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STRENGTH AND DURABILITY STUDIES ON SODIUM NITRITE INHIBITOR IN ORDINARY AND HIGH PERFORMANCE CONCRETE

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Abstract

Deterioration of concrete occurs due to physical actions, chemical reactions and electro chemical reactions at steel / concrete interface causing reinforcement corrosion. Among these, reinforcement corrosion is one of the most important causes of deterioration. Reinforcement corrosion induced by chlorides is one of the most frequent causes of corrosion of steel and 40 percent of steel corrodes due to chloride attack. To delay the corrosion process many techniques such as increasing the concrete cover over rebar, reducing water cement ratio, using denser concrete, coating steel with epoxy, use of corrosion inhibitor are available. In the present investigation the effect of sodium nitrite based corrosion inhibitor in concrete is studied. This research involves the comparative study of mechanical properties and durability properties of conventional concrete and high performance concrete in the case of without and with inhibitor. Corrosion studies such as AC impedance, Potential measurement, Linear Polarization Resistance (LPR), Custom sweep and half-cell potential are evaluated using standard concrete test specimens with different dosages of corrosion inhibitor.

Keywords: Ordinary Concrete, High Performance concrete, Corrosion Inhibitor, Corrosion Resistance Tests.

1. Introduction

Ordinary concrete refers to the ordinary Portland cement as a cementing material, plus sand, gravel, water and admixtures. Because of its rich resources of raw materials, simple production process, good performance characteristics, low price, higher strength and durability, and ease of pouring into a variety of shape components or the overall structure, combined with the reinforcement into the strong, anti-vibration of the reinforced concrete structure, it has been widely used as construction building materials. As concrete is a kind of a combination of ingredients of non-homogeneous materials, its production process also covers the preparation, mixing, vibration and maintenance of such processes, together with cement as a kind of active material. Therefore, the quality factors of raw materials and production processes of certain aspects of their performance and quality are great, and the impact cannot be ignored.

High performance concrete is a concrete mixture, which possesses high durability and high strength when compared to conventional concrete. This concrete contains one or more of cementious materials such as fly ash, Silica fume or ground granulated blast furnace slag and usually a super plasticizer. The term 'high performance' is somewhat pretentious because the essential feature of this concrete is that its ingredients and proportions are specifically chosen so as to have particularly appropriate properties for the expected use of the structure such as high strength and low permeability. Hence, high performance concrete is not a special type of concrete. It comprises the same materials as that of the conventional cement concrete. The use of some mineral and chemical admixtures like Silica fume and Super plasticizer enhances the strength, durability and workability qualities to a very high extent. High Performance concrete works out to be economical, even though its initial cost is higher than that of conventional concrete, because the use of High Performance concrete in construction enhances the service life of the structure and the structure suffers less damage which would reduce overall costs. High-performance concrete characteristics are developed for particular applications and environments; some of the properties that may be required include: high strength, high early strength, high modulus of elasticity, high abrasion resistance, high durability and long life in severe environments, low permeability and diffusion, resistance to chemical attack, high resistance to frost and deicer scaling damage, toughness and impact resistance, volume stability, ease of placement, compaction without segregation, inhibition of bacterial and mould growth. In this study, the effect of sodium nitrite corrosion inhibitor in high performance concrete with different dosages is compared with that of ordinary concrete.

2. Literature Review

In the present investigation the effectiveness of the sodium nitrite inhibitor in various dosages is studied based on the previous investigations by Saura and Zornoza, et al. (2011) Sodium nitrite ($NaNO_2$) has been added to solutions consisting of saturated calcium hydroxide ($Ca[OH]_2$) with progressive additions of iron(II) chloride ($FeCl_2$) to obtain different pH in the basic zone; sodium chloride (NaCl) was used for neutral solutions; and different concentrations of $FeCl_2$ for acid solutions to study its performance as a corrosion inhibitor. Corrosion rates of steels were measured using the polarization resistance technique. Electrochemical impedance and spectroscopy results are also presented to support the observations. According to the results, $NaNO_2$ reduces corrosion levels in basic environments. C.A.Loto (2012) studied Sodium nitrite as the inhibitor in different concentrations. The result obtained showed a reduction in the active corrosion reactions behaviour of the embedded mild steel in concrete added with different concentrations of sodium nitrite. The results are obtained for the varied percent concentrations of sodium nitrite addition (-40,70 and 100 percent) mixed with the concrete test samples. Alonso and Andrade (2003) investigated the corrosion production methods. One of the methods is the use of inhibitors added to the mix. Among the different chemical substances tested as inhibitors in concrete are those that have shown a good physicochemical compatibility with the concrete, such as sodium nitrite. XU Yongmo and SHE Hailong (2004) stated that Carbonation-induced corrosion is one of the most widespread forms of deterioration of reinforced concrete over the world. This paper investigated the effectiveness of corrosion with and without chloride attack. The corrosion potential and corrosion rate by linear polarization resistance method were employed to evaluate the corrosion state.

3 Experimental Investigation

3.1. Mix proportions

The type of cement used in the study is Ordinary Portland Cement (Zuari) 43 grade. River sand conforming to zone II, as per IS 383- 1970 coarse aggregate 12 mm size, super-plasticizer and conplast SP430 are also selected. The mix is designed as per IS 10262 – 2009 for ordinary concrete. The grade of concrete used for this research work is M 30 of mix ratio 1:1.55:2.29 with water-cement ratio 0.45. The same grade is used for High performance concrete (HPC) by replacing cement with Ground Granulated Blast Furnace Slag (GGBS) by 40 percent and 4 percent addition of silica fume (Palani, 2005) and the sodium nitrite corrosion inhibitor is used in various dosages such as 0.5, 1.0, 1.5 and 2.0 percent by mass of cement. The specific gravity and Fineness modulus of fine and coarse aggregate are presented in Table 1.

Table 1 Mix Proportions for M30 concrete

Sl.No	Material	Specific gravity	Fineness modulus	Zone
1	Cement	3.15	-	-
2	Fine aggregate	2.60	3.07	II
3	Coarse aggregate (12.5 mm)	2.71	3.16	-
4	Water	1	-	-

3.2 Details of Cast Specimens

The details of cast specimens and total number of specimen for strength test are shown in Table 2.

Table 2 Details of cast specimen for strength test

Sl. No.	Types of test	Specimens and size (mm)	ONI	OSN (0.5)	OSN (1.0)	OSN (1.5)	OSN (2.0)	HNI	HSN (0.5)	HSN (1.0)	HSN (1.5)	HSN (2.0)	Total No. of Specimens
1	Compression Strength test	Cubes (100)	6	6	6	6	6	6	6	6	6	6	60
		Cylinders (100 × 200)	6	6	6	6	6	6	6	6	6	6	60
2.	Split tensile strength test	Cylinders (100 × 200)	3	3	3	3	3	3	3	3	3	3	30
3.	E for concrete	Cylinders (150 × 300)	3	3	3	3	3	3	3	3	3	3	30

Note:ONI - Ordinary concrete without Inhibitor, HNI - High performance concrete without Inhibitor, OSN (0.5) - Ordinary concrete with 0.5 percent sodium nitrite Inhibitor, HSN (0.5) - High performance concrete with 0.5 percent sodium nitrite Inhibitor

The details of cast specimens and total number of specimen for durability and corrosion tests are shown in Table 3.

Table 3 Details of cast specimen for durability test

Sl. No.	Types of test	Specimens and size (mm)	ONI	OSN (0.5)	OSN (1.0)	OSN (1.5)	OSN (2.0)	HNI	HSN (0.5)	HSN (1.0)	HSN (1.5)	HSN (2.0)	Total No. of Specimens
1.	Water absorption	Cubes (100)	3	3	3	3	3	3	3	3	3	3	30
2.	Acid resistance	Cubes (100)	12	12	12	12	12	12	12	12	12	12	120
3.	RCPT	Cylinders (100 × 200)	3	3	3	3	3	3	3	3	3	3	30
4.	Open circuit potential	Cubes (100)	3	3	3	3	3	3	3	3	3	3	30
		Cylinders (100 × 200)	3	3	3	3	3	3	3	3	3	3	30
5.	Impedance	Cubes (100)	3	3	3	3	3	3	3	3	3	3	30
		Cylinders (100 × 200)	3	3	3	3	3	3	3	3	3	3	30
6.	LPR sweep	Cubes (100)	3	3	3	3	3	3	3	3	3	3	30
		Cylinders (100 × 200)	3	3	3	3	3	3	3	3	3	3	30
7.	Custom sweep	Cubes (100)	3	3	3	3	3	3	3	3	3	3	30
		Cylinders (100 × 200)	3	3	3	3	3	3	3	3	3	3	30
8.	Half-cell potential	Cubes (100)	3	3	3	3	3	3	3	3	3	3	30
		Cylinders (100 × 200)	3	3	3	3	3	3	3	3	3	3	30

3.3. Scanning Electron Microscopy (Sem) Analysis

Scanning Electron Microscopy (SEM) micrographs of the ONI, HNI, OSN (0.5), HSN (0.5), OSN (2), HSN (2) pastes are shown in Fig.1. The images were taken with 1000x magnification.

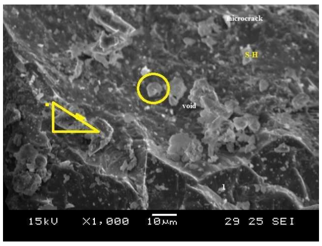


Fig.1 (a) ONI

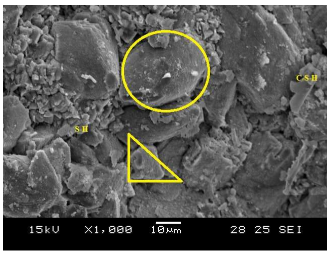


Fig.1 (b) HNI

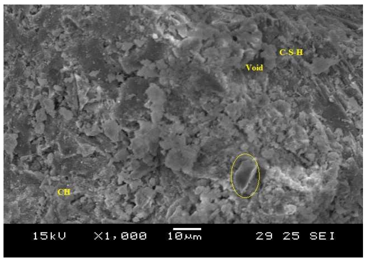


Fig.1 (c) OSN (0.5)

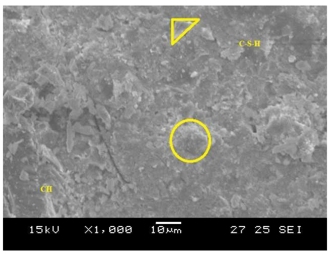


Fig.1 (d) HSN (0.5)

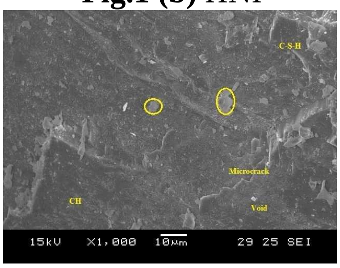


Fig.1 (e) OSN (2)

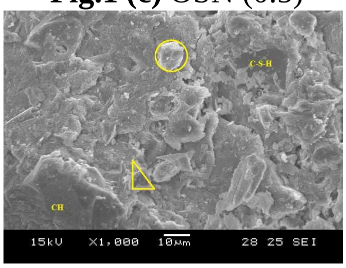


Fig.1 (f) HSN (2)

Figure 1 SEM results of ordinary and high performance concrete without and with inhibitor

These images deal with the chemical analysis of the field of view or spot analysis of minute particles. Figs.1 (a) and (b) represent the SEM picture of ordinary concrete and high performance concrete without any inhibitor addition. The picture shows, in Ordinary concrete, large to small number of voids and microcracks , while in HPC the number of voids and cracks are less. In HPC there are larger spherical and triangle particles which give additional strength to the mix. In both concretes CH (calcium hydroxide) and C-S-H (Calcium hydroxide and silica hydroxide) were found. The addition of sodium nitrite as inhibitor in ordinary concrete is analysed from the Figs. 1(c) and (e). The addition gives the formation of small sized particles and absence of highly ordered crystalline phase represents the reduced strength. Figs.1(d) and (f) show the texture of the particle in high performance concrete with inhibitor. The micrograph really shows the typical porous structure mineral admixture and the difference in surface structure can be clearly seen as elongated particles. This mineral admixture such as silica fume, ground granulated blast furnace slag with large surface area shows excellent reactivity. It imparts stability and cohesiveness to the mixture.

4. Strength Test

4.1. Compressive Strength Test

The compressive strength test on concrete cubes of size 100x100 mm and cylinders of size 100x200 mm was conducted in compressive testing machine 2000 kN capacity. The cube and cylinder compressive strength of ordinary concrete and high performance without inhibitor at 7 days and at 28 days is shown in Fig.2.

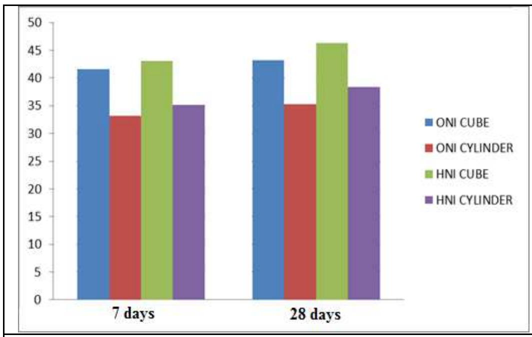


Figure 2. Compressive strength of ordinary and high performance concretes without inhibitor

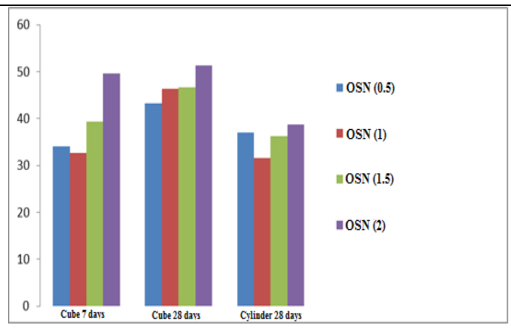


Figure 3. Compressive strength of ordinary concrete with inhibito

The compressive strength of cubes and cylinders of ordinary concrete with inhibitor at 7 days and at 28 days is shown in Fig.3. The compressive strength of cubes and cylinders of high performance concrete with inhibitor at 7 days and at 28 days and the test setup are shown in Fig.4.

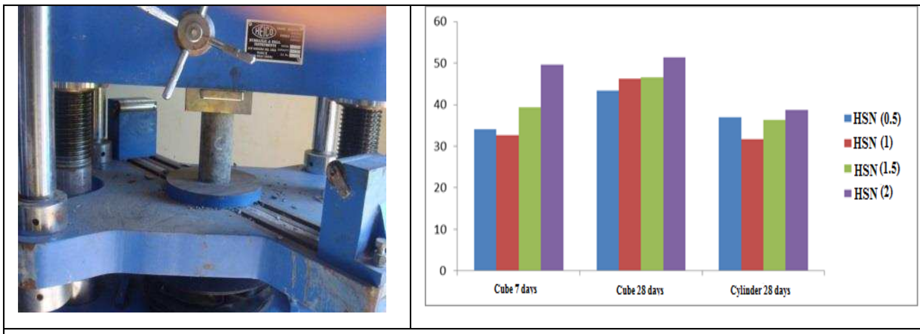


Figure 4. Compressive strength of high performance concrete with inhibitor

4.2. Split Tensile Strength Test

The average value of 3 cylinders was recorded as the strength at respective age. The split tensile strength of cylinders of ordinary and high performance concrete without and with inhibitor at 28 days and the test setup are shown in Fig.5.

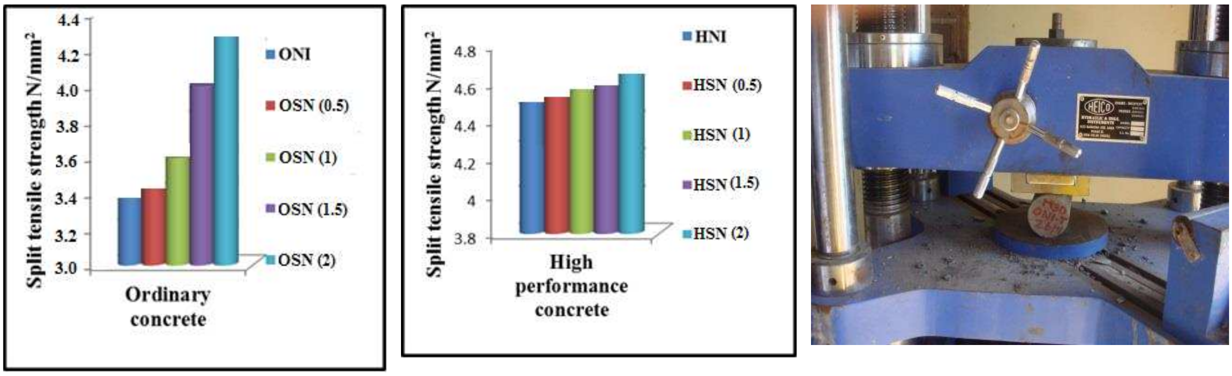


Figure 5. Split tensile strength of concrete specimens

4.3 Modulus of Elasticity of Concrete

The test specimens shall consist of concrete cylinders 150mm in diameter and 300 mm long. Two extensometers are required each having a gauge length of not less than 102 mm and not more than half the length of the specimen. They shall be capable of measuring strains to an accuracy of 2×10^{-6}. The specimen shall be immediately placed in the testing machine and accurately centered. The test setup is shown in Fig. 6a. The load shall be applied continuously without shock. Readings shall be taken at each stage of loading. The stress vs. strain curve for ordinary and high performance concrete without and with inhibitor are shown in Figs. 6b and 6c.

Figure 6a Test setup for Modulus of Elasticity of Concrete

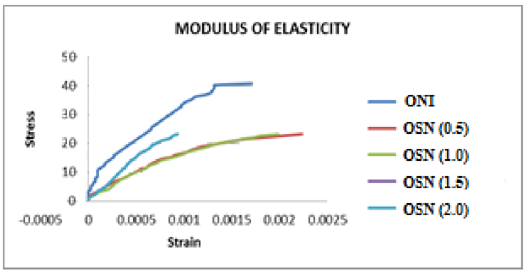


Figure 6b Stress Vs. Strain curve for ordinary concrete without and with inhibitor

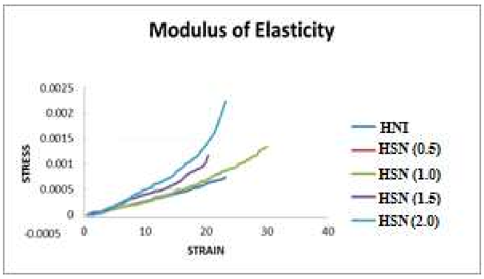


Figure 6c Stress Vs. Strain curve for High performance concrete without and with inhibitor

5. Regression Analysis

SPSS is a Statistical Package for Social Sciences; it is data management software, which is an analysis product. It can carry out a range of important data analyses and management function that includes statistical analyses plus graphical presentation of the data. SPSS is a comprehensive system for analyzing data. SPSS can take data from almost any type of file and use them to generate tabulated reports, charts, and plots of distributions and trends, descriptive statistics, and complex statistical analyses.

For this analysis, minimum three variables are required for each case to form a better equation. In the present research the variables are inhibitor (Sodium nitrite) with different dosages say 0.5 to 2.0 percent, different concrete ordinary and high performance concrete mix ratio (Mix= 1,2).

Empirical relationships are formulated adopting the experimental results and simulated data using SPSS are given below:

Compressive strength

7 days - fck (Cube) = 18.9 + 6.87 Dosage + 6.16 Mix ……. (1)

28 days - fck (Cube) = 28.6 + 5.16 Dosage + 6.22 Mix ……. (2)

fck (Cylinder) = 31.3 - 0.93 Dosage + 3.76 Mix ….(3)

Split tensile strength - fck(Cylinder) = 3.50 + 0.018 Dosage + 0.450 Mix …. (4)

6. Durability Test

6.1 Water Absorption Test

According to ASTM C 642-06, water absorption test was performed on ordinary and high performance concrete without and with inhibitor. Cubes of size 100×100×100 mm were tested after 28 days of curing. The specimens were taken out and dried in an oven at a temperature of 100 to 110°C for not less than 24 hours. Each specimen removed from the oven was allowed to cool in dry air to a temperature of 20 to 25°C and the dry weight was determined. Then the specimens were immersed in water. The wet weights were recorded for every ½ hour for 2½ hours, every 1 hour for 4 hours, 24 hrs, 48 hrs and 72 hrs. The percentage of water absorption was calculated as follows.

$$Percentage\ of\ water\ absorption = \frac{wet\ weight - dryweight}{dryweight} \times 100 \ldots\ldots\ldots (5)$$

The result obtained for water absorption test is given in Table 4. It shows that the ordinary concrete without and with inhibitor has higher water absorption capacity than high performance concrete with sodium nitrite inhibitor.

Table 4 Percentage of Water absorption of concrete cubes

Sl. No.	Duration (minutes)	Percentage of Inhibitor OSN					Percentage of Inhibitor HSN				
		*0.0	0.5	1	1.5	2	*0.0	0.5	1	1.5	2
1.	0	0	0	0	0	0	0	0	0	0	0
2.	30	0.56	0.79	0.47	0.32	0.37	0.28	0.19	0.24	0.19	0.11
3.	120	0.60	1.09	0.64	0.35	0.39	0.32	0.21	0.25	0.24	0.21
4.	210	0.71	1.09	0.72	0.46	0.49	0.36	0.22	0.28	0.27	0.24
5.	330	0.73	1.15	0.75	0.47	0.56	0.28	0.29	0.36	0.29	0.29
6.	1440	0.83	1.74	0.94	0.54	0.59	0.64	0.32	0.37	0.32	0.32
7.	4320	0.87	1.91	0.99	0.57	0.62	0.68	0.38	0.42	0.34	0.34

*0.0 : No inhibitor

6.2 Acid Resistance Test

Concrete cubes of size 100×100×100 mm were cast. After 28 days of curing, specimens were dried out and weights (W1) were noted. The solutions were prepared with various concentrations of HCl (1 percent, 4 percent) and H_2SO_4 (1 percent, 4 percent). Then the specimens were immersed in solutions for 30 days.
The high performance concrete with sodium nitrite inhibitor has reduced weight loss when compared with ordinary concrete without and with inhibitor as the percentage of dosage increases in HCl acid as shown in Fig.7. The high performance concrete with sodium nitrite inhibitor has reduced weight loss when compared with ordinary concrete without and with inhibitor as the percentage of dosage increases in H_2SO_4 acid as shown in Fig.8.

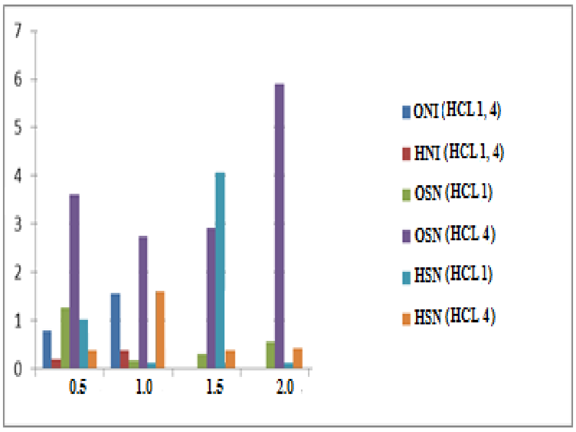


Figure 7. Percentage of loss of water by HCL 1 and 4 Percentage

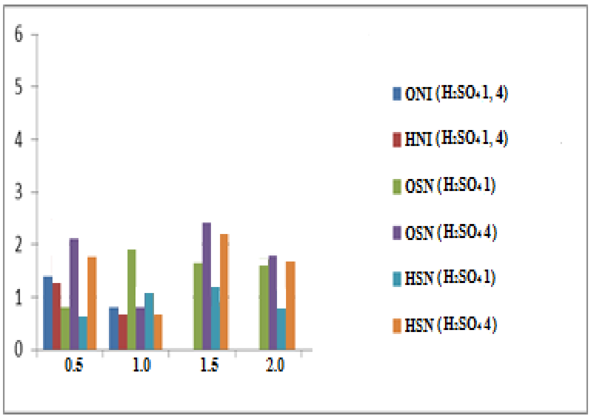


Figure 8. Percentage of loss of water by H_2SO_4 1 and 4 Percentage

6.3 Rapid Chloride Permeability Test

The penetration of chloride ions in terms of coulombs is determined by rapid chloride permeability test according to ASTM C1202. The presence of chloride ion permeability is very low and negligible as the sodium nitrite inhibitor provides better resistance to chloride permeability in concrete. The high performance concrete with sodium nitrite inhibitor is reduced chloride ion penetration when compared with ordinary concrete with inhibitor as shown in Fig.9.

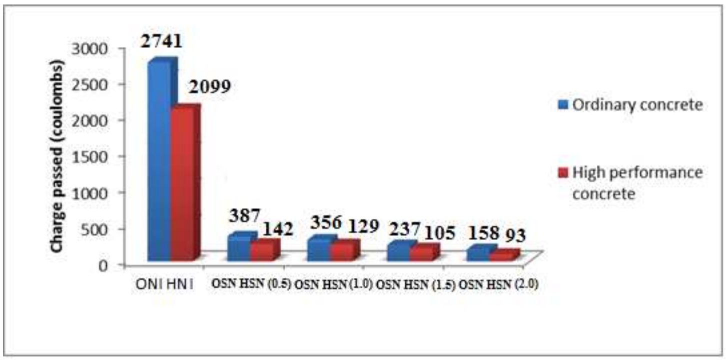


Figure 9. Rapid Chloride Permeability Test results

The ordinary concrete without and with inhibitor shows the corrosion rate moderate to very low whereas in high Performance Concrete, the corrosion rate is moderate to negligible as per ASTM C1202 standards as shown in Table 5.

Table 5 Rapid chloride permeability test result

Sl. No.	Type of concrete	Percentage of inhibitor Sodium nitrite	Cumulative charge passed in coulombs	Corrosion rate
1.	OC	0.0	2741	Moderate
		0.5	387	Very Low
		1.0	356	Very Low
		1.5	237	Very Low
		2.0	158	Very Low
2.	HPC	0.0	2099	Moderate
		0.5	142	Very Low
		1.0	129	Very Low
		1.5	105	Very low
		2.0	93	Negligible

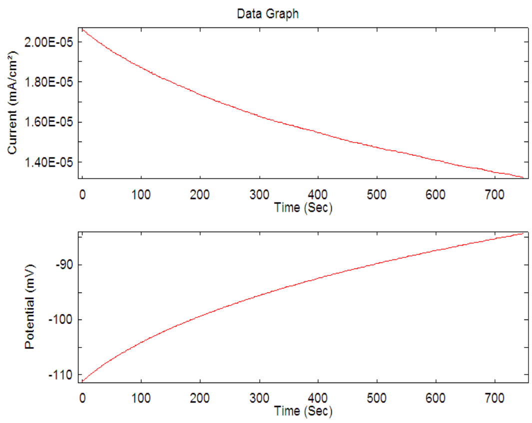
7. CORROSION TEST

7.1. Open circuit potential Measurements

For conducting open circuit potential test concrete cube specimens of size 100 mm × 100 mm × 100 mm had been cast with 10 mm diameter steel rod inserted at the centre up to a depth of 70 mm and cylinder specimens of size 100 mm × 200 mm had been cast with 10 mm diameter steel rod inserted at the centre up to a depth of 120 mm. Ordinary and high performance concrete with different percentage of inhibitor had been considered along with normal concrete for this test. The concrete specimens were placed in the Electrical analyser, the rebar was connected to working electrode 1 and the reference electrode and also auxiliary electrode directly connected to Guard ring was placed over the specimen. The schematic diagram and the electrode connections of Electrical analyser are shown in Fig. 10.

Figure 10. Electrical analyser setup

The function of Working Electrode (WE-1) is to pass the voltage into the rebar embedded in concrete. The Auxiliary Electrode (AE) converts the passed voltage into the required current and the current spreads the entire specimen. The Reference Electrode using the converted current locates the corrosion/weak points in the specimen. The output is given as a graph showing time Vs potential, time Vs current (Fig.11). From the graph voltage ratio has been calculated by the machine.



Delta V (mV) =10.612, Average V (mV) = --125.74, Voltage ratio = Negligible

Figure 11. Open Circuit Potential Test

The Corrosion rates of ordinary concrete and high performance concrete without and with inhibitor are shown in Table 6. The corrosion rate of ordinary concrete without and with inhibitor indicates moderate to negligible corrosion rate whereas high performance concrete without and with inhibitor indicates very low to negligible corrosion rate as per ASTM B611-2005 standards.

Table 6 Open Circuit Potential test results

Sl. No.	Type of concrete	Percentage of sodium nitrite inhibitor	Voltage ratio		Corrosion rate	
			Cube	Cylinder	Cube	Cylinder
1.	OC	0.0	-0.10	-0.14	Very Low	Very Low
		0.5	-0.003	-0.006	Negligible	Negligible
		1.0	-0.41	-0.0004	Moderate	Negligible
		1.5	-0.076	-0.0007	Low	Negligible
		2.0	-0.008	-0.029	Negligible	Very low
2.	HPC	0.0	-0.08	-0.03	Very Low	Very Low
		0.5	-0.002	-0.003	Negligible	Very low
		1.0	-0.003	-0.001	Negligible	Negligible
		1.5	-0.0009	-0.004	Negligible	Negligible
		2.0	-0.0006	-0.0001	Negligible	Negligible

7.2 AC Impedance Test

The Impedance test method measures the corrosion rate using I_{corr} values and also determines the corrosion points available inside the specimens.

Calculation of Corrosion rate

$I_{corr}=B/R_p$ ……….. (6)

Corrosion rate = 0.129xI_{corr} x EW/ dA ……….. (7)

B = *B* is the Stern–Geary constant, Stern–Geary range of 10–30 mV, R_p = Polarization Resistance, E.W=equivalent weight of the corroding species, (g). *A*=exposed surface area of the reinforcing steel, d = the density of the reinforcing steel, in g/cm^3

The Corrosion rates of ordinary concrete and high performance concrete without and with inhibitor are shown in Table 7. The corrosion rate of ordinary concrete without and with inhibitor indicates medium risk to low risk corrosion rate whereas high performance concrete without and with inhibitor indicates medium risk to very low risk corrosion rate as per ASTM CSA/S413-94 standards.

Table 7 AC Impedance test results

Sl. No.	Type of concrete	Percentage of sodium nitrite inhibitor	Corrosion rate mm/year		Corrosion rate	
			Cube	Cylinder	Cube	Cylinder
1.	**OC**	0.0	4.41	1.89	Medium risk	Low risk
		0.5	4.20	1.92	Medium risk	Low risk
		1.0	1.43	2.34	Low risk	Low risk
		1.5	1.60	2.00	Low risk	Low risk
		2.0	4.11	1.67	Medium risk	Low risk
2.	**HPC**	0.0	4.23	1.76	Medium risk	Low risk
		0.5	0.54	1.81	Very low risk	Low risk
		1.0	0.69	1.57	Very low risk	Low risk
		1.5	1.53	1.95	Low risk	Low risk
		2.0	0.90	1.48	Very low risk	Low risk

7.3 LPR Sweep Test

The Linear polarization resistance sweep method measures the instantaneous corrosion rates as compared to other methods on which metal loss is measured over a finite period of time. Instantaneous means that each reading on the instrument can be translated directly into corrosion rate. The experiment can be completed in a matter of minutes and the small polarization from the corrosion potential does not disturb the system. This permits rapid rate measurements (ASTM D2776 & G59) and can be used to monitor corrosion rate in various process streams. The LPR data enable a more detailed assessment of the structural condition and is a major tool in deciding upon the optimum remedial strategy to be adopted. It is thus imperative that the LPR measurements obtained are accurate. In LPR measurements the reinforcing steel is perturbed by a small amount from its equilibrium potential. This can be accomplished potentiostatically by changing the potential of the reinforcing steel by a fixed amount, ΔE- reinforcing steel and monitoring the current decay ΔI, after a fixed time. Alternatively it can be done galvanostatically by applying a small fixed current, ΔI-to the reinforcing steel and monitoring the potential change, ΔE- after a fixed time period. In each case the conditions are selected such that the change in potential, ΔE falls within the linear

Stern–Geary range of 10–30 mV. The polarization resistance, *R*p, of the steel is then calculated from the equation.

$$R_p = \Delta E/\Delta I .... (8)$$

Where, B is the Stern–Geary constant. A value of 25 mV has been adopted for active steel and 50 mV for passive steel.

From which the corrosion rate, *I*corr, can then be calculated

$$I_{corr} = B/R_p .... (9)$$

The Corrosion rates of ordinary concrete and high performance concrete without and with inhibitor are shown in Table 8. The corrosion rate of ordinary concrete without and with inhibitor indicates very low risk corrosion rate whereas high performance concrete without and with inhibitor indicates very low risk corrosion rate as per ASTM D2776 & G59 standards.

Table 8 Linear potential resistance results

Sl. No.	**Type of concrete**	**Percentage of sodium nitrite inhibitor**	**Corrosion Rate (mm/Year)**		**Corrosion rate**	
			Cube	**Cylinder**	**Cube**	**Cylinder**
1.	**OC**	0.0	0.00099	0.0023	Very low risk	Very low risk
		0.5	0.00079	0.0017	Very low risk	Very low risk
		1.0	0.00062	0.0014	Very low risk	Very low risk
		1.5	0.00068	0.0010	Very low risk	Very low risk
		2.0	0.00080	0.0017	Very low risk	Very low risk
2.	**HPC**	0.0	0.00099	0.0012	Very low risk	Very low risk
		0.5	0.00041	0.0011	Very low risk	Very low risk
		1.0	0.00049	0.0010	Very low risk	Very low risk
		1.5	0.00042	0.0004	Very low risk	Very low risk
		2.0	0.00043	0.0003	Very low risk	Very low risk

7.4 Custom Sweep Test

The Custom sweep method or Tafel Extrapolation Method measures the instantaneous corrosion rates. This technique uses data obtained from cathodic and anodic polarization measurements. Cathodic data are preferred, since these are easier to measure it experimentally. In this method, the total anodic and cathodic polarization curves corresponding to hydrogen evolution and metal dissolution are superimposed as dotted lines. It can be seen that at relatively high-applied current densities the applied current density and that corresponding to hydrogen evolution have become virtually identical. To determine the intercept corrosion rate from such polarization measurements, the Tafel region is extrapolated to the corrosion potential.

$$i_{corr} = \frac{\propto\beta}{2.3\,(\alpha+\beta)}\frac{\Delta i}{\Delta E} .... (10)$$

$$i_{corr} = \frac{\propto\beta}{2.3\,(\alpha+\beta)}\frac{1}{R_p} ....(11)$$

$where\ \Delta E/\Delta i = slope\ of\ the\ polarization = polarization\ Resistance = R_p$

$\propto and\ \beta = cathodic\ and\ Anodic\ Tafel\ constants$

The Corrosion rates of ordinary concrete and high performance concrete without and with inhibitor are shown in Table 9. The corrosion rate of ordinary concrete without and with inhibitor indicates moderate risk to very low risk corrosion rate whereas high performance concrete without and with inhibitor indicates very low risk corrosion rate as per ASTM C1543 – 10a standards.

Table 9 Custom Sweep Test Results

Sl. No.	Type of concrete	Percentage of sodium nitrite inhibitor	Intercept Corrosion Rate (mm/Year)		Corrosion rate	
			Cube	Cylinder	Cube	Cylinder
1.	OC	0.0	4.149	4.0024	Moderate risk	Moderate risk
		0.5	0.000148	0.00053	Very low risk	Very low risk
		1.0	0.000111	0.00082	Very low risk	Very low risk
		1.5	0.000095	0.00068	Very low risk	Very low risk
		2.0	0.000101	0.00055	Very low risk	Very low risk
2.	HPC	0.0	0.071008	0.00039	Very low risk	Very low risk
		0.5	0.000200	0.00043	Very low risk	Very low risk
		1.0	0.000280	0.00034	Very low risk	Very low risk
		1.5	0.000254	0.00022	Very low risk	Very low risk
		2.0	0.000243	0.00021	Very low risk	Very low risk

7.5. Half Cell Potential

Half-cell potential measurements provide a classification of the corrosion activity of the steel and indicate locations where the steel is potentially corroding. A half-cell potential measurement apparatus consists of a voltmeter with one lead connected to a reference electrode, normally a copper/ copper sulfate ($Cu/CuSO_4$) electrode, placed on the surface of the concrete and a second lead connecting the voltmeter to the reinforcing steel. Current passes from the reference electrode to the concrete surface through a sponge soaked with an electrolytic solution. The objective of the instrumentation is to measure the voltage, or potential difference, between the rebar and the reference electrode. In the half-cell potential setup, the reference electrode behaves as the cathode, as copper is higher in the galvanic series than steel. Through the circuit created, the potential difference is measured. With the reference electrode acting as the cathode and being connected to the positive terminal of the voltmeter, measured half-cell potentials have a negative value. A half-cell potential measurement results from the multiplication of the reinforcement corrosion potential by the ratio of the internal resistance of the voltmeter to the sum of the internal resistance of the voltmeter and the resistance of the concrete. A schematic of the test circuit is shown in Fig.12.

Figure 12. Half-cell potential

The Corrosion rates of ordinary concrete and high performance concrete without and with inhibitor are shown in Table 10. The corrosion rate of ordinary concrete without and with inhibitor indicates moderate risk to very low risk corrosion rate whereas high performance concrete without and with inhibitor indicates moderate risk to very low risk corrosion rate as per ASTM 876-2009 standards.

Table 10 Half Cell Potential (ASTM C876-2009)

Type of concrete	Percentage of sodium nitrite inhibitor	Potential value mV range		Corrosion rate	
		Cube	Cylinder	Cube	Cylinder
OC	0.0	-335	-278	Moderate	Moderate
	0.5	-87	-56	Very low risk	Very low risk
	1.0	-77	-55.2	Very low risk	Very low risk
	1.5	-77	-49.9	Very low risk	Very low risk
	2.0	-92	-49.6	Very low risk	Very low risk
HPC	0.0	-226	-243	Moderate	Moderate
	0.5	-86.5	-41.5	Very low risk	Very low risk
	1.0	-63	-32	Very low risk	Very low risk
	1.5	-63	-30.7	Very low risk	Very low risk
	2.0	-60.1	-48.2	Very low risk	Very low risk

8. Conclusions

i. The cube and cylinder compressive strengths of high performance concrete with inhibitor was 1.5 percent – 3 percent higher and 1 percent – 2.8 percent higher respectively at 28 days when compared with ordinary concrete with inhibitor as the percentage of dosage increases.
ii. The split tensile strength of high performance concrete with inhibitor was 2.5 percent - 32 percent higher at 28 days when compared with ordinary concrete with inhibitor as the percentage of dosage increases.
iii. The water absorption for high performance concrete with inhibitor reduced by 40 percent when compared to ordinary concrete with inhibitor.
iv. The high performance concrete with inhibitor shows better acid resistance (HCl and H_2SO_4) at 19 percent – 21 percent (measured in weight loss) in 1 percent and 4 percent acid solution when compared with ordinary concrete with inhibitor as the percentage of dosage increases.
v. The presence of chloride ion permeability is very low in high performance concrete with inhibitor (coulombs range:142-93) when compared with ordinary concrete with inhibitor (coulombs range:387-158) as the percentage of dosage increases.
vi. The voltage ratio of open circuit potential in ordinary concrete with inhibitor indicates 'moderate to negligible' rate when compared with high performance concrete which indicates 'very low to negligible rate' as the percentage of dosage increases.
vii. The corrosion rate of A.C. Impedance in ordinary concrete with inhibitor indicates 'medium to low risk' when compared with high performance concrete with inhibitor which indicates `medium to very low risk' as the percentage of dosage increases.

viii. The intercept corrosion rate of custom sweep in ordinary concrete with inhibitor indicates ‘medium to very low risk’ when compared with high performance concrete with inhibitor which indicates ‘very low risk’ as the percentage of dosage increases.

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