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Effect of prior damage on the performance of cement based coatings on rebar: macrocell corrosion studies

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Abstract

The performance of any rebar coating system depends upon its resistance to corrosion in the presence of chloride contaminated concrete. It also mainly depends upon its tolerance towards damage that may occur during handling, transporting and concreting. The severe corrosion of epoxy coated reinforcing steel in long key bridge and other structures in Florida gave raise to the concern over the influence of damages in the coating system [R.J. Kessler, P.G. Powers, Interim report on corrosion evaluation of substructure in Long key bridge, Corrosion Report No. 87-9A, Florida Department of Transportation, Florida, 1987]. The performance of rebar coating such as galvanizing and epoxy based coating with prior surface damage has been evaluated and reported. [J. Hartley, Concrete Jan/Feb (1994) 12–15; A. Sagues, Performance of galvanized rebars in marine substructure service, Project ZE-418, Part I, October, 1994]. To date, the performance of cement based coatings with prior damages has not been widely studied and reported. In the present investigation the effect of prior damage produced during concrete pouring has been studied on inhibited cement slurry coating. To simulate the marine substructure environment, macrocell corrosion has been created via a chloride ion concentration gradient. Test conditions and method of macrocell current measurement as described in ASTM G 109-92 have been followed. The above investigation revealed that the cement based coating appears to have better tolerance towards defects in chloride contaminated concrete as compared to epoxy based coating system. The performance of the coating is independent of the height of concrete pouring. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Rebar coatings; Damages; Macro-cell current; Percentage area rusted

1. Introduction

Steel bar is frequently coated to increase the durability of concrete structures in the marine environment. Fusion bonded epoxy coating and galvanizing are the widely used rebar coating systems in the USA, UK and other countries [2,3]. In India, inhibited and sealed cement slurry coating has been used for some time [4]. This inhibited cement slurry coating is an in situ process to be carried out after all bending and shaping operations are completed at the construction site.

Irrespective of the coating system adopted, any coating is prone to damage. The performance of any coating system depends upon its tolerance towards damages that may occur during handling, transporting and concreting. In certain cases coating defects may lead to initiation of under-film corrosion and may cause disbondment of the coating.

Inhibited cement slurry coating is an inorganic coating system. It consists of four steps viz. pickling, phosphating, application of two coats of inhibited cement slurry coating and sealing. Since this coating is applied at site, damage due to transport and lifting are greatly minimised. This coating has been used in many of the strategic and prestigious structures built on the east and west coasts of India [5]. This coating has been evaluated under different field conditions and also under different accelerated laboratory test conditions. It has a minimum durability factor of 25 [6]. The durability factor can be defined as the corrosion rate of uncoated rebar to the corrosion rate of coated rebar under similar test condition. In situ patch repairing is easy to perform in this system. However, stringent quality control measures at the work site are needed to ensure the performance of this coating. In an earlier work the performance of inhibited cement slurry coating under undamaged

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condition had been studied under macrocell corrosion condition and compared with the uncoated rebar [6]. After 360 days of exposure, negligible rusting was observed in cement slurry coated rods. On the other hand, uncoated rebar had shown 100% rusting. So far performance of cement based coating with prior damage has not been studied and reported.

In the present work, inhibited and sealed cement slurry coating with prior damage has been evaluated under macrocell corrosion condition by creating a chloride ion concentration cell. Inhibitor used in this system is nitrite based which is dissolved in water and mixed with cement to form a slurry and applied as a coating either by brushing or dipping. It protects the steel by creating a passive environment with a high tolerance towards chloride. Sealing of the pores in the coating is effected by giving a silicate based treatment. This treatment seals as well as hardens the coating.

Sagues et al. [1,7] had investigated the effect of prior damage with known damaged area on the performance of galvanized and fusion bonded epoxy coated rebars under macrocell corrosion studies in chloride contaminated concrete. To simulate marine substructure environment they created a chloride ion concentration gradient cell and accelerated the corrosion. In the case of damaged epoxy coated rods the macrocell current was 30.4 $\mu A/cm^2$. From the studies they concluded that an active corrosion condition was observed in damaged epoxy coated rods and possibility of corrosion damage can occur within 10–15 years of service. ASTM (G 109/92) also developed a standard for this type of macrocell corrosion studies in chloride contaminated concrete. The method, as described in the above standard, has been followed in this study.

2. Testing program

Six concrete specimens of size 15 cm × 15 cm × 27.5 cm were cast using a nominal mix ratio of 1:2.2:4.4 (by weight) with a w/c ratio of 0.6. The minimum characteristic compressive strength of this mix was 20 MPa. The composition of ingredients used is given in Table 1. Grade 43 ordinary Portland cement was used. The grading of fine aggregate and coarse aggregate used is given in Table 2. The fineness modulus of fine aggregate is 2.33 and coarse aggregate is 6.5. No plasticizer was added. The coating was applied on 1 m length of 10 mm dia ribbed rods. The average coating thickness was 250 μm. After completion of sealing treatment, the coated rods were placed horizontally in the mould and the concrete was poured over these rods from either 3 or 2 m height. The rods were then carefully washed with water and the extent of surface damage was observed visually.

The damages were small in size (<0.1 mm) and scattered. It was observed that significant damages had occurred in this coating system during concrete pouring. However, the overall percentage of surface damage was assessed as 5–16%. The surface damage obviously refers to the damage of the coating at the surface. Damage does not mean exposure of base metal substrate. Often it was observed that only top layer of the coating had got damaged during pouring of concrete. From these prior damaged rods, 30 cm long pieces were cut and used in casting the concrete specimens. One damaged rod was placed at 20 mm cover at the top while two undamaged rods were placed at 20 mm cover at the bottom. The details of position of the rebars are shown in Fig. 1. Triplicate specimens were cast for each height of fall (viz. 2 and 3 m). The specimens were cured for 28 days. After curing a dam of 7.5 cm height was constructed on

Table 1
Composition of concrete mix used

Ingredients	Kg/m^3 of concrete
Cement	300
Fine aggregate	660
Coarse aggregate	1320
Water	180

Table 2
The grading of the coarse aggregate and fine aggregate

I.S. Sieve size (mm)	Coarse aggregate wt% retained	Fine aggregate wt% retained
12.5	5	–
10.00	45	–
4.75	45	–
2.36	5	0
1.18	–	7
600 μm	–	33
300 μm	–	48
150 μm	–	10
<150 μm	–	2

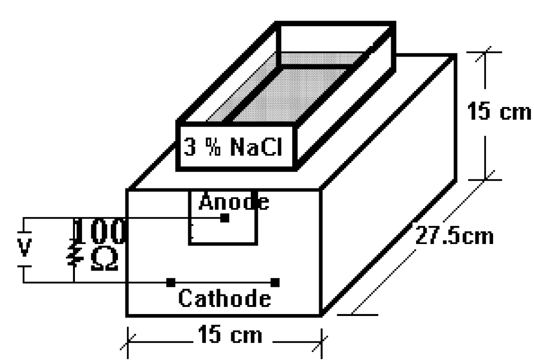

Fig. 1. Specimen for macrocell corrosion setup.

top of each specimen. Each specimen was positioned on concrete pedestal cubes thus allowing a air flow around the specimens.

The top and bottom rebars were electrically short-circuited through a 100 Ω resistor. Three percent NaCl solution was ponded for two weeks and then allowed to dry for two weeks. All specimens were exposed to alternate wetting and drying cycle tests. Half-cell potential of the top and bottom bars and macrocell current were measured periodically as per ASTM G 109-92. After 90 days of exposure, one specimen from each group was broken open for each height of fall. In cement slurry coating no rust was observed. The exposure study was continued and at 450 days of testing, specimens were broken open and the coated rods were visually examined for the extent of rust. The percentage area rusted was measured on each rod.

Concrete samples near the vicinity of anodic and cathodic rebars were collected and analysed for chloride content. The concrete samples were powdered and an extract prepared with deionised water at the ratio of 1:1. The extract was analysed for water-soluble chloride by volumetric analysis.

3. Results and discussion

Table 3 gives data on soluble chloride contents in the concrete near anodic and cathodic regions after 450 days of test. The chloride content near the anode is in the range of 2260–4500 ppm whereas near cathode it is in the range of 160–200 ppm. It shows that during this test a very high chloride concentration gradient cell has been created. It has already been proven that this coating has a high tolerable limit of 10 000 ppm of chloride in 0.04 N NaOH medium under electrochemical corrosion test [5] (Peak-potential test). In concrete as per ACI recommendation the chloride threshold value for corrosion initiation is 0.15% chloride by weight of concrete i.e. around 1500 ppm [8]. In this test, the chloride level around the coated rebar is 2260–4500 ppm and the performance of the coating has thus been evaluated at a chloride level above the threshold value.

Fig. 2 shows the potential–time behaviour of cement slurry coating damaged under 3 m height of fall. From the figure it can be seen that up to 176 days the potentials of the anode and cathode are the same and the value is in the range of −100 to −200 mv. It is in the

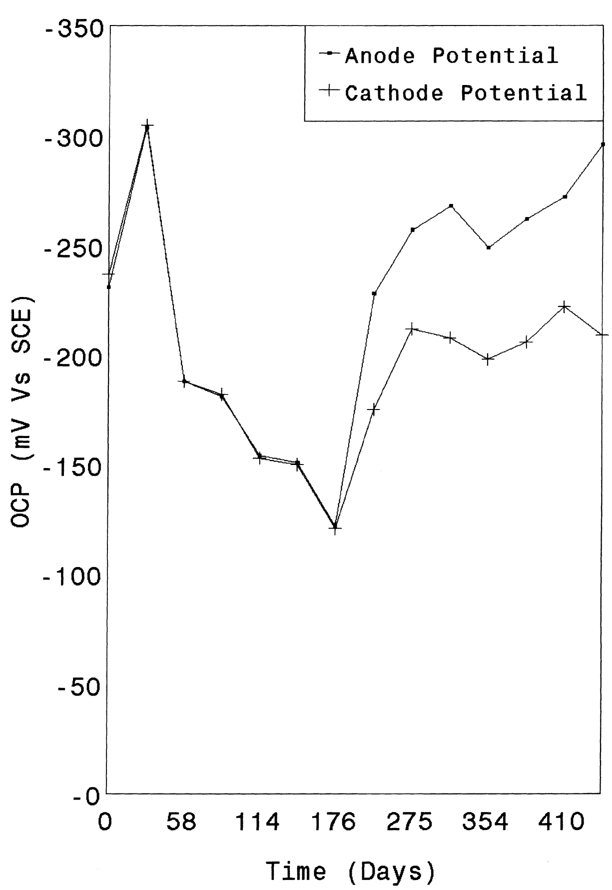

Fig. 2. Potential–time behaviour of inhibited sealed cement slurry coated rebar damaged under 3 m height of concrete pouring.

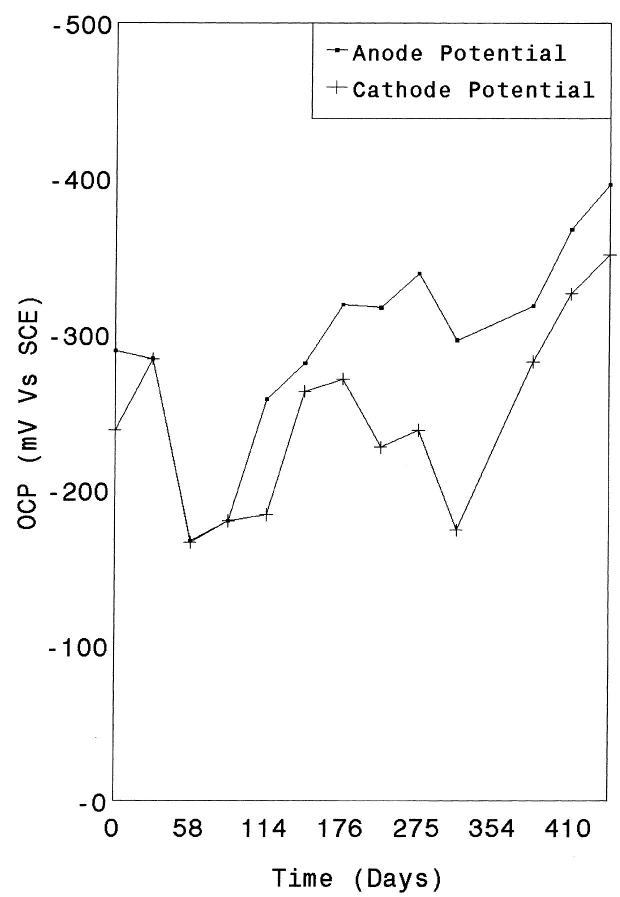

Fig. 3. Potential–time behaviour of inhibited sealed cement slurry coated rebar damaged under 2 m height of concrete pouring.

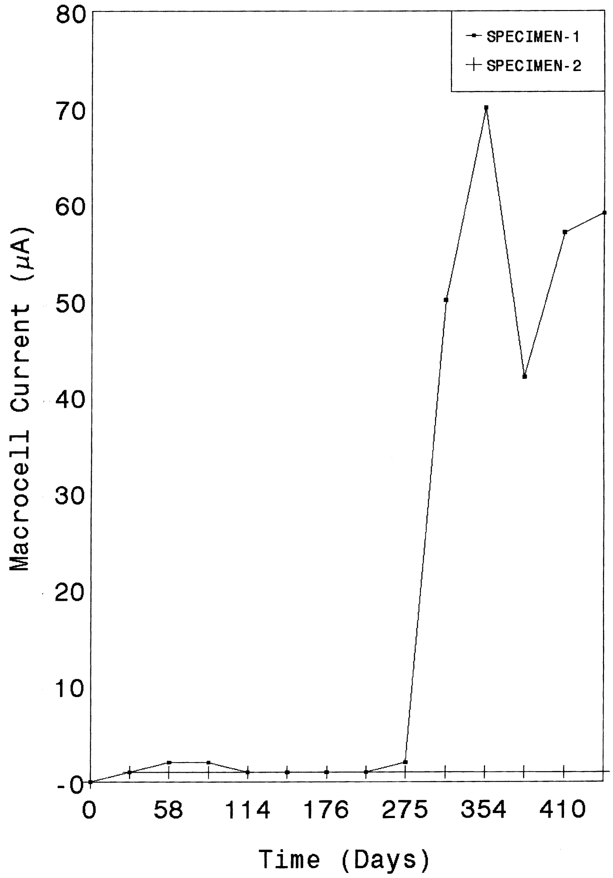

Fig. 4. Macrocell current–time behaviour of inhibited sealed cement slurry rebar damaged under 3 m height of concrete pouring.

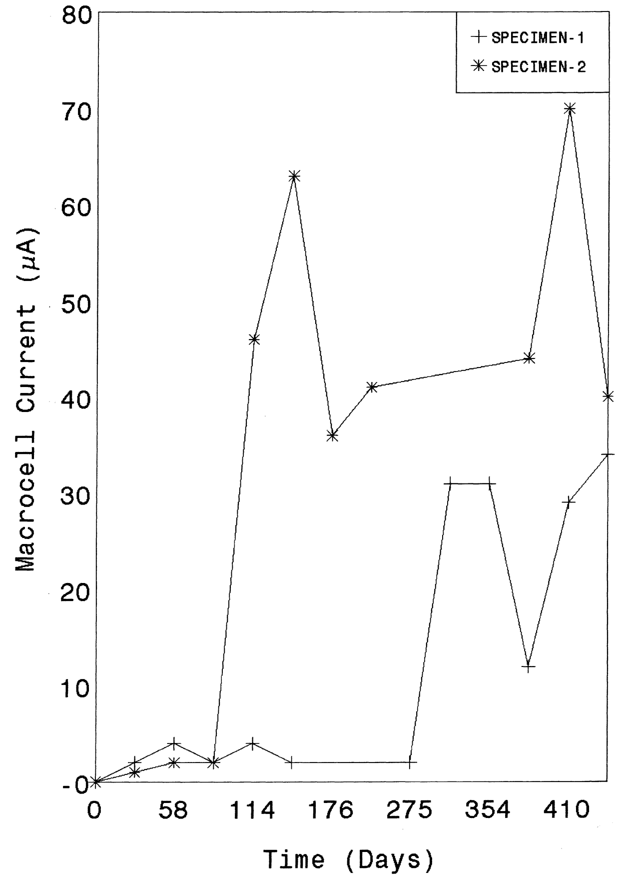

Fig. 5. Macrocell current–time behaviour of inhibited sealed cement slurry rebar damaged under 2 m height of concrete pouring.

passive range. It then increases to a more active potential of −280 mv. Initially the potential difference between anode and cathode is zero and then it increases to 50 mv. In the case of damage produced at 2 m height of fall (Fig. 3) the potential of the anode is passive up to 86 days and this shifts to an active potential of −350 mv after 275 days and still shifts to more active potential of −400 mv at the end of 450 days.

Figs. 4 and 5 show the macrocell current versus time behaviour of cement slurry coating damaged at 3 and 2 m height of fall respectively. In the case of 3 m height of fall (Fig. 4) up to 275 days the macrocell current is 1 μA and then it increases to around 60 μA (0.73 $\mu A/cm^2$) in one specimen and maintains 1 μA in another specimen. The area rusted for the above two specimens are 5% and 0%, respectively. The water soluble chloride (free) present near the anode for the above specimens are 4500 and 2260 ppm, respectively. At the cathode it is 200 and 160 ppm, respectively. From Fig. 5 it can be noted that for the cement slurry coating system subjected to 2 m height of fall, the current range is higher i.e. 30–60 μA (0.4 $\mu A/cm^2$–0.9 $\mu A/cm^2$) when compared to damage produced at 3 m height of fall. The percentage areas rusted are 17% and 6%, respectively.

From the chloride analysis it can be inferred that even in the presence of higher amounts of chloride the cement slurry coating performs better at both levels of damage caused by 2 and 3 m height of concrete pouring.

Table 3
Comparison of free chloride at anode and cathode

Coating system	Water soluble chloride at anode (ppm)		Water soluble chloride at cathode (ppm)	
	Specimen 1	Specimen 2	Specimen 1	Specimen 2
Inhibited sealed cement slurry coating	4500	2260	200	160

Table 4
Comparison of % area rusted at different levels of concrete pouring

Coating system	Height of concrete pouring in metre	Percentage area rusted	
		Specimen 1 (%)	Specimen 2 (%)
Inhibited sealed cement slurry coating	0	Negligible	Negligible
	2	17	6
	3	5	0
Uncoated	0	100	100

In concrete specimens with cement slurry coated rods no cracking was observed. Potential values were also more passive even though damage had occurred during concreting. The spread of rust was only 5–16% at both levels of damage. When visually examining the coated rods the rust was only around the area of damages. No under-film corrosion was observed. Even in presence of 4500 ppm of chloride (Table 3) no rusting was observed in the undamaged portion. This is due to the passivating behaviour of the cement slurry coating. Cement slurry is a conducting coating with a breakdown voltage of only 0.2 kV. Hence in presence of damage the undamaged area gives protection to the damaged area to a certain level and if the area of the damage is large, corrosion occurred but restricted to only around the region of damages. Damages that occurred during concrete pouring cannot be repaired and this investigation has shown that the inhibited cement slurry coating system has higher tolerance towards damages when compared to epoxy based coating. It was reported that if the epoxy coating is severely damaged it behaves similar to uncoated bar [9].

One other observation is that the height of concrete pouring either 2 or 3 m has no apparent influence on the performance of coating. It would be expected that if the height of concrete pouring was less it would produce less damage but in this testing the opposite was found. Table 4 shows that at 2 m height of fall the area rusted is 6–17% whereas at 3 m height it is 0–5%. Hence other factors are apparently more significant than the height of pouring.

4. Conclusions

1. Test method as outlined in ASTM G109-92 for evaluating chemical admixtures was followed and found useful to evaluate coating damage.
2. Inhibited and sealed cement slurry coating has better tolerance towards damage caused by pouring when compared to epoxy based coating.
3. Since damage cannot be avoided in construction practices, cement based coatings appear to have better tolerance towards coating damage and, in presence of damage to the coating, it exhibits better performance in chloride contaminated concrete when compared to epoxy based coatings.

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