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Effect of Vapour Phase Corrosion Inhibitor on Rebar Embedded in Concrete

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Abstract:-The problem of rebar corrosion in concrete is an issue of main concern in durability of structures for practicing civil engineers and researchers worldwide. A simpler approach of application of vapour phase corrosion inhibitors (VPCI), its effectiveness in prevention of rebar corrosion needs to be critically evaluated. High accelerated corrosion experimental studies (HACEs) were conducted on a weaker M20 and other M40 concrete specimen of diameter 40mm cylindrical form with 8mm rebar embedded in it with 16mm cover maintained on all sides. The corrosion inhibitor used in this study, KP-200 has elements that act as both cathodic as well as anodic inhibitor Corrosion inhibitor admixture KP-200 was added 1% v/v of the cement as recommended by manufacture. E_{corr} value < - 0.800V was considered as failure criteria for rebar corrosion. From the measurements of coulombs consumed and on actual inspection it is observed that in weaker concrete longevity is increased by 18.24% and in stronger concrete by 26.24%, when the above corrosion inhibitor admixture is used.

Keywords: *vapour phase corrosion inhibitor, rebar, corrosion, half-cell potential, weight loss.*

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INTRODUCTION

Reinforced cement concrete is the most versatile and potentially one of the most durable materials that a designer can choose for almost any type of structure [ ]. Reinforced concrete is highly susceptible to environmental attack; therefore unless some measures are adopted to counteract its deterioration and thereby improving durability of concrete structures, these would get damaged and sometimes even fail. This results in heavy cost of repairs and rehabilitation of structures. Vapor phase corrosion inhibitors have been developed to prevent corrosion of reinforcement [ ]. The corrosion inhibitor used in this study, KP-200 is one such corrosion inhibitor admixture which has elements that act as both cathodic as well as anodic inhibitor. Due to electrochemical nature of the corrosion mechanism, different electrochemical tests are planned to be carried out in this study. The 'Half-cell potential' (E_{corr}) measurement, indicative of probability of corrosion of reinforcement is the basic test followed by corrosion current measurement [ ]. It requires certain number of coulombs (ampere-hours) before a member fails due to corrosion. The extent of corrosion is given in terms of corrosion-current density I_{corr} and time, with proper protection method, the I_{corr} for the given steel bar would be less and hence would take more time for failure[ ]. The time of failure, hence can be conveniently measured in terms of coulombs consumed by the specimen.

EXPERIMENTAL WORK

For the simulation of study specimen, as corrosion affected structure, its size is taken small. For High accelerated corrosion experiments , the specimens are placed in saline (3% NaCl) medium giving them a constant DC voltage of 7.5 volts by means of rectifier throughout the experiment.

CEMENT- Ordinary Portland cement confirmed with Indian standard IS: 269-1976 has been used for mixes. The initial and final setting times of cement have been observed through standard Vicat's apparatus as per IS: 403-1968.

AGGREGATE- In view of the small size of specimen, only fine sand, minimum 10mm size and maximum 20mm size, is used to get homogeneous mixture. The properties of aggregates were determined as per IS: 2386-1963.

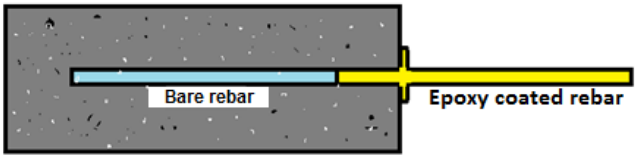
REINFORCEMENT- High yield strength deformed bars, 8mm diameter confirming to IS: 1786 are used as reinforcement .As per ASTM procedure the bars were cleaned with an acidic solution and made free from any corrosion product.

CHEMICAL- KP200 - commercially available vapor phase corrosion inhibitor admixture.

MIX PROPORTION- Preparation, mixing, casting and sampling of fresh concrete was done in accordance with IS: 1199-1959 (Method of sampling and analysis of concrete) .There are two types of specimen made from each mix

1.A control specimen (CS) and 2.Specimen with VPCI admixture (CI).

SPECIMEN DETAILS: There are different tests to be carried out in this study. Keeping this in mind sufficient number of specimen were cast from each mix. In split mould 40mm diameter and 80mmlong , 8mm diameter HYSD steel bar as reinforcement is placed centrally such that, 16mm cover is present on all sides .To provide same cover on top and bottom of cylinder the bar was held 16mm from the bottom of the mould and 16mm length of the bar from top end was insulated.



C/S showing details of Cylindrical Mould

TEST SETUP

PULL OUT TEST- For the reliable performance of reinforced concrete structure, it is necessary to have the bond strength at the rebar [ ]. The most commonly adopted method of testing the bond strength is the pull- out test. In the pull-out test, steel in tension is in contact with concrete in compression.

HALF-CELL POTENTIAL- A copper-copper sulphate half-cell (CSE) according to ASTM standards[ ] consists of a rigid glass tube 20mm diameter, a porous plug at the bottom and a copper rod 6mm diameter that is immersed within the tube in a saturated copper sulphate crystals dissolved in distilled water solution. The half-cell potential is measured at an interval of 150 hrs. The average value of the set of three samples against CSE of each specimen is considered for the analysis. The half-cell potential v/s CSE values, as per ASTM suggestions are given below. But, with the change in temperature, composition of steel and quantity of ingredients of concrete, these values may not perfectly apply to Indian conditions.

COLOMBS MEASUREMENT

To find out the total coulombs consumed on each specimen, it is essential to monitor the current periodically. The current in each path needs to be measured at regular interval. Multiplication and duration for which it is flowing gives the total coulombs consumed by each specimen[ ]. Two samples of each specimen are connected in series and all four sets of specimen are connected in parallel.

RESULTS AND DISCUSISON

BOND STRENGHT

With the advancement of corrosion, it is expected that the bond between steel and concrete is weakened and hence less pull will be required for pulling out the bar[ ]. The result obtained of the pull out test at the end of electrochemical tests on various samples is shown in the table. The effect of corrosion of rebar in the reinforced concrete samples on band strength after they were subjected to accelerated corrosion indicates that,

- There is loss in pull out force of order of 29 % in weak plain concrete and of 23 % in strong plain concrete.
- Loss in pull out force reduces to 4.5 % in weak concrete with corrosion inhibitor admixture and to 6 % in strong concrete with corrosion inhibitor admixture.

Table 1: Effects on Bond Strength

	**Pull out Force (N)**			
	28 days	**28 Days curing + 90 Days natural condition**	**28 Days Curing + 90 Thermal Cycles Of 60 ^{0}C**	**At Half-cell Potential value - 0.800 volts**
M-20(CS)	6420.20	6485.36	6561.00	4572.85
M-20(CI)	6860.42	6388.42	6884.18	4780.50
M-40(CS)	10190.77	9898.48	9894.42	7459.68
M-40(CI)	10230.33	10098.35	9988.33	7892.48

POTENTIAL MEASUREMENT

Using standard procedure laid down by ASTM [ ], the extent of corrosion was monitored from the half-cell potential measurements [ ]. These were carried out on the samples at the periodic intervals and at different locations on the specimen. Each specimen was immersed in saline medium (3.5 % NaCl) and connected to the terminal of rectifier. Each specimen was surrounded by stainless steel mesh, the cathode connected to positive pole of rectifier. Stainless Steel mesh provides easy access to electrolyte and equal current in all directions. The larger area of mesh also ensures that there is no cathodic protection-taking place, which could actually retard the process of corrosion. The applied potential is kept constant 7.5 volts DC. The corrosion current thus increases and hence the rate of corrosion. The half-cell potentials are measured at an interval of approximately 100 hours. Yhe results are given in table 6. ASTM guidelines were followed as given below

1. If half-cell potential is numerically greater than -0.35 V to CSE, then there is 90% probability of corrosion occurring.2. Half-cell Potential values as much as -0.8 V to CSE indicate total failure.

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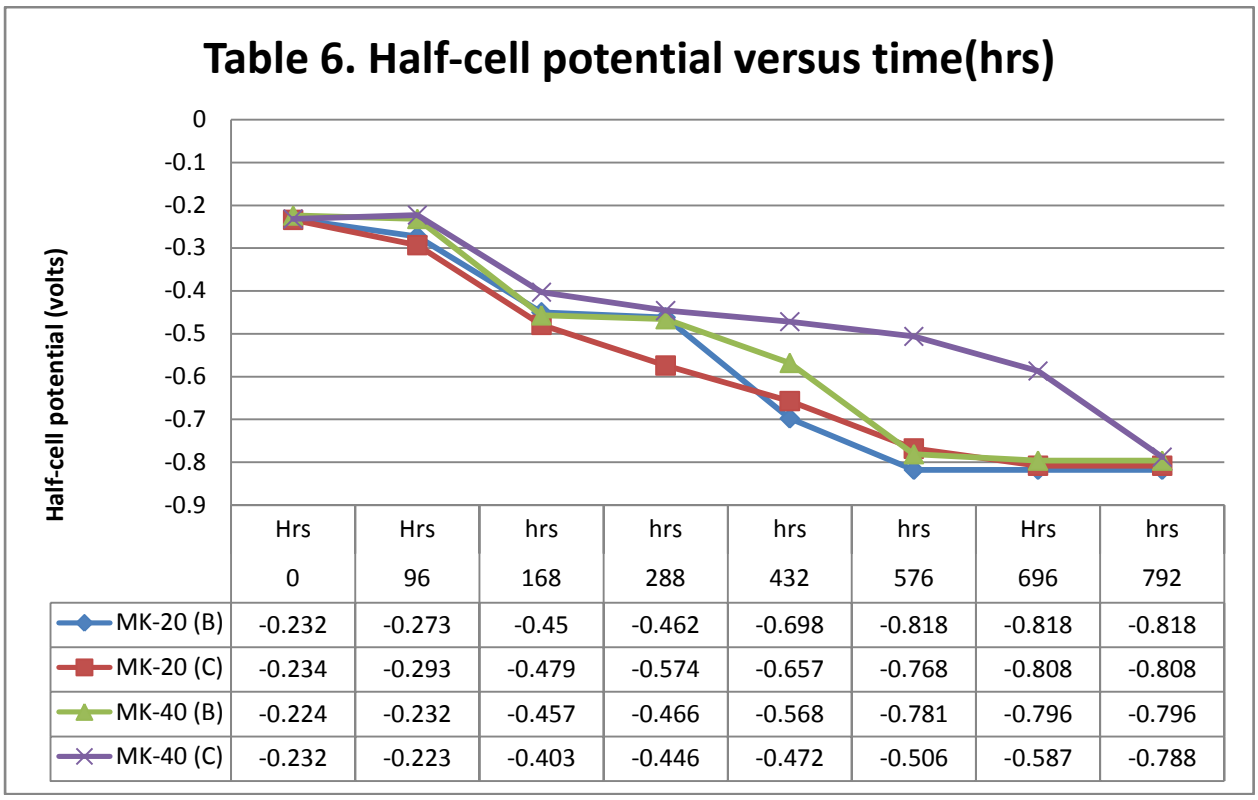

	Hrs 0	Hrs 96	hrs 168	hrs 288	hrs 432	hrs 576	Hrs 696	hrs 792
MK-20 (B)	-0.232	-0.273	-0.45	-0.462	-0.698	-0.818	-0.818	-0.818
MK-20 (C)	-0.234	-0.293	-0.479	-0.574	-0.657	-0.768	-0.808	-0.808
MK-40 (B)	-0.224	-0.232	-0.457	-0.466	-0.568	-0.781	-0.796	-0.796
MK-40 (C)	-0.232	-0.223	-0.403	-0.446	-0.472	-0.506	-0.587	-0.788

COULOMBS MEASUREMENTS

The total number of coulombs for complete failure provides a rough guideline for monitoring the extent of corrosion. The coulombs required for the loss in weight by 20% was chosen as criteria for complete failure of structure. Due to the application of corrosion inhibitors in the form of admixture the life of structure is increased. In weak concrete, longevity of structure was found out to be increased by 1.18 times due to KP-200.However in strong concrete; longevity was improved by 1.26 times with the use of KP-200.

Table 3 : Coulombs consumed (Samples cured for 28 days and connected in circuit)

	**Coulombs consumed(mA.hrs**	**Theoretical weight loss (%)**		**Actual weight loss(%)**
		Faraday's law	**Cover Meter**	
MK-20 (CS)	5882	30.81	32.78	29.88
MK-20 (CI)	5634	22.58	21.06	21.29
MK-40 (CS)	2894	13.68	14.50	12.77
MK-40 (CI)	1768	08.44	06.88	8.52

TABLE 4: LONGEVITY OF STRUCTURE INCREASED BY CORROSION INHIBITOR APPLICATION

Longevity increased due to VPCI admixture KP-200	
Weak concrete (20Mpa)	18.24%
Strong concrete(40Mpa)	26.24%

CONCULSION

In this study corrosion inhibitor admixture KP-200 was used. From the experiments carried out in the study it is observed that,

- Half –cell potential of rebar was increasing negatively showing the extent of corrosion. It gives probability of corrosion activity, but the ASTM criteria may not exactly suit the Indian conditions.
- KP-200 does not have detrimental effect on hardened concrete properties like compressive strength, bond-strength, water absorption and bulk density.
- 90-thermal cycles, each at 60^{o} for 6 hours, neither change the properties of plain as well as corrosion inhibitor added concrete nor do they reduce effectiveness of corrosion inhibitor .

- The findings of electrical studies reveal that there is significant advantage of using VPCI admixture. VPCI admixed specimen consumed lesser coulombs over control specimen. The effect is more prominent in stronger concrete.
- The application of VPCI reduces the rate of corrosion.
- The half-cell potential Vs CSE indicates that the critical value is reached earlier in control specimen than VPCI coated specimen, in weak as well as strong concrete.
- Loss in pull out force reduces to 4.5 % in weak concrete with corrosion inhibitor admixture and to 6 % in strong concrete with corrosion inhibitor admixture.
- The thermal cycles study on VPCI coated specimen reveal than even at 60^0C, the effectiveness is not affected adversely. This was a major concern in view of volatile nature of the VPCI.
- From the number of coulombs consumed the amount of steel lost due to corrosion can be estimated. Also the longevity can be estimated from coulombs measurement.

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