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INHIBITED AND SEALED CEMENT SLURRY COATING OF STEEL REBAR - A STATE OF ART REPORT

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Reinforcement rods get rusted at site or during storage before they are laid in concrete. The salts present in the rust can continue the rusting process inside the concrete. In marine atmospheres, corrosive salts enter into the pores of the concrete and bring about accelerated rusting of reinforcements leading to premature failure of structures. Under such extreme conditions it is necessary to give a protective coating to steel reinforcements before they are laid in concrete. In the midst of two well known systems to protect the steel viz., epoxy coating and galvanising, there seems to be another coating system based on inhibited cement slurry which is comparatively cheaper. A detailed report on the performance of the above coating system is presented in this paper.

Key words:- Marine atmosphere, rusting of rebars, inhibited cement slurry.

INTRODUCTION

Use of rusted reinforcement rods coupled with expoure to industrial and marine atmosphere lead to premature failure of R. C. C. structures. The instance of failures indicate that within 20 to 30 years, the durability of marine structures is adversely affected, *ie* the actual trouble free life of structures in aggressive environment is only about one fifth of the design life, unless some effective protective measures are taken at the initial stage itself. India with its nearly 5600 km of coastal line has to maintain many strategic reinforced and prestressed concrete structures such as bridges, offshore structures etc., which are affected by saline action.

A protective anticorrosive treatment to steel reinforcement before it is laid in concrete can guard against this chloride corrosion of steel. So protection is better than cure when it comes to corrosion.

When it comes to coating of steel reinforcement three different types of approaches have been made. They are metallic coatings which can give sacrificial protection to steel reinforcement, insultating type of coatings based on epoxy/polymer and passivating type of coating based on cement.

Studies have been carried out on the effects of nickel, cadmium, copper, lead and tin besides zinc coating to steel in concrete [1]. The studies indicated that apart from cadmium none of the other coatings were satisfactory. However, in recent years, there has been an increasing use of

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galvanising as a protection against corrosion of reinforcing steel, particularly in UK and USA [2]. But zinc has got a low tolerable limit towards chloride and therefore is not likely to give satisfactory protection in marine atmosphere [3].

The ability to maintain a high electrical insulation value in the presence of water is also highly desirable. The property enables the coating to remove or isolate the well-coated steel from the environment and hence from participating as either an anodic or cathodic area. However a defect in this type of coating may lead to serious localised corrosion. A coating based on polymer resin has been developed in UK, [4] but the long term behaviour of polymer coating on reinforcement in concrete is yet to be known. Powder epoxy coating to steel rebars is being used as one of the most positive methods of bridge deck protection [5, 6].

Characteristics of different types of coatings are given in Table I [7].

TABLE I

DIFFERENT TYPES OF COATINGS FOR STEEL REBAR

System	Disadvantages
Coatings not Suitable	
Red Lead	Deterioration in alkaline medium
Coal tar enamel	Brittle, subject to cold flow, sticky
Asphalt	Subject to cold flow
Phenolic	Deterioration in alkaline medium
Urethane	Hard, brittle, intolerant to poor surface preparation
Neoprene	Poor bond
Vinyl	No concrete to vinyl bond
Aluminium	No electrical insulation effect Rapid corrosion in presence of chloride
Coatings Suitable	
Zinc/cadmium	Sacrificial, rapid corrosion in presence of chloride, no electrical insulating effect
Nickel/copper	Not suitable for chloride exposure, no electrical insulating effect, galvanic corrosion
Epoxy	Hard and brittle. In many formulations will not bend or stretch. Many formulations have poor bond. Only powder epoxy suitable
Chlorinated rubber	May bond to both concrete and steel

Since the steel reinforcement embedded in concrete is surrounded by an alkaline medium, a coating based on cement is expected to be more combatible. For that a cement coating is a passivating type of coating and may have higher tolerance towards defects. Because of the surrounding concrete which is again alkaline, galvanic effect is likely to be pronounced.

Various passivating treatment for reinforcing steel have been suggested, such as pickling in hydrochloric acid followed by treatment with phosphoric acid [8] and treatment with a hydrolysable silicate or hydrated silica [9]. Simple preliminary coating of steel with a dense mortar is recommended to counteract acid fumes [10]. The application of coatings of cement containing paints with water proofing admixtures [11] or of slurries of lime and cement with casin or bone glue [12, 13] is also recommended as an anti-corrosive measure. Bitumen paints are said to protect reinforcement from calcium chloride in concrete, but some paints of this type prevent the formation of bond between the steel and concrete [14]. Combinations of inhibiting agents in cement slurries are also proposed, notably sodium dichromate [15], sodium carbonate, sodium phosphate [16], sodium benzoate [17, 18] and also barium chromate [19]. But all these methods do not appear to have made much headway either because of their doubtful field performance or of their adverse effect on bonding.

Keeping both economy and efficiency in view, Central Electrochemical Research Institute, Karaikudi, India has developed a coating based on Portland Cement slurry admixed with corrosion inhibitors [20]. The coating is made impermeable to salts by a sealing treatment. The various properties of this newly developed coating viz. corrosion resistance, bonding strength, behaviour under load, etc., are discussed in detail in this paper. The application procedures, technical specification, approximate quantities of chemicals involved, availability etc., are given in Annexure.

PROPERTIES OF THE COATING

Mechanical properties

The bonding strength between the coated reinforcement and concrete was tested by conducting standard pull out tests in a 30 tonnes Avery Testing Machine. Direct tension test and bending test under 3 point loading were also carried out on coated rebars. The various mechanical properties of the coating are given in Table II. It may be seen that the coating is sufficiently hard to withstand handling stresses. The coating is also able to take up the working stresses when the structure is loaded in tension. However the coating is to be applied to the rebars after all the bending operations are completed.

TABLE II

MECHANICAL PROPERTIES

a)	Average Thickness of the coating	0.3 mm
b)	Rockwell superficial hardness	40 HR 15 N
c)	Direct Tension Test on coated rebar (The coating started cracking only when the yield stress of steel is exceeded)	2800 Kg. cm^{-2}
d)	Bending Test on Coated bar	5100–5400 Kg. cm^{-2} (compression) 5700–6000 Kg. cm^{-2} (Tension)
e)	Bending Strength	

Concrete mix	Dia of reinforcement	Average bond stress Kg. cm^{-2} Untreated	Treated
M 15	25 mm	47.5	48
M 15	13 mm	20	22.6
M 27	20 mm	—	41

Electrochemical properties:

The potential–time behaviour of the cement coated rebar was compared with uncoated rebar in 3.5% NaCl solution for a period of 30 days. The surface condition was then visually examined. The results are given in Table III. It may be observed that the inhibited cement slurry coating keeps the steel nobler by more than 100 mV. Visual observation shows that because of the high alkalinity developed by the inhibitor admixture and because of the imperviousness imparted by the sealing treatment, the steel is maintained in passive condition even in presence of 3.5% NaCl solution.

TABLE III

POTENTIAL–TIME BEHAVIOUR IN 3.5% NaCl SOLUTION

Duration	E, mV V ∧ SCE Cement Coated	Uncoated
30 seconds	- 240	- 550
60 minutes	- 480	- 670
240 minutes	- 584	- 718
30 days	- 654	- 764
Visual observation	Good	Heavily Rusted

The tolerable limit for chloride in 0.04N-NaOH medium was studied by both anodic polarisation technique and peak potential technique [21]. These studies showed that the uncoated steel rebars have a low tolerable limit for chloride in 0.04N-NaOH medium. Figures 1 and 2 and table IV show that the tolerable limit is raised considerably by this coating.

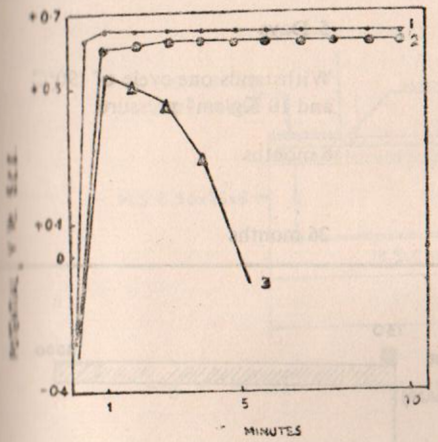

Fig. 1.

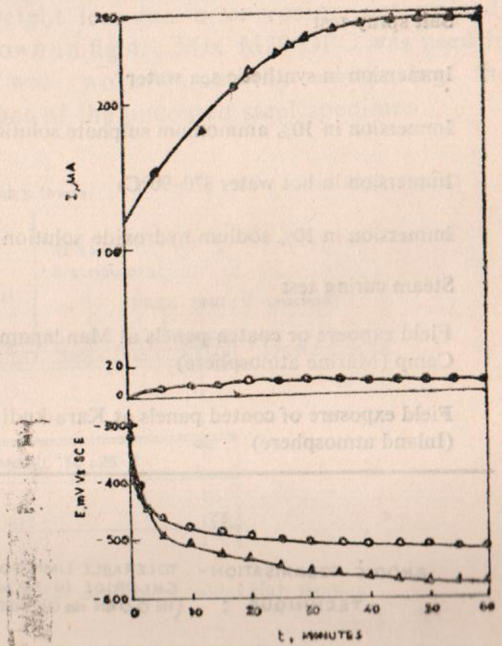

Fig. 2.

Fig. 1 Anodic Polarisation Technique
1) 0.06N NaOH 2) 0.06N NaOH + 15 ppl Chloride and
3) 0.06N NaOH + 50 ppl Chloride

Fig. 2 E Vs t Curves in 0.04N NaOH + solution
(○) 10,000 ppm chloride (△) 20,000 ppm Chloride

TABLE IV

TOLERABLE LIMIT FOR CHLORIDE IN 0.04N–NaOH MEDIUM

Technique	Tolerable Limit for Chloride in ppm. Uncoated rebar	Coated rebar
Anodic polarisation Technique (Galvanostatic)	130	4500
Peak-Potential Technique (Potentiostatic)	1000	10000

Corrosion resistance properties :

The coated rebars were subjected to standard salt spray test, immersion tests, field exposure studies and steamcuring tests. The results of these tests are summarised in Table V and fig 3. It is clearly seen that this inhibited and sealed portland cement coating is able to offer very satisfactory protection to steel reinforcements.

TABLE V

CORROSION RESISTANCE

Test	Test Duration
Salt spray test	2000 Hours
Immersion in synthetic sea water	30 Days
Immersion in 10% ammonium sulphate solution	15 Days
Immersion in hot water (70–90°C)	7 Days
Immersion in 10% sodium hydroxide solution	5 Days
Steam curing test	Withstands one cycle of 190°C and 10 Kg/cm² pressure
Field expoure or coaten panels at Mandapam Camp (Marine atmosphere)	6 months
Field exposure of coated panels at Karaikudi (Inland atmosphere)	26 months

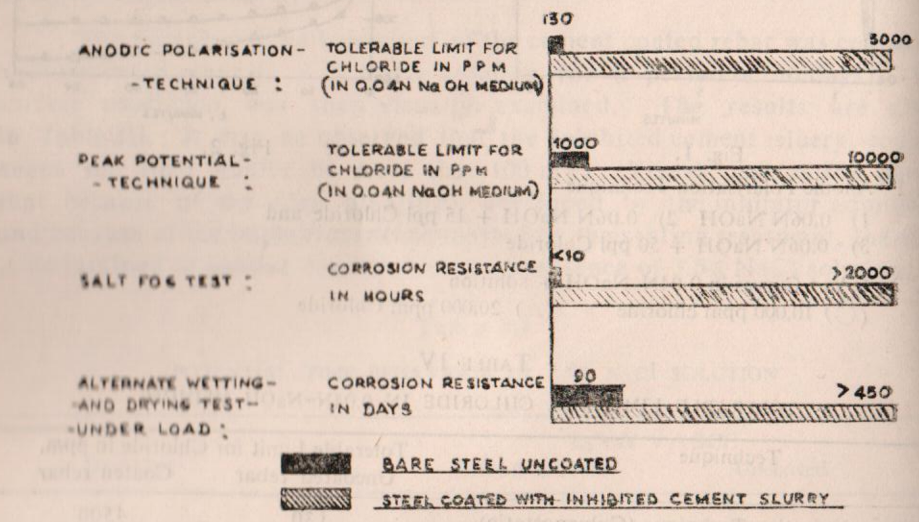

Fig. 3. Comparative performance of inhibited cement slurry coating in laboratory accelerated corrosion tests

Coating evaluation using precracked model slabs :

A notched and cantilever loaded slab was used to produce crack of specified width parallal to the length of test specimen embedded in concrete. The slab was fixed at one end in between two M. S. plates and stressed to produce crack of desired width. By downward deflection at the free end a single longitudinal crack formed along the root of the notch parallal to the test specimen. The width of the crack was accurately monitored using travelling microscope. After precracking, the salb along with the loading frame was taken to the exposure yard and subjected to alternate wetting and drying test. At the end of the test period, the slab was broken open, test specimen removed, derusted and weight loss due to corrosion determined. The precracking arrangement is shown in fig 4. Mix M20 OPC was used in these studies. Durability factor was worked out by comparing the corrosion rate of coated steel with that of the uncoated steel specimen.

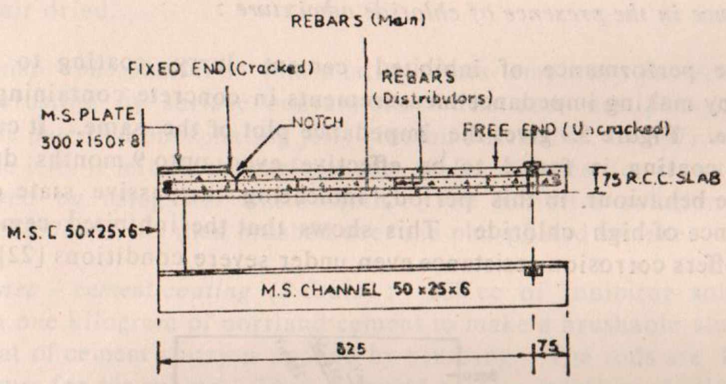

Fig. 4 Precracking arrangement for cantilever model slab studies

At the exposure yard the slabs were subjected to alternate wetting with 3% NaCl solution and drying whereas at Mandapam, the slabs were subjected to alternate wetting with natural sea water and drying. The results are given in table VI. It is seen that the inhibited cement slurry coating is able to increase the durability by a factor of 25 to 35 even under this cracked model slab studies with a crackwidth of 0.3mm.

TABLE VI

EXPOSURE STUDIES ON PRECRACKED MODEL SLABS AT KARAIKUDI & MANDABAM

Crackwidth mm	Expoure period days	Corrosion Rate (mmpy) uncoated 'a'	coated 'b'	Durability Factor 'a/b'
0.3 (Karaikudi)	182	0.257	0.007	36
0.3 (Mandapam)	365	0.102	0.004	25

Alternate wetting and drying tests :

Mix M20 OPC concrete cubes of 100 mm size with steel specimens were subjected to alternate wetting and drying tests under uncracked condition at Corrosion Testing Station, Mandapam, using natural seawater. These studies show a corrosion rate of 0.271 mm/year for uncoated specimens against 0.004 mm/year for inhibited cement slurry coated specimens leading to a durability factor around 68. This shows that the durability factor is still higher under uncraked condition compared to craked condition.

Performance in the presence of chloride admixture :

The performance of inhibited cement slurry coating to steel was assessed by making impedance measurements in concrete containing 4% NaCl admixture. Figure 5. gives the impedance plot of the same. It can be seen that the coating is found to be effective even upto 9 months due to the capacitive behaviour in this period, indicating the passive state of steel in the presence of high chloride. This shows that the inhibited cement slurry coating offers corrosion resistance even under severe conditions [22].

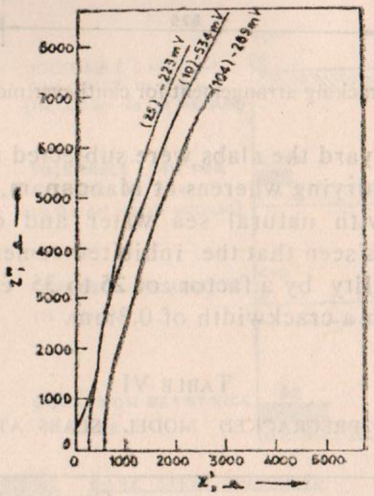

Fig. 5. Impedance behaviour of RC specimens with CECRI inhibited cement slurry coating to steel.

COST OF TREATMENT

Field data collected during 1986 at one of the bridge sites show that the cost of the treatment is around Rs. 1200/metric tonne of steel or approximately Rs 46/m². Roughly it works out to 25% of the cost of the steel.

ANNEXURE

Application procedure :

1st step – derusting : Since rust tends to absorb salt and moisture and accelerated corrosion, use of rusted steel in concrete is to be avoided. Derusting is done by dipping the reinforcement rods in the derusting solution (Indian Patent No. 465/Cal/75) till the rust is removed satisfactorily and a bright surface is obtained. Normally this may take about 15 to 30 minutes. This is followed without delay by cleaning the rods with wet waste cloth carrying alkaline powder. Alternatively the rods may be rinsed well in good water and air dried.

2nd step - phosphating : Phosphating offers temporary protection and prevents rerusting by surface conversion. The rods are phosphated by brushing the patented phosphating jelly (Indian Patent No. 109897) with fibre brush. The jelly is left on the surface for 40-60 minutes for reaction and then removed by using wet waste cloth. The inhibitor solution (Indian Patent No. 109784/67) is then brushed over the phosphated surface.

3rd step – cement coating (2 coats) : 500 cc of inhibitor solution is mixed with one kilogram of portland cement to make a brushable slurry and the first coat of cement slurry is applied by brushing. The rods are kept for 12 to 24 hours for air curing. Then patented sealing solution (Indian Patent No. 112440/67) is brushed. 600 cc of inhibitor solution is mixed with one kilogram of portland cement to make a brushable slurry and the second coat of cement slurry is applied by brushing. Air dried for 12-24 hours.

4th step – sealing : Sealing solution is brushed and kept for 4 hours 2nd coat of sealing solution is then applied. This sealing process effectively seals the pores in the cement coat and makes it impermeable.

The entire procedure will take about three days.

Patented products involved :

		Patent No.
i)	Acid inhibitor in solid form (Derusting Solution)	465/Cal/75
ii)	Rust preventing composition (Phosphating Jelly)	109897
iii)	Corrosion prevention in reinforced concrete and brick constructions (Inhibitor solution)	109784/67
iv)	Portland cement coating for steel (Sealing solution)	112440/67

Approximate quantity of products required per ton of steel reinforcement :

Derusting Solution	50-75 litres
Phosphating Jelly	10 litres
Inhibitor Solution	15-20 litres
Sealing Solution	15-20 litres
Cleaning Powder	1.5 Kg
Portland Cement	15 Kg

Important note :

a) The cement slurry coating should be given only after all shaping and bending operations are completed. No reinforcement bars shall be bent after giving the coating.

b) Specified thickness of the coating should never be exceeded. For this, the specified consistancy should be maintained. Excess coating thickness may lead to peeling/flaking.

REFERENCES

1 C E Bird and F J Strauss, *Mater Prot* 6-7 (1967) 48

2 L H Everett and K W J Treadaway Current paper CP 3/70 Building Research Station, Garston, Watford WD2 7JR UK (1970)

3 N S Rengaswamy and V S Muralidharan *Corrosion Bulletin* 4-4 (1984) 189

4 A Harry Cock, *Concrete (London)* 11-1 (1977) 31-33

5 R Janes Clifton, *Materials Performance* 15, 5 (1976) 14-17

6 W P Kilaresh, Epoxy Coatings for Corrosion Protection of Reinforcement steel, Chloride Corrosion of steel in Concrete, ASTM STP629, D E Tonian and S W Dean Jr Ed ASTM (1977) p 82

7 T E Backstrom, Corrosion of metals in concrete, Publication SP-49, *American Concrete Institute* USA (1975) p 103

8 B F Troupyanskii, *Stroit prom* 31 (1953) 9

9 A G Metallo Chemishe Fabrick Germ Pat 676 842 13 June (1939), *Chemi Abstr* 33 (1939) 7518

10 M Surlen, *Chem Abstr* 23 (1929) 4041

11 M Figaret, *Pemit Pigm Vern* 30 (1954) 393

12 L H Sommonsson and L T Ulfstedt, U S Pat 261 1945 30 Sept (1952), *Chem Abstr* 47 (1952) 475

13 L H Sommonsson and L T Ulfstedt, U S Pat 2591625 1 April (1952) of *Chem Abstr* 46 (1952) 6582

14 M Hamada, *Trans Inst Jap Archit* 9 (1938) 51

15 Centre Belg de' tude de la corrosion Cebelcor Belgium Pat 506, 131, 16 Jan 1952 of *Chem Abst* 48 (1954) 7530

16 Centre Belg de tude la corrosion, Belgium pat 509, 370 18 June (1952) of *Chemical Abst* 48 (1954) 7530

17 T D Robson, *Corros Technol* 2 (1955) 66 & 96

18 G Dougill *Br Pat* 506131

19 L T Ulfstedt Internatinella, Siporex Aktiebolage Sived Pat 152, 961, 3 Jan 1956 *Chem Abstr* 50 (1956) 7047

20 N S Rengaswamy T M Balasubramanian and K S Rajagopalan *J Electrochem Soc* India 26 2 (1977) 19

21 K S Rajagopalan N S Rengaswamy T M Balasubramanian G Venkatachari and R P Singh, *Preprints of the second International symposium on Industrial and Oriented Basis Electrochemistry* SAEST Karaikudi 623 006 (INDIA) (1980) p 6. 21.1

22 S Srinivasan G Venkatachari N S Rengaswamy and K Balakrishnan, *Proc 10th International Congress on Metallic Corrosion* : Central Electrochemical Research Institute Oxford and IBH Publishing Co., Pvt. Ltd. New Delhi Vol II (1987) 1525

DISCUSSION

G. B. Naik, Thana Creek Bridge Division, New Bombay

Q. Is there a coating which will protect M. T. S. strands before prestress and which will not become brittle after prestressing? What is its durability?

A. To our knowledge, no such coatings have been tried on prestressing steel

S. C. Gupta, Thane creek Bridge Metropolitan Transport (Railways), Bombay

Q. Is bending and welding of bars is permitted after the treatment

A. No.

Q. Phosphating and again cleaning is a cumbersome process. Can it be simplified?

A. Through cumbersome it is an essential step.

Q. At what stage the derusting acid has to be changed? What is the test procedure to be adopted at the site for the the same.

A. We have to change the derusting solution when the expected efficiency is not obtained.