

AN EXPERIMENTAL STUDY ON PREVENTION OF REINFORCEMENT CORROSION IN CONCRETE STRUCTURES

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ABSTRACT

Due to rapid urbanization all over the world, there is a necessity to construct and use concrete structures with reinforcement of steel viz. high rise buildings, tunnels, railway sleepers, bridges, turbo generator foundations, nuclear power plants, dams, reservoirs etc.

Corrosion of embedded steel of the pre-stressed concrete structure is a universal problem and has revived scientific attention during the last few decades. In general the loss of alkalinity of concrete caused by the entry of carbon dioxide leads to the corrosion of reinforcement, if moisture and oxygen are present. Many developments regarding to physical properties of embedded metal and the concrete have come up. However, regular monitoring of the health of concrete structure has become a very complicated task, because of the intricate and sophisticated design of structures and use of complicated instruments, the interpretation of data requires specialized knowledge. Here an attempt has been made to visualize the “surface-state of the steel embedded in concrete concast, though the interpretation of potential-time data, potential being recorded routinely. Some easily available common materials have been used to see their performance on the potential development at the metal solution interface-Polystyrene, red oxide, black Japan and aluminum paint have been examined. Bond strength between reinforcement and concrete is also taken into consideration while using paint as an anticorrosive material.

Red oxide has been tested as a concrete admixture. Chemicals like sodium Hexa-meta phosphate (HMP) and calcium chloride have been tested for their positive and negative behavior of the maintenance/deterioration of stable potential.

Keywords: *Concrete, Structure, Corrosion, Bond strength, Reinforcement, Durability, Potential, Pre-stressed concrete.*

1. INTRODUCTION

In every country tons of steel is used to strengthen the concrete structures in the form of embedded ribs, hence life of those embedded ribs pose a constant challenge of corrosion to scientists and engineers. Already, much attention has been paid to the research work in this field and to the development of process and products to meet the challenge. Although enormous amounts of literature remains for user engineers to get help from, but the main drawback lies with the laboratory data and users avail raw materials which often result into disastrous findings, much away from the laboratory predictions. Residual life in most cases is too much dependant on the raw-materials and workmanship in practice. The residual life of the concrete structures exposed to varied and aggressive environment depends on the depth of carbonation and de-alkalization of the cast-concrete is a well known phenomenon, yet focus on this aspect is very limited. Also, methods of de-carbonization and delayed alkalization have not been paid systematic research approach.

When steel embedded in concrete corrodes, the increase in volume from metallic steel to corrosion product produces an expansive force, which can rupture the concrete. After a crack has been formed in this way, the steel corrodes even more rapidly, leading ultimately to complete failure of the structural member involved. Therefore premature deterioration of reinforced concrete structures due to corrosion of the reinforcing steel is a concern worldwide.

In some publication Viz. David, P.et.al.[1], Blighat, G.E.[2] and others, corrosion prevention technique of concrete structure has been discussed. They have shown that a water proof coating on the surface of the concrete prevents the entry of salt, water and air, which would prevent steel corrosion. This method of corrosion prevention had met with many objections from Civil Engineers who have strong ideas on the subject of appearance of reinforced concrete structures. However, it has been reported that, even though the waterproof coating is applied, the aggressive materials have penetrated.

One of the method of corrosion prevention technique is to screen the steel itself from the concrete and thus from the aggressive medium. This can be achieved either by employing a non-reaching metal coating, paint or other type of coating, or by producing a non-reactive film using inhibitors or polarization techniques.

The effectiveness of addition of Sodium benzoate, Sodium nitrate or Calcium chromate complexes to the mix, application of slurry of Portland Cement Paste to the steel and a coating of an epoxy base laid on the steel, have been reported as another alternative method of Corrosion Protection.

Methods of corrosion prevention based on the addition of materials to the mix have been attempted purely for practical and economic results, since it can be simply determined whether the additives have any significant detrimental effects on the concrete or not.

Again procedures involving treatment of the steel in value is also a very important consideration of possible loss of steel/concrete bond strength, either before or after some slight corrosion has occurred, this aspect of the problem has also received attention.

However in this investigation an attempt has been made

- To establish the simple potential measurement data that can be utilized to understand the surface condition of concast materials.
- To study the role of well known coating applied to steel before its embedment as concast.
- To study the role of additions of one inhibitive and other aggressive compound in the making of solution.
- To study the role of red oxide addition in cement at the time of casting the concrete.

The above objectives i.e.; to study the role of these variable parameters have been attempted through the measurement of potential variation with time.

2. EXPERIMENTAL PROGRAMME

Concrete structures are often strengthened with steel embedded ribs interspersed within the lattice and are well protected by alkaline environment of the concrete. But in general the concrete structures are normally exposed to environmental variables such as water, various anions, tidal waves, splashed and thermal fluctuations, etc. Therefore it is essential to know the role of so many variables to find out the exact life span of any concast. Fig.1 shows the details of test specimen embedded in concrete.

The following materials have been used to do the experimental investigation

2.1 Reinforcement/Concrete

- **Steel for embedment** – Commercially available 6mm dia. M.S. bar of 100 mm long were ground with 200 grit paper followed by 600 grit papers; finally polished, cleaned in distilled water, dried and kept in desicator before embedded into concrete.
- **Concrete** – Birla super slag cement was used for making concrete. Locally available river sand of F.M. 2.37 was used as Fine aggregate. The coarse aggregate (stone chip) was thoroughly washed, then dried in open atmosphere and finally sieved with a sieve of mesh 10mm. The aggregate that passed through the 10mm mesh and retained at 6 mm mesh were used for concreting purpose.

2.2 Chemicals

- 5% NaCl solution (S_1) – 10 lits of 5% NaCl solution was prepared in distilled water. The concast was immersed into this solution. The exposure to 5% NaCl solution as a general condition, in which potential measurement was routinely done to observe the change in potential (ΔE vs. t) as measure of metal behavior inside the concrete, on which its life depends.
- HMP solution – In some experiment the solution of 5% NaCl with 0.01% (S_2) and 5% NaCl with 0.1% (S_3) sodium hexa meta phosphate (Ranbaxy made LR grade) was prepared.
- $CaCl_2$ solutions (S_4) – In some experiment the solution was 5% NaCl with 1.0% $CaCl_2$ (Ranbaxy made LR grade).

2.3 Concrete Additives

In some experiment while preparing the concrete of M20 grade (1:1.5:3) the following additives were mixed

- (a) 0.5% red oxide (w/w) [Tata product commercial grade].
- (b) 1.0% red oxide (w/w) [Tata product commercial grade].

2.4 Coating of Mild Steel Bar.

The reinforcement of 6mm dia. mild steel was thoroughly ground, polished, cleaned and embedded in concrete during casting and the concast was cured for 28 days by submerging under water at ambient condition. In some experiment the reinforcement was initially coated with,

- (a) 8mg polystyrene/ml of benzene (one coat) (MC₁)
- (b) 16mg polystyrene/ml of benzene (one coat) (MC₂)
- (c) Red oxide paint (one coat) (MC₃)
- (d) Black Japan paint (one coat) (MC₄)
- (5) Aluminum paint (one coat) (MC₅)

3. CONCAST PREPARATION

Cement, Sand and stone chips in a ration of 1:1.5:3 were thoroughly mixed. The water-cement ratio (W/C) was kept as 0.55 and a uniform mixture was prepared. It was then placed in a pre-designed mould with reinforcement (Ref.Fig.1). It was then placed on to a vibratory table for compaction. After 24 hours, the concast was demoulded and finally cured by dipping in water for about 28 days.

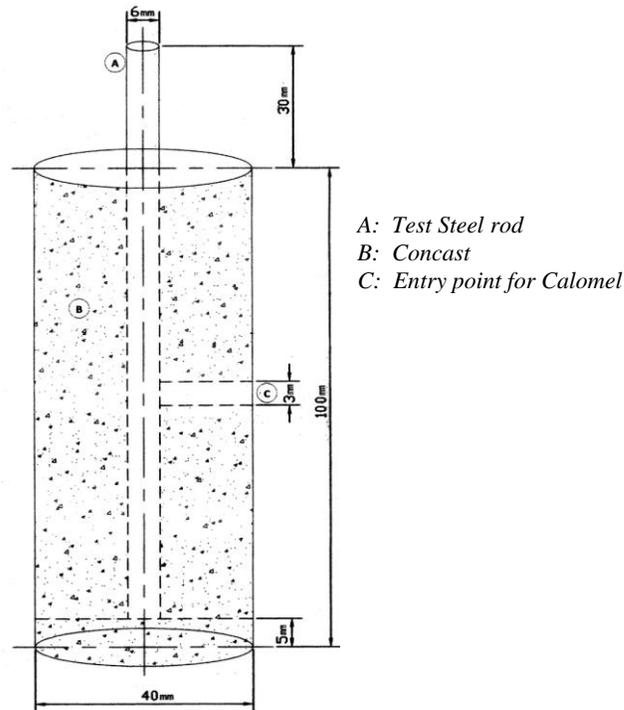


Fig.1: Schematic Diagram of the Test Specimen

4. EXPERIMENTAL PROCEDURE & PRESENTATION OF RESULT

After 28 days of curing all the different varieties of concast test samples of uncoated and coated steels in ordinary concrete and in concrete with red oxide etc. were immersed in solutions of different varieties and potential was measured as a measure of metal behaviour inside the concrete.

The basic data of potential measurement was made with ordinary concrete with embedded simple steel (uncoated MU) in the solution (i.e.; 5% NaCl (S₁)). The observed data of potential shift of the above experiment was used for comparison with data of potential shift observed with concrete (with variables) embedded steel (coated & uncoated). The corrosion of steel embedded in concrete and exposed to different environment has been investigated with the following perspectives:

- (a) The surface filming properties under the influence of concrete coverage produces an alkaline environment which is generally conducive to the protective health of the film existing on the surface of embedded steel. Since alkali does not increase the corrosion rate of steel, a stable film in the surface of embedded steel is expected.
- (b) Carbonation and De-alkalization – Moisture entry through the pores of concrete body or water permeated under total/partial submerge condition or under intermittent/alternate/splash condition, are very general phenomena. Such porous structures not only allow water entry, but also there is an entry of variety of anions and carbon dioxide. Acid formation due to soluble CO₂ is the cause of carbonation and this results into loss of alkalinity i.e., de-alkalization. This carbonation zone has an effect in the bonding properties of the concrete and also film-stability on the steel embedded in concrete.

Corrosion problems are best dealt with the principles of electro chemistry. In this present investigation the test sample and its environment was depicted as:

- (i) Steel specimen as reinforcement.
- (ii) Steel reinforcement as embedded in concrete (Concast).
- (iii) Environment is alkaline.
- (iv) Metal develops a protective oxide film.
- (v) The PH of environment (~12) may change with water entry.
- (vi) Environment may be further damaged by carbonation followed by de-alkalization.
- (vii) Due to change of PH from 12 to 9 to 8 even acidic.
- (viii) In this situation, protective film on metal is damaged either locally or thoroughly.
 - (a) If the film is damaged locally, then the potential change (ΔE) is not in great degree. But, there is a danger of pit initiation.
 - (b) If the film is damaged thoroughly, the ΔE may tend towards negative direction.
- (ix) If the metal is provided with a barrier type of coating, then depending upon the type of coating the ΔE may tend towards positive direction. Therefore trend towards shift of potential gives sufficient first hand information regarding the "State of affairs" on the metal/solution interfaces.

Table 1 shows the role of red oxide power when mixed with concrete. It indicates the potential value of uncoated steel(MU) embedded in cast specimen in 5% NaCl solution and the potential changes of other two casts in the same solution, at different time intervals.

Table 1 ΔE vs. Time (t) in S-1 solution of MU vast in concast 1, 2 & 3

Sl. No.	Time intervals (Δt)	Potential (ΔE)			Remarks
		Ordinary concrete (CON1)	CON2*	CON2**	
1.	0 min	-630	-681	-702	Note: *CON2 – Concrete mixed with 0.5% of Red oxide powder (w/w) *CON3 – Concrete mixed with 1.0% of Red oxide powder (w/w)
2.	30 min	-658	-671	-698	
3.	90 min	-679	-660	-667	
4.	3 days	-596	-652	-645	
5.	14 days	-585	-650	-610	
6.	28 days	-540	-647	-567	

Table 2 represents the variation of potential shift with respect to time interval when embedded reinforcement in concrete was coated with different coatings.

Table 2 ΔE vs. Time at various coatings and immersed in S-1 solution (i.e.; 5% NaCl)

Sl. No.	Time interval (Δt)	Concast MU (in mV)	MC1 (mV)	MC2 (mV)	MC3 (mV)	MC4 (mV)	MC5 (mV)
1.	0 min	-630	-640	-535	-625	-514	-610
2.	30 min	-658	-667	-529	-610	-529	-621
3.	90 min	-679	-639	-589	-580	-562	-602
4.	3 days	-596	-570	-640	-629	-591	-584
5.	14 days	-585	-560	-660	-597	-627	-560
6.	28 days	-540	-542	-520	-589	-630	-567

Table 3 presents the variation of potential shift with respect to time under the exposure of MC1 and MC2 at different solution.

Table 3 ΔE vs. Time Interval under the exposure of MC1 and MC2 immersed in different solution.

Sl. No.	Time Interval	Concast MU in mV				MC1 in mV				MC2 in mV			
		S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
1.	0 min	-630	-690	-625	-615	-640	-542	-590	-587	-535	-684	-575	-625
2.	30 min	-658	-635	-592	-596	-667	-590	-617	-622	-529	-562	-603	-602
3.	90 min	-679	-581	-580	-564	-639	-605	-632	-634	-589	-622	-611	568
4.	3 days	-596	-567	-612	-589	-570	-578	-593	-586	-640	-637	-576	-559
5.	14 days	-585	-640	-630	-639	-560	-507	-574	-570	-660	-587	-549	-551
6.	28 days	-540	-681	-640	-712	-542	-489	-561	-542	-520	-567	-534	-541

5. DISCUSSION OF THE RESULT

The red oxide powder is generally used for coating systems as a pigment; but it is not treated as a good chemical resistant. Expecting less corrosive resistant power, it was added with concrete to know its performance on the final potential value.

The text result indicate that (a) at a lower value of red oxide content, the red oxide particles (inside the concrete) behave as a cathodic particulates, which shifts the potential towards negative value and (b) with increase in red oxide content to 1.0%, the cathodic activity of red oxide particles become less important and this is offset by the gross volume of 1% red oxide, which sends the potential shift to positive direction due to aggregation of red oxide particulate.

Table 2 indicated that the final potential shown by MC1 (PSY, 8 mg/ml) was more positive than any other coating. The consistent data indicates a stable surface-film in existence.

The most negative value was shown by MC4 (Black Japan). It may have happened due to the predominant role of volume of carbon particles. The film did not show any deterioration.

The red oxide paint had given quite a positive shift in final potential but at the initial stage the values are irregular in nature.

Table 3 presented the variation of MU, C1 and MC2 immersed into different solutions. The variations are irregular in nature. The various symbols and abbreviations used in the text are as follows:

MU	: Uncoated Mild Steel
MC1	: Mild Steel-Coated with 8 mg Psy/ml Benzene (one coat)
MC2	: Mild Steel-Coated with 16 mg Psy/ml Benzene (one coat)
MC3	: Mild Steel-Coated with Red Oxide paint (one coat)
MC4	: Mild Steel-Coated with Black Japan paint (one coat)
MC5	: Mild Steel-Coated with Aluminum paint (one coat)
CPN1	: Simple concrete in the ratio of 1:1.5:3 (Cement: FA: CA)
CPN2	: Simple concrete + 0.5% W/W red oxide powder
CPN3	: Simple concrete + 1% W/W red oxide powder
S-1	: 5% NaCl solutions
S-2	: 5% NaCl solutions with 0.01% HMP
S-3	: 5% NaCl solutions with 0.1% HMP
S-4	: 5% NaCl solutions with 1.0% CaCl ₂
NaCl	: Sodium chloride
CaCl	: Calcium chloride
HMP	: Sodium hexa meta phosphate
FA	: Fine aggregate (Sand)
PSY	: Polystyrene
W/C	: Water/Cement ratio
W/W	: Percentage weight/weight

6. CONCLUSIONS

In the present investigation a good number of variables have been studied which concluded the following important findings:

- (1) Polystyrene (PSY) coatings have given good results. A thin coat was sufficient in some applications, such as in NaCl and low dosage HMP added solution. A thicker coating of PSY gave better results in some other condition such as when the solution contained CaCl₂.
- (2) In most of the systems measured potential values were sufficiently indicative of surface conditions. This has been verified comparing the ΔE vs. t results of a variety of combinations of coatings, solutions and concrete additions.
- (3) Explanation of shift of potential gave a broad idea to the applicability of the system, because in most of the cases comparisons were made with the blank condition.
- (4) Among the coatings, polystyrene coating and red oxide coating performed better.
- (5) The ΔE vs. t of the Black Japan coating system showed a continuous negative shift, but it was attributed to particulate behavior.

- (6) Finer particles of red oxide were explained to give negative shift of ΔE , whereas coarser aggregate of red oxide (due to increase in red oxide content) resulted in positive ΔE shift.

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