INHIBITED PORTLAND CEMENT SLURRY COATING TO PREVENT STEEL REINFORCEMENT CORROSION

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The problem of reinforcement corrosion is briefly discussed with reference to instances of failures, factors responsible and preventive methods in general. Earlier work on coating to steel reinforcements is described and the need for the development of a cheap and effective coating to steel is pointed out. Data on bonding properties, laboratory performance, field exposure studies and feasibility trial at Pamban bridge site on a new inhibited cement slurry coating developed in the Institute are presented and it is concluded that the new coating can give satisfactory protection to steel reinforcements both during storage and when laid in concrete under aggressive atmospheric conditions without having any adverse effect on the bonding between steel and concrete It is also shown that the coating procedure is quite feasible under field conditions.

The problem of reinforcement corrosion - instances - causes.

The annual demand of reinforcing steel in this country during 1970-71 was of the order of 1.5 million tons.[1] Total investment on reinforced concrete structures during the Fourth Five Year Plan period was estimated[2] to be Rs. 2000 crores. This may be expected to be more than Rs.3000 crores during the current plan period.

The corrosion of steel reinforcement embedded in concrete is of greater importance than the other cases of corrosion of metals not merely because of the greater tonnage of metal involved but also because of the load bearing nature of the steel-concrete combination. In a general way it may be stated that concrete of good quality offers better protection than one of bad quality, but a question of greater interest is whether all good quality concrete will give adequate protection.

A survey[3-4] conducted by the National Buildings Organisation, New Delhi and the Centra Electrochemical Research Institute, Karaikudi, revealed premature failure of roofings of reinforced concrete and reinforced brick constructions in this country. Our country has a long coast line with a number of rivers requiring the construction of numerous bridges along the coast for maintaining vital communication links. Studies conducted on a few of these structures revealed[5] that they had deteriorated within a short span and have thus become a problem of immediate concern. The present codal specifications prevalent in the country apart from recommending additional cover of concrete and limiting the crack widths within acceptable limits, offer guidance to the designer.

As a protective material for steel, concrete allows water, oxygen and salts to pass through it, not withstanding its very valuable property as a load-bearing material when reinforced with steel.[6-8]. However, the liquid phase in concrete is highly alkaline with a pH of 12-13 and in this pH range steel becomes passive and gets protection. This protection may be endangered by one or more of the following factors[9] : (i) use of poor quality concrete, (ii) inadequate cover, (iii) the pressure in concrete of chloride and sulphate in amounts sufficient to break down the passivity, (iv) the use of rusted steel reinforcement, (v) the use of corrosive substances as admixtures and (vi) cracks in the cover.

Preventive methods

Since corrosion of reinforcing steel is due primarily to the penetration of moisture, chloride and air, preventive methods must either prevent the penetration of these materials or render the reinforcement passive to their action. Though the application of water impermeable surface coating to concrete[10] can be considered for both existing structures and those to be constructed in future, once salts and moisture are present in concrete, the effectiveness and durability of surface coating over concrete becomes questionable.[11] It is common experience that reinforcement rods get rusted at site or during storage before they are laid in concrete. The salt present in the rust can continue the rusting process inside the concrete and it may not be possible for an inhibitor admixture in concrete to counteract their harmful effects. In marine atmosphere, corrosive salts can get into the pores of the concrete and are thereby likely to increase the salt concentration at the reinforcement. Besides, concrete itself may be subjected to deterioration due to sea water action. Under such extreme conditions, it is necessary to give a protective coating to steel reinforcement before it is laid in concrete.

Earlier work on coating to steel reinforcements

Bird[12] studied the effects of metallic coatings such as nickel, cadmium, copper, lead and tin besides zinc coating to steel in concrete. The tests indicated that apart from cadmium, none of the other coatings were satisfactory. However, in recent years, there has been an increasing use of galvanising as a protection against corrosion of reinforcing steel, particularly in U.S.A. and U.K.[13] It is of prime importance that bond strength should not be lowered significantly when galvanised steel is employed. Much interest has been shown in this aspect and experiments have yielded variable results. Loss of bond with galvanised wire reinforcement has been recorded by Bird[14] Corrosion of galvanised steel has been reported[15-17] and additional protection of a bitumen paint coating has been advocated. Besides galvanising is not cheap. It adds about 65% to the basic fabricated cost of the reinforcing.[18]

Various passivating treatments for reinforcing steel have been suggested, such as pickling in hydrochloric acid followed by treatment with phosphoric acid[19] and treatment with a hydrolysable silicate or hydrated silica.[20] Simple preliminary coating of steel with a dense mortar is recommended to counteract acid fumes[21] The application of coatings of cement containing paints with water proofing admixtures[22] or of slurries of lime and cement with casein or bone glue[23,24] 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.[25] Combinations of inhibiting agents in cement slurries are also proposed, notably sodium dichromate,[26] sodium carbonate, sodium phosphate,[27] sodium benzoate[28,29] and also barium chromate.[30] 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. At present the cost of epoxy coatings and the precision techniques involved present practical difficulties in their use. Experience with long term behaviour of polymer coatings on steel in concrete is yet to be known.

From the point of view of economy and bonding characteristics, it was decided to examine the efficiency of the various inhibitor additions to cement slurry that have been suggested in literature. Immersion tests conducted in synthetic sea water showed that ammonium stearate- glue mixture seemed to be the most effective of all the systems examined.[31] Even this system failed when tested under more accelerated condition in a salt fog chamber. Apart from the poor corrosion resistance, the adhesion and hardness of the coating systems were also very poor. Finally a new protective coating based on cement slurry and an inhibitor system was developed and the characteristics and efficiency of the new coating system are presented in this paper.

New inhibited cement slurry coating developed at C.E.C.R.I., Karaikudi

The new coating is based entirely on indigenously available raw materials and it does not incorporate any toxic constituents. The coating can be applied by brushing, dipping or spraying. Brushing is easier and economical. It is preferable that the coating is applied on the steel reinforcement after all the bending operations are over so that the damage to coating during bending is minimised. However, the defects if any in the coating can be easily touched up.

Bonding properties

The bonding strength between the coated reinforcement and concrete was tested by conducting standard pull out tests in a 30 Tons Avery Universal Testing machine. The average of nine results is shown in table I and it may be seen that the coating does not adversely affect the bonding. No adverse report has been received from Tamil Nadu Highways department who conducted pull out tests with a number of bars with the new coating system reported here.[32]

TABLE I

No.	System	Bonding Strength (Average) Kg/cm²
1.	Control (without any coating on steel)	20 (20.6 ± 3)
2.	Steel coated with cement slurry developed at C.E.C.R.I., Karaikudi.	22.6 (23.15 ± 3.85)

Laboratory performance

The laboratory performance of the new coating is compared with those of some commonly known protective schemes for steel structures in table 2 and 3 and it is seen that the new protective coating is resistant to chloride, alkaline medium, sulphate and high temperature.

TABLE 2 Comparison of the Performance of the new Coating Developed with some Commonly Known Protective Schemes

Test	Protective scheme	Performance
300 hr in salt fog chamber	New scheme	Good
	4 coats of bituminous paint	Good, but paint softens and is easily removed
	2 coats of red lead + 2 coats of red oxide	Good
Immersion in 10% sodium hydroxide solution for 5 days	New scheme	Good
	4 coats of bitumious paint	Good, but bulging all over the surface
	2 coats of red lead + 2 coats of red oxide	Paint dissolves
Immersion in ammonium sulphate solution for 15 days	New scheme	Good
	4 coats of bituminous paint	Good
	2 coats of red lead + 2 coats of red oxids	Good
Immersion in hot water (70-90°C) for 7 days	New scheme	Good

TABLE 3 Comparison of the Performance of the new Coating with that of Portland Cement Slurry Coating

Protective coating	Protection against corrosion (300 hr in salt fog chamber)	Abrasion resistance and adhesion
Portland cement slurry coating	Uniform and heavy rusting of steel base	Easily removed when scrapped with a sharp tool
New protective coating	Steel base unaffected	Hard to remove by brushing or scraping

Field Exposure Studies

Field investigations were also undertaken at a number of sites representing different climatic zones in the country to test out the new coating since it was felt that field evaluation will carry more conviction with the engineers, architects and builders. For field studies 152.5 mm (6") size concrete cubes with embedded steel specimens of the type shown in figure was used This type of specimen has the advantage that the effect of cover thickness is studied along with the other parameters. On the basis of analysis of a large number of samples of cement sand, water and stone aggregate collected from various places in the country the ranges of chloride and sulphate that are likely to be present in concrete have been worked out earlier.[7] The protection afforded by inhibited cement slurry coating was studied in concrete containing maximum amounts of chloride and sulphate in the above range.

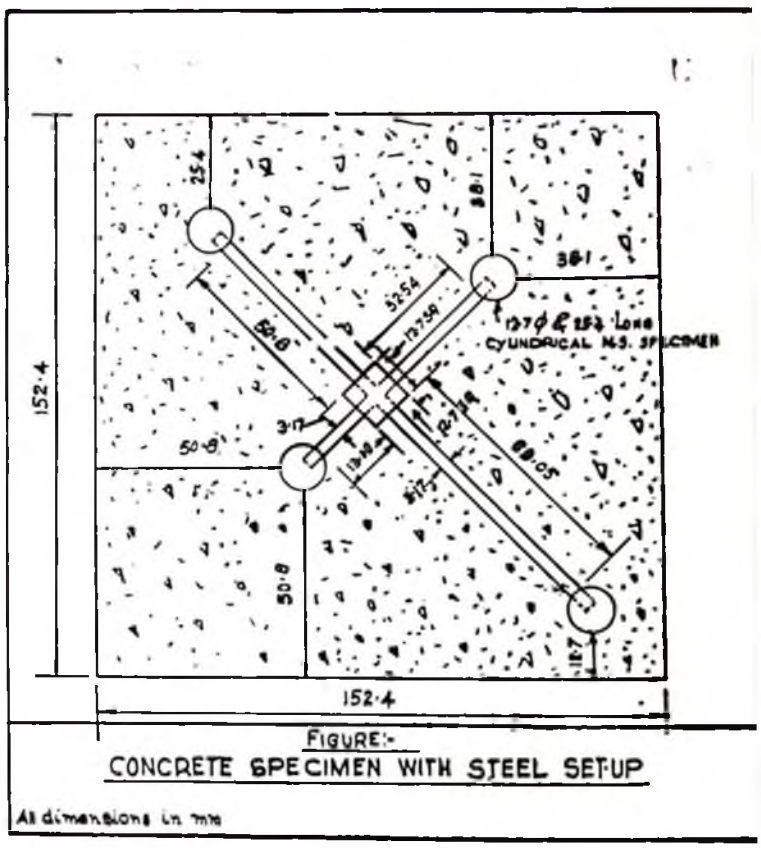


FIGURE:-
CONCRETE SPECIMEN WITH STEEL SET-UP

TABLE 4 PERCENTAGE PROTECTION GIVEN BY CEMENT SLURRY COATING

Sl. No.	Exposure Station	Exposure period (months)	Maximum Salt Cover Thickness (mm)				Cement coating to steel (Maximum Salt) Cover Thickness (mm)			
			13	25	38	50	13	25	38	50
1.	Mandapam	12	10	nil	90	90	nil	100	100	50
		24	10	10	50	100	100	100	100	100
		48	10	nil	100	50	100	100	100	100
2.	New Delhi	12	nil	100	90	nil	100	100	100	100
		41	nil	50	nil	100	75	100	100	100
3.	Jorhat	20	nil	100	95	90	100	100	100	100
		36	nil	50	50	50	100	100	100	100
4.	Bangalore	22	nil	nil	100	100	87	40	100	100
		45	nil	100	100	90	100	100	100	100
5.	Bombay	43	nil	nil	50	nil	92	100	100	100
6.	Nagpur	12	nil	100	100	100	70	100	100	100

Referring to tables 4 and 5, it is seen that even at 13 mm cover 100% protection is obtained at Mandapam, New Delhi, Jorhat and Bangalore. 70-90% protection is obtained at Bombay, and Nagpur. At 25 mm cover and above 100% protection is obtained at all stations.

TABLE 5 Weight Loss in Millimetre/year :

Sl. No.	Exposure Station	Exposure period (months)	Maximum Salt Cover Thickness (mm)				Cement coating to steel Maximum Salt Cover Thickness (mm)			
			13	25	38	50	13	25	38	50
1.	Mandapam	12	0.0040	0.0040	—	0.0006	0.0075	—	0.0010	0.0003
		24	0 0188	0.0025	—*	0	0	0	0	0
		48	0.0100	—	0	—	—	0	0	0
2.	New Delhi	12	0.0183	0	0	0.0190	0	0	0	0
		41	0.0199	0.0005	0.0122	0	0.0050	*	0	0
3.	Jorhat	20	0.0177	0 0006	0.0002	—	0	0	0	neg*
		36	0 0155	0.0013	0 0018	0.0094	0	0	0	0
4.	Bangalore	22	0.0143	0.0104	0	0	0.0019	0.0062	0	0
		45	0.0049	0	0	0	0	0	0	0
5.	Bombay	43	0.0201	0.3121*	—*	0.0073	0.0017	—	—	—
6.	Nagpur	12	0.0250	0	0	0	0.0858*	0	0	0

* 2 out of 3 good.

To assess the extent of protection given by the new coating to steel reinforcements during storage at site, 150mm x 100mm cement coated mild steel panels were exposed at the most aggressive shore site at Mandapam Camp. Tamil Nadu and it was found that the coating gives temporary protection upto a period of 5-6 months under such extreme conditions.

Feasibility trial at Pamban bridge site, Mandapam, Tamil Nadu.

The construction of a high level bridge across Pamban Strait near Remeswaram Island on National Highway 49 (Madurai-Dhanushkodi Road) at an estimated cost of Rs.5.3287 crores is in progress. Total amount of steel involved in the work is estimated to be of the order of 4500 tons. The construction site is surrounded by sea on both sides and is subject to high saline atmosphere. Electrical transmission poles erected at site have shown heavy rusting and spalling within few years of erection. Reinforcement rods stored at site get heavily rusted before use in concrete. Hence at the request of the Pamban bridge authorities, a feasibility trial on the coating procedure was conducted at bridge site. Reinforcement rods of different diameters (10mm-34mm) and different lengths (1 metre to 3 metres) weighing about 250 kgs were used for trial and demonstration. Later Rs. 15,000 worth of chemicals were supplied to authorities for treating about 35-50 tons of steel reinforcements going into construction.

The coating procedure is given in Annexure. In field scale, the approximate cost of the inhibited cement slurry coating per ton of steel reinforcement may work out to Rs. 170-180.

Conclusion

On the basis of accelerated laboratory tests and field exposure studies carried out in different places in the country it is concluded that the new inhibited cement slurry coating developed at C.E.C.R.I., can give satisfactory protection to steel reinforcements both during storage and when laid in concrete under aggressive atmospheric conditions without having any adverse effect on the bonding between steel and concrete. Large scale trial and demonstration studies carried out at a construction site show that the coating procedure is quite feasible under field conditions.

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ANNEXURE

Particulars About Portland Cement Coating to Steel Reinforcements

(Process developed at Central Electrochemical Research Institute. Karaikudi).

Coating Procedure :

Dip the reinforcement rods in the derusting solution (Indian Patent No.465/Cal/75) and remove the rods as soon as the rust is removed satisfactorily and a bright surface is obtained. This should be followed without delay by cleaning the rods with wet waste cloth carrying alkaline cleaning powder (e.g. "BIZ") and brushing the phosphating jelly (Indian Patent No.109897) with fibre brush.

Leave the phosphating jelly on the surface for 45-60 minutes and remove the jelly by using wet waste cloth.

Next brush the inhibitor solution (Indian Patent No 10 784/67) and brush the first coat of (cement slurry is prepared by mixing 500 c.c.s. of inhibitor solution for each 1000 g of portland cement).

All these steps are to be completed in the same day. After 12-24 hours of air drying brush the sealing solution (Indian Patent No. 112440/67) and brush the second coat of cement slurry.

After 12-24 hours of air drying brush the sealing solution and after 4 hours of air drying again brush the sealing solution.

Solution consumption per ton of reinforcing steel.

Derusting solution	50 litres	)
Phosphating jelly	10 ,,	|
Inhibitor solution	20 ,,	} (approx.,)
Sealing solution	20 ,,	|
Cleaning powder	1.5 kg	|
Portland cement	15 kg	)

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