RAPID CHLORIDE PERMEABILITY TEST FOR EVALUATING THE DURABILITY PARAMETERS OF CORROSION INHIBITING ADMIXTURES.

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Abstract:

Corrosion of reinforcing steel represents the most widespread form of deterioration of concrete structures. Various types of corrosion inhibitors have been developed and marketed to mitigate corrosion in concrete structures. This paper deals with testing of two commercially available Corrosion inhibitors to determine the effectiveness and their influence on Durability of Concrete (with OPC and PPC) using Rapid Chloride Permeability Test (RCPT). The rapid chloride permeability tests revealed that the resistance of concrete for the ingress of chloride ions is improved by addition of corrosion inhibitors.

Key Words: *Corrosion inhibitors, Anodic Inhibitor/ Calcium Nitrite based inhibitor, Bipolar Corrosion inhibitor, Rapid chloride permeability test (RCPT),*

1.0 INTRODUCTION:

It is generally accepted that the embedded steel in concrete itself forms a passive film on the surface and protects the steel against corrosion [12]. If certain deleterious factors and agents are prevented, the concrete surrounding the reinforcing steel alone is ideally suited for preventing the corrosion of steel. However, the entry of moisture, electrolytes and oxygen by diffusion into the concrete through the hairline cracks in the concrete surface can destroy the passive environment and instigate the galvanic corrosion cells. Among the electrolytes, chloride salts are most prominent in promoting the corrosion [2].

The chlorides ions destroy the protective oxide layer on steel rebar which initiates the corrosion. As corrosion progresses, complex oxides are formed and cause expansion resulting in disbanding of rebar. The rust volume will be two to four times greater than the volume of the parent steel, resulting in large stresses that ultimately crack and spall the concrete cover. The initiation time of corrosion depends on quality and thickness of the concrete cover and the permeability of concrete. It is important to know the initial Chloride content since they are present in the concrete mix ingredients from cement, aggregates, and water. They can also diffuse from outside of the structure [1, 7,8 and 13].

Corrosion inhibitors can be added during mixing the fresh concrete or can be applied on the surface of hardened concrete structures [3]. For preventing the corrosion of steel in concrete in the presence of chloride ions, the use of corrosion inhibitors in concrete is an alternative option [5,10]. The use of different classes of corrosion – inhibiting admixtures in concrete have been reviewed by various authors. Earlier studies looked at numerous corrosion inhibition admixtures with the most attention focused on sodium nitrite, Potassium chromate, Sodium benzoate and stannous chloride [11].

In the Indian market, the two commercially available inhibitors are the anodic inhibitors and the bipolar inhibitors. Anodic corrosion inhibitors, which are mostly nitrite-based, display corrosion protection through a partial interface process. The use of amino alcohol-based bipolar corrosion inhibitors has increased recently, but studies related to these types of inhibitors are lacking [6].

The corrosion-inhibiting admixtures improve the properties of concrete by changing the chemistry of the pore water solution. For assessing the quality-control parameters in projects, a simple to conduct test is preferred that can be performed in a short time. The Rapid Chloride Permeability Test (RCPT) meets these goals. First developed by Whiting in 1981 [15] RCPT has had results that correlate well with results from the classical 90-day salt ponding test [9].

Two commercially available Corrosion inhibitors were tested to determine the effectiveness and their influence on Durability of Concrete (with OPC and PPC) using Rapid Chloride Permeability Test (RCPT).

2. MATERIALS AND METHOD

2.1 Materials

M 35 grade concrete using OPC was used to assess the effect of corrosion inhibitors in terms of modification of workability and compressive strength of concrete. The properties of each of these materials used in the concrete are tested and used for mix design of concrete. The materials are tested in conformation with the IS code.

The materials used for this experimental work are:

- Cement: Ordinary Portland Cement

- Sand : Zone II
- Coarse aggregate: HBG 20 mm graded
- Water: potable water
- Commercially available Anodic (Calcium nitrate based) corrosion inhibiting admixtures (CNIA)
- Commercially available Bipolar corrosion inhibiting admixtures (BIA)

2.1.1 Ordinary Portland Cement (OPC)

53 grade Ordinary Portland Cement conforming to IS:8112 is used in this study.

2.1.2 Portland Pozzolona Cement (PPC)

PPC conforming to IS 1489 is used in this study

2.1.3 Anodic Corrosion inhibitors:

A commercially available Anodic Inhibitor (Calcium Nitrite based inhibitor) was used in this study. This is a chloride free, ready to use aqueous solution of calcium nitrite. Calcium nitrite is an ingredient which reacts chemically to interrupt chloride induced corrosion. Nitrites (Calcium or sodium salt) are anodic inhibitors, they compete with chloride ions for the ferrous ions at the anode to form a film of ferric oxide [4].

2.1.4 Bipolar Inhibitor

A commercially available bipolar inhibitor was also used in this study for comparison. This is an Amino alcohols based inhibitor, such as ethanolamine and Di-methyl ethanol amine, control corrosion by attacking cathodic activity, blocking sites where oxygen picks up electrons and is reduced to hydroxyl ion and they also absorb at anodic sites as well.

The chemical based inhibitor containing molecules in which electron density distribution causes the inhibitor to be attracted to both anodic and cathodic processes. Due to the good quality of its vapour pressure and distribution with the moisture within the concrete, these molecules migrate to the steel and form a monomolecular layer along the reinforcement in concrete. Thus corrosion vis-à-vis micro cell formation is inhibited. The test parameters of the corrosion inhibitors are given in table 2.1.

Table 2.1 : Test parameters of the corrosion inhibitors

S No	Test Conducted	Calcium Nitrite Inhibitor	Bi Polar Inhibitor
1	Dry Material content (by % weight)	31.78	16.15
2	pH	6.03	8.17
3	Ash content (by % weight)	15.55	17.59
4	Relative density	1.18	1.1
5	Chloride (%)	Nil	Nil

2.2 Mix proportions

M35 grade concrete using OPC was used to assess the effect of corrosion inhibitors. Based on the properties of the ingredients, the mix was designed for M35 grade of concrete as per IS 10262:2009. The concrete specimens were cast to study the modification of the strength and durability parameters of concrete. The various mix proportions used in this study are given in table 2. The Calcium Nitrite Inhibitor is designated as CN and Bi-polar inhibitor is designated as BI.

Table 2.2 : Details of Concrete mix proportions

S NO	**Specimen Combination**	**Cement**	**Coarse Agg**		**Fine Aggregate**	**Water**	**Inhibitor**	**Remarks**
		KG	20mm KG	12mm KG	KG	Litre	Litre	
1	M35 GRADE CONCRETE WITH (OPC)	360	690	460	710	167	0.00	OPC Control Mix
2	M35 OPC + CN2%	360	690	460	710	159.80	7.20	2% Inhibitor
3	M35 OPC + CN5%	360	690	460	710	149.00	18.00	5% Inhibitor
4	M35 OPC + BI2%	360	690	460	710	159.80	7.20	2% Inhibitor
5	M35 OPC + BI5%	360	690	460	710	149.00	18.00	5% Inhibitor
6	M35 GRADE CONCRETE WITH (PPC)	390	676	482	740	172	0.00	PPC Control Mix
7	M35 PPC + CN2%	390	676	482	740	164.20	7.80	2% Inhibitor

8	M35 PPC + CN5%	390	676	482	740	152.50	19.50	5% Inhibitor
9	M35 PPC + BI2%	390	676	482	740	164.20	7.80	2% Inhibitor
10	M35 PPC + BI5%	390	676	482	740	152.50	19.50	5% Inhibitor

2.3 Rapid Chloride Permeability Test (RCPT)

Standardized testing procedures are in AASHTO T 277 or ASTM C 1202. The RCPT is performed by monitoring the amount of electrical current that passes through a sample 50 mm thick by 100 mm in diameter in 6 hours (see schematic figure 2.1). This sample is typically cut as a slice of a core or cylinder. A voltage of 60V DC is maintained across the ends of the sample throughout the test. One lead is immersed in a 3.0% salt (NaCl) solution and the other in a 0.3 M sodium hydroxide (NaOH) solution. Based on the charge that passes through the sample, a qualitative rating is made of the concrete's permeability, as shown in Table 2.3.

Table 2.3: Qualitative rating of Concrete's permeability vs Charge passing

Chloride permeability	Charge passing, coulombs
High	> 4000
Moderate	2000 to 4000
Low	1000 to 2000
Very low	100 to 1000
Negligible	< 100

Versatile and easy to conduct, the RCPT has been adopted as a standard and is now widely used [14]. The current that passes through the sample during the test indicates the movement of all ions in the pore solution (that is, the sample's electrical conductivity), not just chloride ions.

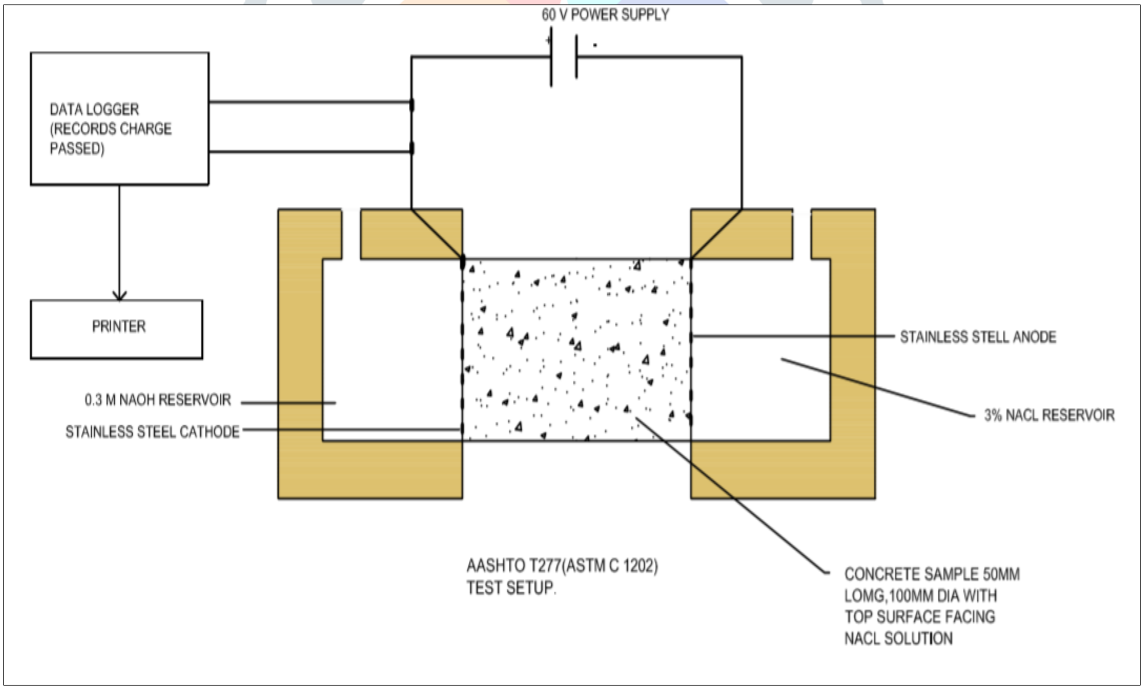

Figure 2.1 : RCPT Test set up (AASHTO T277/ ASTM C 1202)

2.4 RCPT Test Procedure

- The concrete specimen shall be removed from water at the end of soaking period and blot off the excess water and transfer it to a sealed container maintained at 95% relative humidity. The specimen shall be placed in a voltage cell.
- Place a 100mm outside diameter by 75 mm inside diameter by 6mm circular vulcanized rubber gasket in each half of the test cell. Insert the sample and clamp the two halves of the cell together to seal.

- Fill the inside of the cell containing the top surface of the specimen with 3.0% NaCl solution (cell connected to the negative terminal of the power supply) and the other side with 0.3 N NaOH solutions (cell connected to the positive terminal of power supply).
- The temperature of the specimen, applied voltage cell and solutions shall be maintained at 20 to 25 °C when the power supply is turned on.
- Read and record current at every 30 in for a period of 6 hours. Each half of the test cell shall remain filled with the appropriate solution for the entire period of the test.

Result:

- The total charge passed is a measure of the electrical conductance of the concrete during the period of the test.
- The total charge is calculated using the trapezoidal rule as given below:

$$Q = 900(I_o + 2I_{30} + 2I_{60} + \ldots\ldots\ldots\ldots + 2\,I_{300} + 2I_{330} + I_{360})$$

Where:

Q = charge passed (coulombs)

I_o = current (amperes) immediately after voltage is applied

I_t = current (amperes) at t min after voltage is applied

Note: If the specimen diameter is other than 95mm, the value for total charge calculated using the above mentioned formula should be multiplied by the ratio of the cross-sectional areas of the standard and the actual specimens.

$$Q_s = Q_x \text{ x } (95/x)^2$$

Where:

Q_s = charge passed through a 95 mm diameter sample

Q_x = charge passed through a x mm diameter sample

x = diameter in mm of the non-saturated specimen

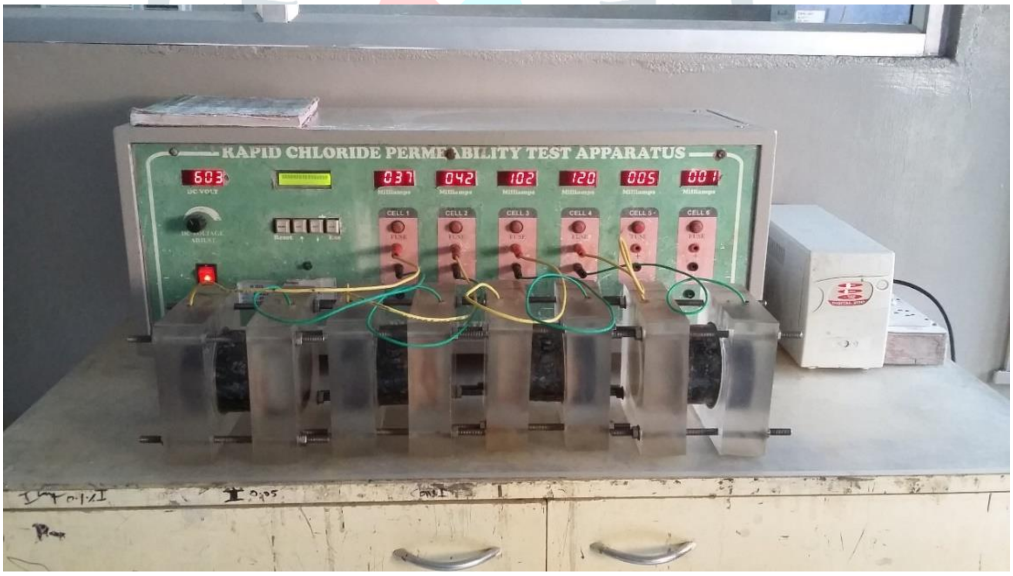

Fig. 2.2. RCPT test setup in laboratory

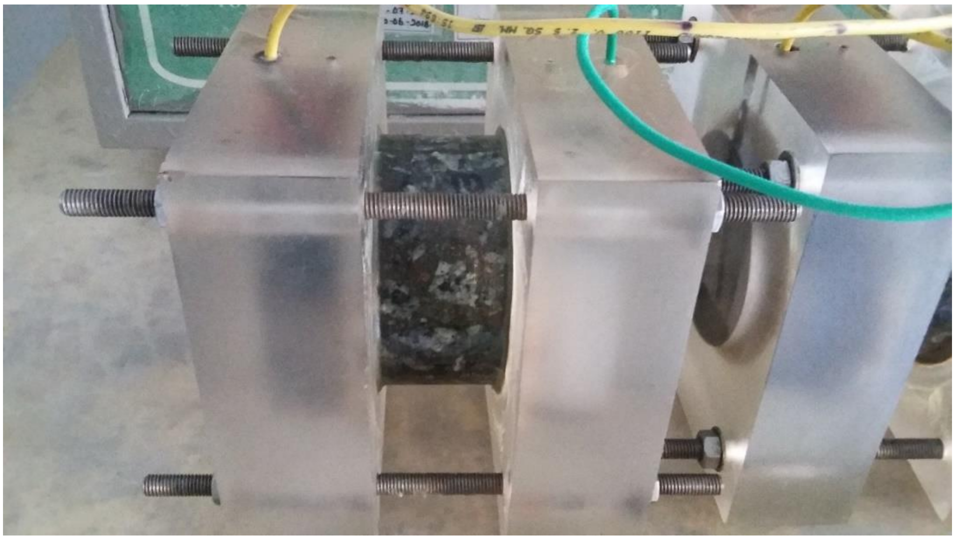

Fig. 2.3. Concrete specimen placed in the corrosion cell

3.0 Results and Analysis:

As a part of durability studies, Rapid chloride permeability test and water permeability test were conducted for durability measurement by the addition of corrosion inhibitors (calcium nitrite and bipolar inhibitor at 2%, 5%).

Table 2.4: RCPT values for OPC mixed with Corrosion Inhibitors

S.NO	IDENTIFICATION	RCPT Value (Coloumbs)	Remarks
1	OPC (control mix)	1125	Low Chloride Permeability
2	OPC +2% CN	950	Very Low Chloride Permeability
3	OPC +5% CN	1010	Low Chloride Permeability
4	OPC +2% Bipolar	843	Very Low Chloride Permeability
5	OPC +5% Bipolar	921	Very Low Chloride Permeability

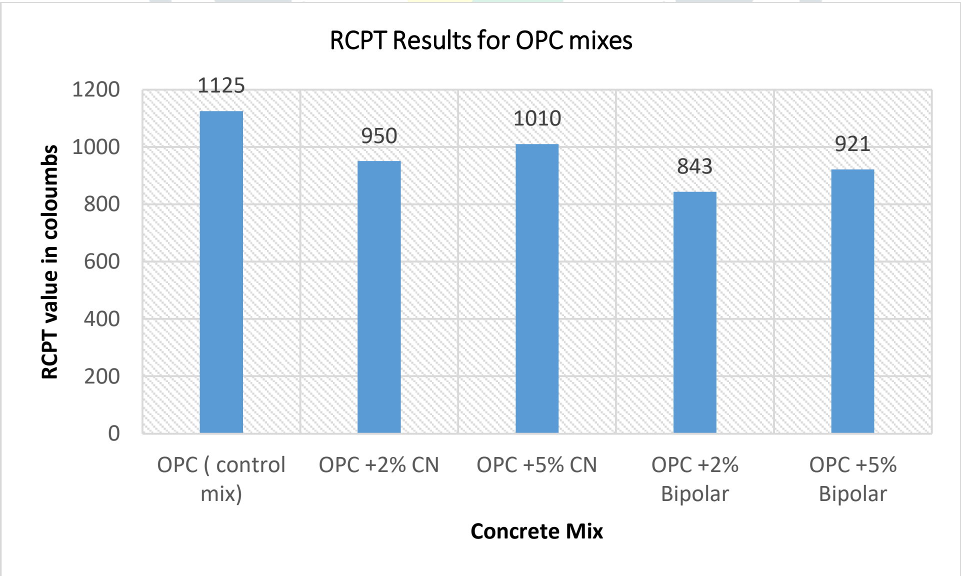

Figure 2.4: RCPT Results for OPC mixed with Corrosion Inhibitors

Table 2.5: RCPT values for PPC mixed with Corrosion Inhibitors

S.NO	IDENTIFICATION	RCPT Value (COLOUMBS)	Remarks
1	PPC (control mix)	1120	Low Chloride Permeability
2	PPC +2% CN	705	Very Low Chloride Permeability
3	PPC +5% CN	996	Very Low Chloride Permeability
4	PPC +2% BI	690	Very Low Chloride Permeability
5	PPC +5% BI	809	Very Low Chloride Permeability

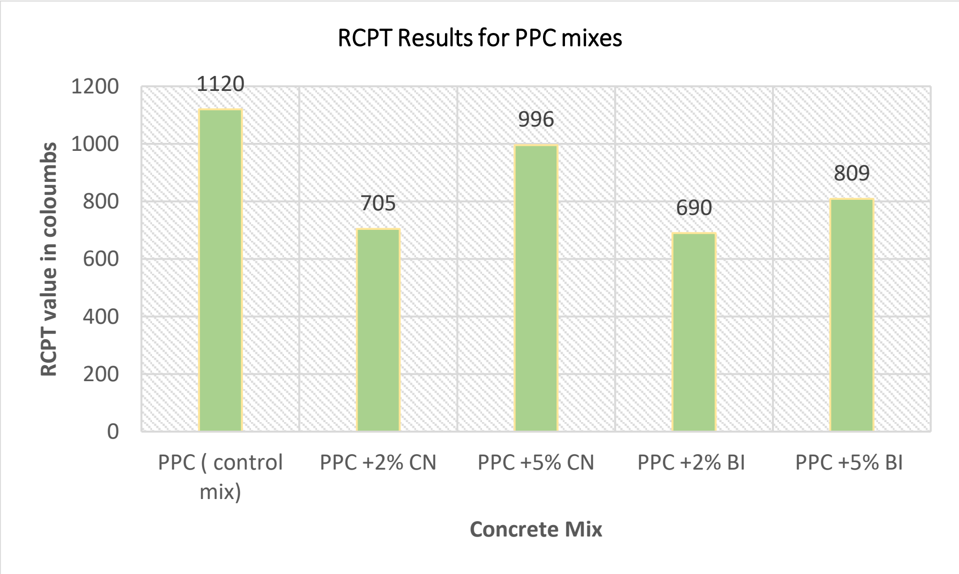

Figure 2.5: RCPT Results for PPC mixed with Corrosion Inhibitors

3.4 Conclusions:

- There is no improvement in the workability of OPC concrete mixes or PPC concrete mixes by addition of both the Corrosion inhibitors compared to the control mix.
- The rapid chloride permeability tests revealed that the resistance of concrete for the ingress of chloride ions is improved by addition of corrosion inhibitors.
- Addition of 2% Calcium Nitrite inhibitor shows 15 % improvement in RCPT value. 5% addition of Calcium Nitrite inhibitor shows 10.25 %improvement in RCPT value.
- Addition of 2% Bipolar inhibitor shows 25 % improvement in RCPT value. Addition of 5% Bipolar inhibitor shows 18 % improvement in RCPT value. These results indicate that the bipolar inhibitor has a superior anti-corrosion effects which can be attributed to chloride ion binding property.

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