB steel rebars.

2 Experimental

2.1 Sample preparation details

Test samples of 70 mm length were cut from the supplied lengths of each variety of rebar for static immersion corrosion testing and salt fog testing. Likewise, test samples of 40 mm length were prepared from each type of supplied rebar for effecting galvanic corrosion measurements using a potentiostat/ galvanostat. Adequate care was taken during sample preparation to avoid introduction of surface damages, especially in the coated rebar samples, in the form of knicks, cuts, scratches and peel-off/ exfoliation of coatings. Prior to experimentation, the cut ends of the rebar samples were masked with an organic lacquer to prevent exposure to the test environment for all test procedures.

2.2 Test environments

Two test environments were primarily selected for corrosion testing of rebar samples: (a) 3.5% sodium chloride (NaCl) solution (b) artificial concrete pore solution with 0.1M NaCl. The artificial concrete pore solution was prepared using 0.06M potassium hydroxide (KOH), 0.2M sodium hydroxide (NaOH) and 0.001M calcium hydroxide [$Ca(OH)_2$]. All test solutions were prepared using analytical grade chemicals and distilled water. The static immersion corrosion testing was conducted in the more aggressive 3.5% NaCl solution. However, the galvanic corrosion measurements were effected in both test solutions to study and quantify the degree of galvanic protection afforded by the sacrificial zinc-based Zinga and galvanized coatings. The salt fog testing was conducted using the fog generated with 5% NaCl solution in accordance the relevant test standard ASTM B117.

2.3 Static immersion corrosion testing

Rebar samples of both coated and uncoated varieties were held under a state of static immersion in 3.5% NaCl solution at ambient temperature for increasing exposure periods ranging from 15 to 90 days. The static immersion corrosion testing was conducted for evaluating the rebar corrosion behaviour under conditions of static immersion in a corrosive environment. During the test period, the rebar samples were held under total immersion in glass beakers filled with 1 litre of the test solution. The test procedure was executed in complete accordance with the ASTM standard G31. Weight loss measurements were recorded for the rebar samples after predetermined periods of exposure, viz., 15, 30, 45, 60 and 90 days. The weight loss per unit area for rebar samples was plotted as function of increasing time of exposure in order to gain an insight into the corrosion kinetics of coated and uncoated rebars in 3.5% NaCl under conditions of static immersion.

2.4 *Salt fog corrosion testing*

Rebar samples were also subjected to salt fog exposure in a salt spray chamber, Weiss Technik model SSC 450, for increasing periods of exposure ranging from 15 to 90 days at a chamber temperature of 30 °C. A test solution of 5% NaCl and compressed air were used to generate the salt mist inside the chamber and the test was performed in conformity with ASTM standard B117. The weight loss per unit area of the rebar samples was determined at the end of each exposure period, viz., for 15, 30, 45, 60 and 90 days to study the relative corrosion kinetics/ behaviour of coated and uncoated rebars under conditions of 5% salt fog exposure.

2.5 *Galvanic corrosion measurements*

Galvanic corrosion measurements were recorded for galvanic couples set up in a electrochemical cell between a Zinga-coated rebar and an uncoated SRMB rebar in one experiment and between a galvanized rebar and an uncoated SRMB rebar in another case using a computer-controlled EG&G PARC model 273A potentiostat/ galvanostat in both 3.5% NaCl and chloride-containing artificial concrete pore solutions. The artificial concrete pore solution was prepared using a chemical ingredient composition described earlier. The testing was conducted in conformity with the guidelines for conducting and evaluating galvanic corrosion tests detailed in ASTM standard designation G71-81 (2003).

For galvanic corrosion studies, only Zinga-coated and galvanized SRMB rebar samples were selected, keeping in the view the sacrificial and galvanic nature of protection that these two coatings afford to the underlying steel bar in addition to barrier protection. On the contrary, because the dielectric (non-conductive) epoxy coating affords only a barrier protection to underlying steel bar and will not exhibit a "galvanic effect" when coupled with a plain uncoated rebar, it was not selected for galvanic corrosion measurements.

In the experiments, the galvanic corrosion measurement itself was effected on the uncoated SRMB rebar in the case of each couple in the form of galvanic current versus time (I vs t) plots in order to study and compare the degree of sacrificial protection provided by Zinga and galvanized coatings respectively. The measurements were taken with the potentiostat functioning as a "zero-resistance ammeter" (ZRA). The equilibrating kinetics of the galvanic current on the uncoated SRMB rebar and its equilibrium value were considered for the comparative assessment of degree of sacrificial anode cathodic protection (SACP) conferred by the two zinc-based coatings.

3 Results and discussion

3.1 Static immersion corrosion testing

Table 2 shows the weight loss per unit area for the coated and uncoated rebar samples with increasing period of exposure from 15 days to 3 months under static immersion in aggressive 3.5% NaCl solution. The same experimental data is also illustrated graphically in Fig.1 for better clarity. Among the coated rebars, namely, Zinga-coated, galvanized and epoxy-coated, the Zinga-coated rebar exhibited slowest corrosion kinetics in the form of relatively minimal weight losses with increasing period of exposure. More significantly, the Zinga-coated rebar showed no weight loss for up to 45 days in stark contrast to all other coated varieties of rebars. This is presumably indicative of the slower corrosion propensity of Zinga-coated rebar under immersed condition in 3.5% NaCl solution. The epoxy-coated rebar, on the other hand, showed specific weight losses intermediate to the Zinga-coated and galvanized SRMB rebars during the entire duration of exposure. The galvanized rebars, thus by far, exhibited comparatively faster corrosion kinetics, higher weight losses and least corrosion resistance among the three coated rebars studied. It is likely that the binder-mixed, Zn-dust based Zinga coating suffers lower sacrificial loss of Zn than a conventionally employed galvanized coating on steel due to discrete dispersion of zinc within the binder material. This was also largely substantiated during galvanic corrosion measurements, the results of which are presented in a following section of this report.

Of the uncoated steel rebars, viz., plain carbon SRMB and corrosion resistant low alloy, the latter rebar displayed markedly sluggish corrosion kinetics, substantial lowering in weight losses and impeding of corrosion rates during the entire length of exposure under static immersion in 3.5% NaCl solution. This is, in all likelihood, attributable to the additions of corrosion resistant alloying elements, which was confirmed by chemical analysis of the rebars (Table 1).

3.2 Salt fog corrosion testing

Table 3 shows the specific weight losses for coated and uncoated rebar samples with increasing time of exposure under 5% NaCl salt fog. The weight loss per unit area was again evaluated for the rebars at periodic, predetermined exposure intervals ranging from 15 days to 90 days. The results are also depicted in the form of a graph in Fig.2 for the ease of comprehension. Under conditions of salt fog exposure, the Zinga-coated rebar samples again exhibited lowest weight losses and corrosion rates among the coated rebars. The Zinga-coated rebar showed no weight loss up to 15 days in 5% salt fog following which very nominal weight losses were recorded with increasing duration of exposure. In comparison, although the epoxy-coated rebar suffered no weight loss up to 30 days of exposure, comparatively higher weight losses were incurred after the 30-day period with increasing corrosion losses occurring through the holidays/ defects in the coating. The galvanized rebars once again suffered the highest weight losses among all coated rebars, which is, in all probability, reflective of the rapid sacrificial consumption of Zn from the hot-dip coating in the aggressive salt fog environment.

3.3 Galvanic corrosion measurements

Figs.3 and 4 show the variation in galvanic current for uncoated SRMB rebars in couple with Zinga-coated and galvanized rebars in 3.5% NaCl and artificial concrete pore solutions respectively. The galvanic current for the uncoated rebar is seen to reduce and equilibrate to extremely low values more rapidly when in couple with Zinga-coated rebar in both test environments. In 3.5% NaCl solution, the galvanic current for uncoated rebar in couple with Zinga-coated rebar equilibrates to low value within 10 seconds whereas it attains an equilibrium low value after nearly 50 seconds when coupled with galvanized rebar. This is indicative of the faster kinetics of galvanic protection afforded by the Zinga-coating in 3.5% NaCl solution. Also, the equilibrating galvanic current value for the plain rebar is marginally lower at 1.5 μA when coupled with Zinga-coated rebar in comparison to 1.6 μA when in couple with a galvanized rebar. This undoubtedly signifies a greater degree of galvanic protection afforded by Zinga-coating in 3.5% NaCl aqueous environment.

Likewise, in artificial concrete pore solution with 0.1M NaCl, the galvanic current for the plain rebar equilibrates to a low value within 30 seconds when in couple with Zinga-coated rebar as opposed to nearly 50 seconds when coupled with galvanized rebar. Also, the equilibrium value for galvanic current is 0.01 μA in case of Zinga-coating as compared to 0.2 μA for galvanized coating implying remarkably higher degree of galvanic protection afforded by the former coating.

The above results clearly underline the superior corrosion performance of Zinga-coated rebars in 3.5% NaCl and artificial concrete pore solutions under the experimental conditions employed for laboratory evaluation.

4 Conclusions

a) The relative corrosion performance of Zinga-coated, galvanized, epoxy-coated and plain uncoated SRMB steel rebars was evaluated using two standard corrosion test procedures: (i) Static immersion corrosion testing and (ii) Salt fog corrosion testing. The galvanic protection afforded by the Zn-containing Zinga and galvanized coatings was studied and compared using galvanic corrosion measurements made with a potentiostat.

b) Under conditions of static immersion in 3.5% NaCl solution, the Zinga-coated SRMB rebar exhibited the lowest corrosion rate among all coated varieties of rebars with increasing period of exposure up to 3 months. Notably, the Zinga-coated rebar exhibited no weight loss up to 45 days of exposure in the aggressive environment.

c) In 5% NaCl salt fog exposure, the Zinga-coated rebar again exhibited lowest weight losses and greatest corrosion resistance among the coated rebars studied during the entire duration of exposure up to 3 months. In this case, the Zinga-coated rebar showed no weight loss for the exposure period up to 15 days.

d) The galvanic corrosion measurements made in 3.5% NaCl and artificial concrete pore solutions confirmed a greater degree of sacrificial, galvanic protection afforded by the Zinga coating to the underlying steel rebar. This was revealed by the rapid lowering and equilibrating characteristics as well as the low magnitudes of galvanic current on electrochemically-coupled uncoated rebars in the two test environments.

e) The above results demonstrate the superior corrosion performance of Zinga-coated rebars over other coated rebar varieties. The superior corrosion resistance is attributable in part to: (i) greater degree of galvanic protection afforded by the Zn-based coating (ii) lower sacrificial consumption of Zn due to discrete dispersion of Zn dust within the binder material and (iii) barrier protection afforded by the organic binder material itself.

Table 1 Chemical composition of supplied plain carbon and corrosion resistant low alloy steel rebars (wt%)

Steel rebar	C	Mn	Si	S	P	Corrosion resistant alloying elements
Plain carbon SRMB	0.27	0.59	0.25	0.068	0.062	-
Corrosion resistant low alloy	0.21	0.90	0.37	0.031	0.038	~ 1.00

Table 2 Weight loss per unit area for the coated and uncoated steel rebars as a function of increasing period of exposure under conditions of static immersion in 3.5% NaCl solution

Period of exposure (days)	Weight loss per unit area (mg/cm^2)				
	Zinga-coated SRMB steel rebar	Galvanized SRMB steel rebar	Epoxy-coated SRMB steel rebar	Uncoated plain carbon SRMB steel rebar	Uncoated corrosion resistant low alloy steel rebar
0	0	0	0	0	0
15	0	2.48	0.40	8.54	2.52
30	0	3.47	1.33	12.98	4.74
45	0	2.37	0.94	15.62	6.62
60	0.07	3.89	1.07	18.09	11.90
90	1.23	4.94	2.11	27.22	17.03

Table 3 Weight loss per unit area for the coated and uncoated steel rebars as a function of increasing period of exposure under conditions of 5% salt fog exposure

Period of exposure (days)	Weight loss per unit area (mg/cm^2)				
	Zinga-coated SRMB steel rebar	Galvanized SRMB steel rebar	Epoxy-coated SRMB steel rebar	Uncoated plain carbon SRMB steel rebar	Uncoated corrosion resistant low alloy steel rebar
0	0	0	0	0	0
15	0	16.63	0	4.54	11.12
30	1.03	24.69	0	31.17	21.87
45	3.30	39.63	4.54	55.30	36.29
60	2.95	47.24	7.46	85.52	83.83
90	3.05	53.12	7.98	106.34	98.01

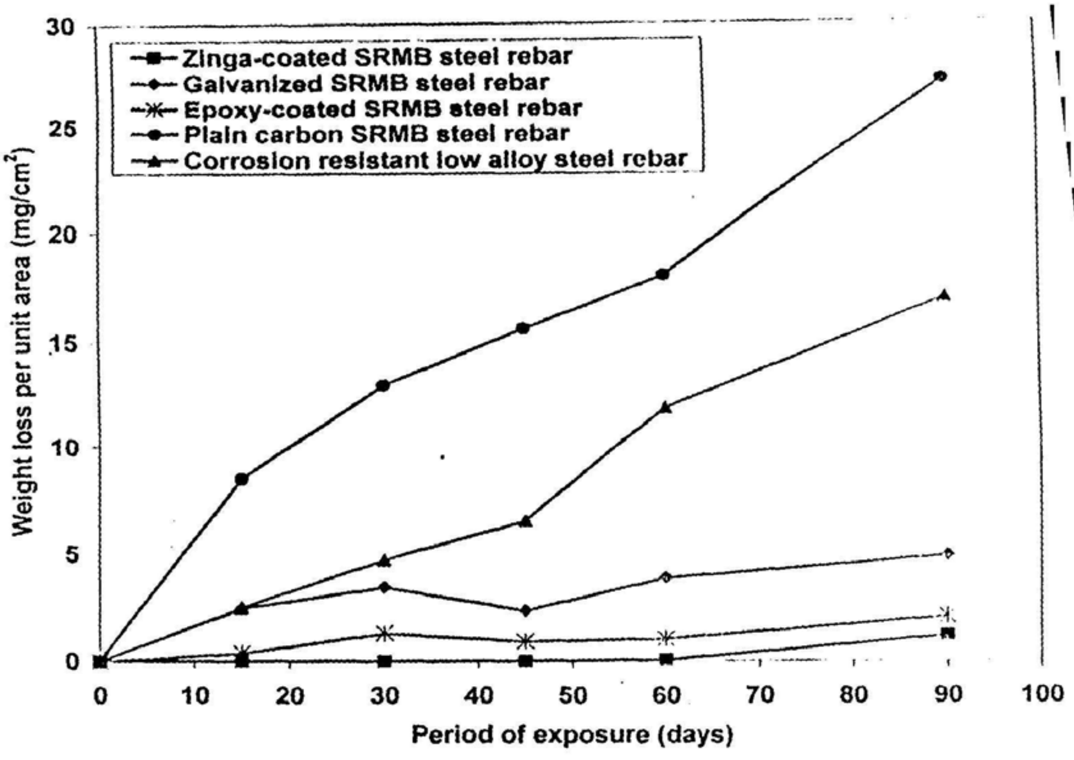

Fig.1 Weight loss per unit area as a function of period of exposure for coated and uncoated steel rebars under conditions of static immersion in 3.5% NaCl solution at ambient temperature

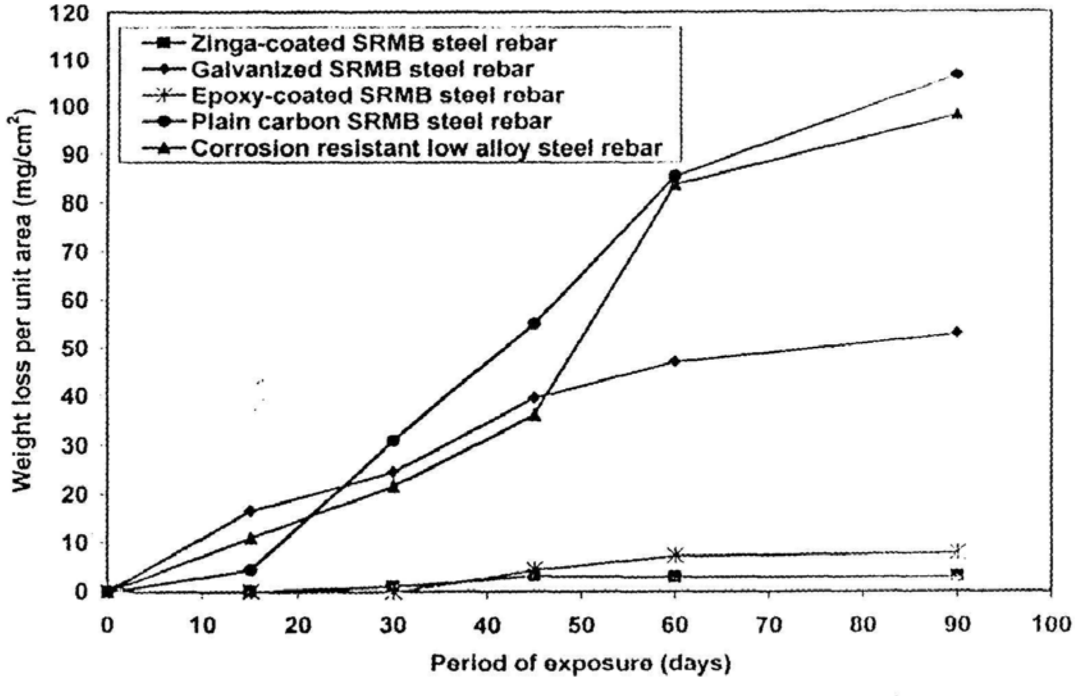

Fig.2 Weight loss per unit area as a function of period of exposure for coated and uncoated steel rebars under conditions of 5% salt fog exposure at ambient temperature

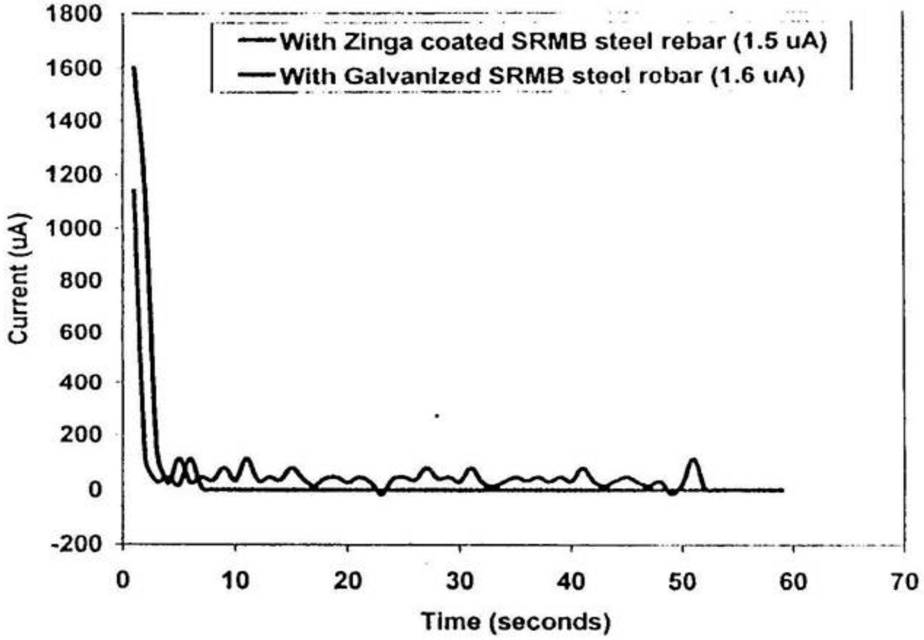

Fig.3 Variation in galvanic current for uncoated SRMB rebars in couple with Zinga-coated and galvanized SRMB rebars in 3.5% NaCl

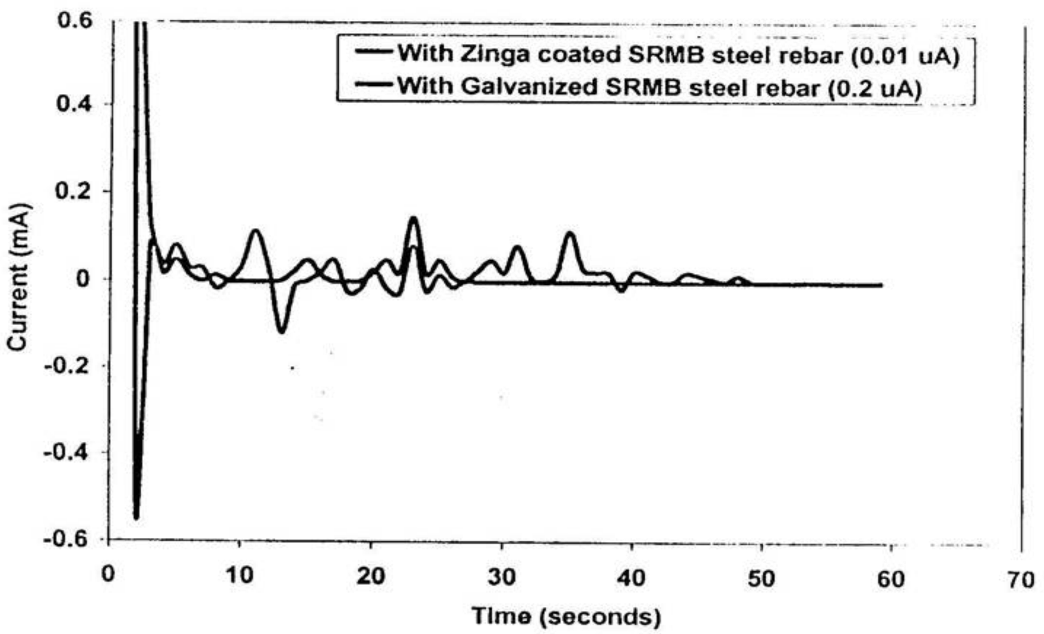

Fig.4 Variation in galvanic current for uncoated SRMB rebars in couple with Zinga-coated and galvanized SRMB rebars in artificial concrete pore solution with 0.1M NaCl