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DEVELOPMENTS AND APPLICATION OF VOLATILE INHIBITOR ADDITIVES IN MORTAR FOR REPAIR OF CONCRETE STRUCTURES

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ABSTRACT

Repairs and rehabilitation of concrete structures is one of the most challenging job engineering fraternity faces today all over the world. Corrosion of reinforcing steel has been identified as the single largest factor responsible for deterioration of reinforced concrete structures.

Effective procedures employed in the past to combat reinforcement corrosion have required either extensive cutting out and replacement of contaminated concrete at the level of embedded steel and treating the same with conventional protective measures or the use of electrochemical measures such as cathodic protection. Alternatively corrosion inhibitors either contact or volatile type have been used over the past decade. This paper presents the experimental work carried out to identify effective volatile corrosion inhibitors as an admixture in repair mortar adopting to Indian tropical conditions.

INTRODUCTION

Reinforcing bar in sound concrete is normally protected from corrosion by a passive film, which is stabilized by the alkaline pore electrolyte phase of the hardened cement paste. This passive film serves as a barrier to metal dissolution. Once this passive film breaks down due to reduction in alkalinity, which is either because of carbonation or chloride ion penetration, the process of corrosion begins at rapid pace. Since the volume of corrosion product is normally several times greater than the original metal, the associated stresses in the concrete can lead to cracking and spalling.

India has more than 6000 km of coastline and this problem is very common in all the RC structures. The problem is more severe due to tropical climate, which facilitates easy penetration of chloride ions due to wide variations in day and night temperature.

The traditional approach of removing cracked and contaminated concrete, cleaning the exposed steel and repatching with a repair mortar can be time consuming and expensive if it is to be carried out thoroughly enough for long term effectiveness. Alternatively electrochemical methods such as impressed current cathodic protection, realkalization etc are capable of arresting corrosion in contaminated concrete but they depend on availability of an anode system and long term monitoring of the installations.

An economical and simple alternative is the use of corrosion inhibitors, which can be either surface applied or used as an admixture in repair mortar. Though several volatile and contact inhibitors are reported to be useful as an admixture in repair mortar to provide for long term durability, data on their effectiveness in tropical climatic conditions is scant.

In this paper the research work undertaken to develop volatile corrosion inhibitor as an admixture to repair mortar is reported and its suitability of application in tropical climate is studied.

EXPERIMENTAL WORK

Experimental studies were undertaken in three stages.

Stage I	Development of suitable volatile corrosion inhibiting admixture using potentiodynamic technique. Reagents used – Amines salts with benzoic acid and carbonic acid.
Stage II	Effect of the chosen inhibiting admixture on the physical and mechanical properties of repair mortar in normal conditions and after thermal cycles.
Stage III	Corrosion studies on repair mortar by potentiodynamic method at ambient temperature and after thermal cycles.

Stage I **Development of suitable volatile corrosion inhibiting admixture by potentiodymanic studies in 3.5% NaCl solution.**

The experiments were carried out using three electrode system with mild steel as working electrode and graphite with 10 times more area as counter electrode. The reference electrode was saturated calomel electrode. All the experiments were carried out at ambient temperature (~30^{0}C) with constant stirring in 3.5% NaCl solution. In some experiments the solution was saturated with lime.

The working electrode was polished to 800 grit, washed thoroughly with water and distilled water. It was then cleaned with alcohol and conditioned in the electrolyte for a minimum of 30 min.

Various combinations of the inhibitors were tried and corrosion current density i_{corr} was found out by extrapolation of the Tafel slope from the region of 100 to 200 mV overvoltage from E_{corr} value[2]. At times it was difficult to draw the anodic slope. In such cases the corrosion current density was found out by the intersection of cathodic slope with line for E_{corr} value. The experiments were carried out with a locally available potentiostat (Autopro-Model No. EI 2200)

The studies were carried out with the two types of volatile inhibitors, i.e carbonate based and benzoate based, together with the addition of polymer resin additives and the other adsorption type inhibitors. Strength of the inhibitor was maintained constant in all the experiment i.e 1% which is normally recommended for mixing with mortar. The results of the potentiodynamic experiments and measurements of i_{corr} are shown in Table 1.

It was hence found that composition 8 comprising of volatile inhibitor as well as adsorption inhibitor and the polymer additive gave the corrosion current density, which is about 5 times less. In view of better performance amongst all combinations this particular composition 8 was used as admixture in concrete for further studies.

Stage II **Effect of the chosen inhibiting admixture on the physical & mechanical properties of repair mortar in normal conditions and after thermal cycles.**

It was necessary to find out if the corrosion inhibitor when used as an admixture has any adverse effect on the physical and mechanical properties of the concrete, such as setting, workability and compressive strength. It was also important to see its performance when ambient temperature is high, as is the case in tropical countries. In order to ascertain this, the test specimens were subjected to the thermal cycles, after curing for 28 days. Each cycle consisted of heating at 60°C for six hours followed by holding at room temperature (~30°C) for 18 hours. Each test specimens was subjected to 90 thermal cycles and then tested for the same properties. At least three test specimens were used for each set of experimental conditions and the results shown are the average of three values obtained from each set. The results of the mechanical and physical properties of the plain and admixtured concrete before and after thermal cycles are shown in Table 2.

From Table 2 it can be seen that the chosen admixture does not have any adverse effect on setting time and workability. The repair mortar with admixture appeared more cohesive during mixing and the compressive strength and pull out load showed marginal improvement (5 to 7%). Even after 90 thermal cycles there was almost no change in mechanical strength for both RMP and RMA samples.

Stage III **Corrosion studies by potentiodynamic method at ambient temperature and after thermal cycles.**

Specimen preparation: Cylindrical concrete specimens of 4 cm diameter and 8 cm long were cast with high yield strength deformed steel bar (HYSD) of 8mm diameter embedded centrally ensuring 16 mm cover from all sides and bottom. Three specimens were cast for each mix and the average was taken.

Electrochemical Studies: At the top, the protruding bar was protected with coating except where DC voltage was connected. Each test specimen was immersed in the saline media (3.5 percent NaCl solution) and connected to the positive terminal of the rectifier. The salt solution was changed periodically when the change in colour was significant. Each specimen was surrounded by stainless steel wire mesh, the cathode and connected to –ve pole of a rectifier. Due to transport of anions through the concrete, corrosion of deformed bar took place, reducing the bond between steel and concrete. Since the applied potential of 3.0 V was constant, decreasing IR drop resulted in increasing the corrosion rate. An ammeter in series measured the current for each corrosion cell. Three samples of each specimen were connected in series. The corrosion potential against copper / copper sulphate electrode was measured in the standard manner as described in ASTM[1]. From the above measurement of total current and duration the number of coulombs was calculated. Same number of specimens are given the thermal cycles and then connected in the circuit.

Bond Test (pull-out method): Evaluation of pull-out force is the most important part of corrosion study. As the corrosion advances the bond between rebar and concrete is significantly affected reducing the pull-out force. Hence to evaluate corrosion, corroded specimens were subjected to pull-out test to assess bond strength.

RESULTS AND DISCUSSION

Corrosion of embedded steel in concrete is guided by the formation of potential difference between cathodic and anodic sites, which is responsible for the development of corrosion current. Although the corrosion current gives the corrosion rate, the extent of corrosion has to be measured in terms of number of coulombs. In the stage II studies, tests were carried out on fresh and hardened repair mortar to find out any deleterious effect of corrosion inhibiting admixture. Further Stage III studies comprised of electrochemical tests to assess their effectiveness in corrosion protection.

Effect on Fresh and Hardened Repair Mortar: It is evident from result tabulated in Table 2 that corrosion inhibitor admixture does not cause any changes in fresh and hardened state with respect to mechanical strength characteristics. Even after 90 thermal cycles no changes were observed.

Bond Strength: Bond strength between reinforcement and concrete interface is the single most vital factor for the reliable performance of reinforced concrete. Due to corrosion of rebar, bond strength is affected most and hence performance of reinforced concrete. From Table 3, the bond strength of plain specimens (RMP) was reduced to 10 – 15 % of original strength after accelerated corrosion test, indicating bond failure. In the admixtured mortar (RMA) upto 80% of bond strength remained intact. Even after 90 thermal cycles there was no reduction in bond strength as compared to normally cured specimens.

Corrosion: The current was measured at regular intervals and the cumulative number of coulombs consumed was calculated for both normal cured & thermal cycled specimens. The half-cells potentials were measured at the interval of 150 hours. In accordance with ASTM[1] the potential of -780 mV against CSE was considered as the criterion for total failure. The results tabulated in Table 3 clearly indicate that number of coulombs consumed by admixtured RMA specimens were about 50 % as compared to plain RMP. Even after 90 thermal cycles similar trend of upto 53% reduction was noted.

CONCLUSIONS

1. Though all the volatile inhibitors under study have shown reduction in corrosion current, the one having best results and compatible with polymer additive and concrete was chosen for further studies.
2. The incorporation of corrosion inhibitor, i.e. amine salts of benzoic and carbonic acid, into repair mortar does not impair physical and mechanical properties. On the other hand repair mortar becomes more cohesive and marginal improvement in both compressive and bond strength was noted.
3. Electrochemical studies reveal significant advantages with the admixture as seen in the reduction of number of coulombs and substantial improvement of bond strength compared to plain specimens.
4. The important finding is the effectiveness of volatile corrosion inhibitor even at elevated temperature of 60°C. In tropical countries like India where temperature in summer varies between 40°C to 48°C in most parts, the data generated would be very useful.

REFERENCES

1. Standard test method for Half-cell potentials of uncoated reinforcing steel in concrete C 876-91 ASTM.
2. Standard reference test method for making potentio static and potentiodymanic Anodic polarization measurements G5-94 ASTM.
3. C.L.Page, V.T.Ngala and M.M.Page, Magazine of Concrete Research, February 2002.
4. P.Rodriguez, E. Ramirez and J.A.Gonsalez: Magazine of Concrete Research, June 1994.

Table 1 : Results of potentiodynamic measurements.

No	Composition	i_{corr} (10^{-8} A/cm^2)	No	Composition	i_{corr} (10^{-8} A/cm^2)
1.	Plain–no addition	28	5.	Cathodic Inhibitor (100%) + Lime	14.3
2.	Inhibitor A (Carbonate) + Inhibitor B (Benzoate)	12	6.	Composition 2 (60%) + Cathodic Inhibitor B (20%) +Polymer additive	24
3.	Composition 2 (80%) + Lime + cathodic Inhibitor A (20%)	10.3	7.	Composition 2 (80%) + Cathodic Inhibitor B (20%)	13
4.	Composition 2 (50%) + Cathodic Inhibitor B (50%) + Lime.	18	8.	Composition 7 (80%) + Polymer additive + lime.	6.4

Table 2: Results of physical & mechanical properties.

Repair Mortar	Composition	Workability Flow (mm)	Setting Time (min)		Compressive Strength (N/mm^2) 7cm X 7 cm Cube Size		Pull Out Force (N).	
			Initial	Final	Normal (28days)	After 90 Thermal Cycles	Normal (28days)	After 90 Thermal Cycles
Repair Moratr Plain (RMP)	Cement : 100 Graded Sand : 300 Water : 45	120	150	310	23.2	23.4	7560	7620
Reapir Mortar Admixtured (RMA)	Cement : 100 Graded Sand : 300 CI Admixture : 1 Water :45	123	140	320	24.7	24.5	7820	7850

Table 3: Results of electrochemical studies

Specimens	No. of Coulombs consumed (mA-hrs)		Pull out force (N)			
	Normal	After 90 thermal cycles	Normal		After 90 thermal cycles	
			Before	After Corrosion	Before	After Corrosion
RMP	3930	3870	7560	930	7620	828
RMA	1932	2076	7820	6055	7850	6178