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ORGANIC/METALLIC COATINGS FOR REBARS

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Rebars in R. C. C. construction are generally of mild steel. Due to porous nature of concrete structures, sulphate, chloride, oxygen and moisture penetrate the concrete in course of time and corrode the steel bars even though it has got a passive film due to the alkaline environment. This problem is severe in coastal areas of our country. Corrosion product of the steel rebar increases its volume upto 10–12 times due to which cracking and spalling takes place, leading to failure of the concrete structures. Metallic or organic coatings are applied on the rebar in order to prevent its corrosion. The organic coatings used are Epoxy (liquid/powder) vinyl, phenolic, polyurethane, zinc rich and polypropylene etc. and metallic coatings like Zn, Cd, Cr, Ni and Al are considered. This review paper describes the performance of organic/metallic coating on rebars.

Key words : Rebar, Galvanizing, epoxy.

INTRODUCTION

It is known that steel exposed to moist air and salts undergoes corrosion and forms corrosion products which occupy large volume. But when embedded in concrete, a thin passive oxide film rapidly forms in the steel in the presence of oxygen and water soluble alkaline hydration products of concrete. The quality of concrete and its thickness will provide protection against the ingress of moisture, oxygen and other corrosion elements.

However, the passivating film is not giving continuous protection to steel when concrete is exposed to marine and industrial atmospheres. Once corrosion occurs, the massive increase in volume of the corrosion products causes spalling and cracking leading to failure [1]. This paper reviews the data obtained on different metallic and organic coatings for rebars.

METALLIC COATINGS

During the past twenty years several reports [2, 3] have been published which show that the deterioration of concrete is due to rebar corrosion in corrosive environment. Galvanised steel was generally recommended for long durability.

A study of galvanised steel reinforcing bar which had been embedded in concrete for 54 years exposed to sea, showed that most of the zinc film was intact [4]. Penetration and rusting of steel bars had occured in only

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few places. The potential Vs pH diagram for zinc on water shows extensive corrosive zones at both low and high pH values. The diagram indicates zone of passivation in the pH range 8.5 to 11.7 corresponding to the formation of Zn $(OH)_2$ [5]. Zinc in contact with fresh mortar (pH 13) may undergo some corrosion.

It is mentioned that the existing data on corrosion rates of zinc coated steel do not allow the performance over 60 years life period especially where variable environmental conditions prevail [6]. On the assumption that the corrosion data for zinc can be used to predict the life expectancy of galvanised coatings, zinc and zinc/iron alloy layer are considered to corrode approximately at the same rate [7].

Corrosion probes were made from 99.95% pure zinc foil of 0.15mm thickness, cleaned with silicon carbide of 600 grade papers and degreased with acetone [8]. Parts of these zinc probes were chromated. These probes were embedded in 1 : 1 : 6 (Cement : lime : sand) mortar block. Corrosion measurements were made using CK-3 portable corrosometer manufactured by Magna Instruments Ltd, at 100% relative humidity at 25° ± 1°C for nearly four years. The results are given in the Table I.

TABLE I

RESULTS OF CORROSION TESTS

Sample details	Time for initial corrosion (days)	Integrated corrosion rate (mpy)
Zinc/mortar	a) No corrosion at 1367 days	—
	b) No corrosion at 1367 days	—
Chromated Zinc/mortar	a) Slight attack commencing at start of test	0.01
	b) Slight attack commencing at start of test	0.01
Zinc/mortar carbonated	a) Between 214 and 434 days	0.02
	b) Between 275 and 434 days	0.03
Chromated zinc/mortar carbonated	a) Between 434 and 501 days	0.005
	b) No corrosion at 731 days	—
Zinc Mortar 1.5% $CaCl_2$	a) Between 908 and 1067 days	0.12
	b) Slight attack commencing at start of test	0.005
Chromated Zinc/Mortar 1.5% $CaCl_2$	a) Slight attack commencing at start of test	0.01
	b) -do-	0.01
Zinc/Mortar carbonated 1.5 $CaCl_2$	a) Between 8 and 32 days	0.36
	b) Between 32 and 109 days	0.40
Chromated Zinc/mortar carbonated 1.5% $CaCl_2$	a) Slight attack commencing at start of test	0.005
	b) Between 8 and 32 days	0.05

N. B: "a" and "b" are duplicated experiments

No corrosion was found on zinc in uncarbonated samples with no chloride additions. Zinc probes protected by chromate passivation coatings showed substantial reduction in corrosion rate ranging from 0.005 to 0.05mpy for highly-carbonated samples containing 1.5% $CaCl_2$.

Tests were conducted on 60 stressed concrete beams reinforced with galvanised bars or black steel bars [9]. 24 of these were tested after exposure to 3% sodium chloride solution for a duration of 6-12 months in cracked condition. The longer the duration of exposure to NaCl solution, the lower was the fatigue strength of a bar in concrete due to corrosion near the crack openings. However, the degree of reduction of fatigue strength was less, for galvanised steel bars. The durability of reinforced concrete against 3% NaCl solution or sea water will be improved by using galvanised reinforcing bars. By using galvanised steel, the durability of concrete members with cracks of about 0.3 mm width will have the same durability as ordinary reinforced concrete with crack width of about 0.2 mm. The use of galvanised steel did not significantly affect the fatigue strength.

The performance of plain round bar, deformed reinforcing bar and galvanised steel bar has been studied [10]. After aging for 28 days, the concrete specimens were maintained at a working stress of 20000 psi. Specimens subjected to air showed no cracks or rust stains after 24 months. In 4% NaCl solution for 3 days, alternating with 4 days of drying, four out of six reinforcements with black bar cracked after 9 months and another one after 18 months. None of the six galvanised bar specimens cracked after 15 months exposure. Three specimens cracked between 16-23 months. The remaining 3 specimens were uncracked after 23 months. In 4% NaCl solution with impressed anodic current of 20 mA / sq.ft. specimens with black reinforcement showed vertical cracking in one month. After 2 months exposure, the cracks appeared in the specimens with galvanised reinforcement. The average length and width of cracks were less for specimens reinforced with galvanised bars than for either plain or with deformed black bar.

Galvanised reinforcement can be advantageous in an aggressive environment, first by protecting the steel before concrete is cast, second by delaying rust stains, crack formation and spalling of concrete and reducing the rate of attack. Some studies show that galvanised steel can tolerate a substantially higher chloride ion concentration without film breakdown and loss of passivity [11].

Various metallic coatings over steel have been evaluated [12]. Specimens with coatings and bare steel were embedded in concrete blocks which were exposed in a high humidity room for two months to determine the weight loss. After exposure the specimens were removed from concrete, cleaned and reweighed. Similar bare metal specimens were immersed in sea water and the weight loss was determined after 2 months exposure. Only cadmium and zinc provided galvanic protection to steel under the environmental conditions. In sea water, copper, nickel, tin and lead were cathodic to steel (Table II). Lead and tin were anodic to steel as long as pH remained strongly alkaline but the rates of self corrosion were relatively higher. Zinc (1.0 Oz/sq. ft) and cadmium (0.53 Oz/sq. ft)) coated steel rods together with uncoated control specimens were embedded in concrete blocks. The blocks were cured for 7 days and then exposed to salt spray test. After 3 years exposure the control steel and galvanised steel showed general corrosion. Cadmium coating had only blackened and in fact showed a slight increase in weight as compared with its original weight.

TABLE II

POTENTIAL MEASUREMENTS AGAINST SCE AND WEIGHT LOSS

	Normal Potential	Sea water		Mortar		Mortar Containing 1% salt
		Potential	Weight loss mgm/cm²	Potential	Weight loss mgm/cm²	potential
Nickel	−0.484	−0.210	0.1	+0.040	0.00	−0.140
Copper	+0.110	−0.210	4.3	−0.200	0.42	−0.200
Steel	−0.674	−0.720	15.3	−0.180	0.00	−0.450
Tin	−0.370	−0.490	1.1	−0.980	2.50	−1.010
Cadmium	−0.636	−0.760	4.3	−0.870	1.50	−0.830
Lead	−0.360	−0.510	4.4	−0.650	6.85	−0.760
Zinc	−0.996	−1.060	9.4	−0.450	0.17	−0.795

ORGANIC COATING

The performance of the epoxy coated reinforcing bar has been compared with plain uncoated and galvanised bars. The tests were carried out on centrally reinforced concrete prisms with variable cover thickness and preformed cracks of maximum width of 0.10-0.25 mm

The epoxy coated bars were produced by the process (blast cleaning, preheating, electrostatic - spraying and baking). If any holidays were present they were touched up. These test specimens were embedded, in square concrete prism with various thickness of 20, 40 and 70 mm. The concrete was designed for the compressive strength, 240 kg/cm² after 28 days. The specimens were loaded gradually until the stress in the bar reached a value of 3000 Kg/cm².

The bars were subjected to a tensile stress of 2000 Kg/cm² and immersed in sea water at 60°C for 6 hours and allowed to dry in the atmosphere for 6 hours. This wet and dry cycle of six hours repeated for 24 months. The wet and dry cycle of six hours was chosen to represent the high and low tides.

In another study, specimens with tensile stress of 2000 kg/cm² were also exposed in the tidal zone for 24 months. Red rust completely covered the surface of the concrete embedded with uncoated bars with 20 and 40 mm cover thickness. In the case of galvanised bars with cover thickness of 20mm, 70% of the area had been covered with red rust formation. Specimens with 40 and 70 mm concrete cover thickness showed only 4-8% red rust formation. Powder coated epoxies showed no red rust formation on the surface The epoxy powder coated bars with 200 um thickness or more has retained the initial values of gloss, adhesive strength, peeling and hardness even after 24 months against chloride attack irrespective of the concrete cover thickness.

The performance of Epoxy, powder epoxy, polyvinyl chloride, polypropylene (powder) phenolic nitrile and zinc rich coatings has been investigated for one year in the following media:

i) 3 M $CaCl_2$ aqueous solution
ii) 3 M NaOH aqueous solution
iii) a solution saturated with $Ca(OH)_2$ and $CaSO_4.2H_2O$ and also containing 0.5M $CaCl_2$.

In general epoxy coatings (both liquid and powder) were not affected by these chemicals.

Chloride permeation characteristics were determined using the permeability cell [15]. The cured films of powder epoxies were essentially impervious to chloride ion during the exposure period of atleast 37 weeks. More variable results were obtained with the cured films of liquid epoxies. The moderately thick film (7 ± 2mil) of powder epoxy coatings performed adequately under bond test. A few polyvinyl chloride coatings with 875 μm (35 mil) thickness passed.

Acceptable bond strength for coated bars is taken as not less than 80% of the strengh of uncoated bars. Powder and liquid epoxy coated bars with thickness about 10 mils developed bond strength which were only slightly less than the bond strength of uncoated bars. PVC coated bars had only about 14-60% of the bond strength of uncoated bars.

CONCLUSION

While selecting a coating system for rebar first consideration should be given to the durability of the coating when exposed to the aggressive environment. The coating should tolerate poor surface preparation, have easy applicability in the field and it should provide adequate bond strength to steel and concrete. It appears from the review that the zinc, cadmium coatings, epoxy coating (liquid resin and powder) chlorinated rubber and vinyl coatings may be considered for detailed studies.

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