EFFECT OF CORROSION ON STEEL IN
CHLORIDE INDUCED WATER BY
CONDUCTING POTENTIODYNAMIC
INVESTIGATIONS

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ABSTRACT

This paper presents the findings of an experimental investigation of
potentiodynamic study on reinforcing steel in chloride induced water. The major test
variables included cement type. Various corrosion zones of different cement types was
identified. The corrosion resistance properties of each concrete sample were studied
by performing electrochemical tests.

Key words: Concrete, potentiodynamic, cement, electrochemical.

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1. INTRODUCTION

Cement is very important material for the construction of national economy. In cconcrete
technology, cement plays an major role of an binding material. The binding component in
concrete has a pH of 11, which is alkaline in nature. When this pH of the concrete drops
roughly around 6 or 7, the ability of cement to hold together the components of concrete is
compromised. The concrete is subjected to a process called Carbonation. Carbonation is a
process in which pH levels of the concrete are lowered due to various factors during
concreting [1]. It is the reaction between the cement in concrete and carbon dioxide in air. The
concrete cover protects the reinforcing steel, when carbonation process occurs it attacks the
thin protective layer of ironoxide surrounding the reinforcing steel and hence initiates the process of corrosion. The passivity of the concrete is disturbed and hence the corrosion process is accelerated thereby causing a failure. Some investigations have been carried out to determine the effect of contaminant chloride concentration on corrosion behaviour of the reinforcing steel in alkaline simulated concrete pore solution.

In this paper, results of an experimental investigation is presented whereby potentiodynamic test have been carried out in four types concrete using different cements those are OPC, PPC, PSC and ACC(Anti-corrosive cement) reinforcing steel embedded in the cylinder mould [2]. These moulds were immersed in chloride solution using 3.5% NaCl. The main objective of the present work is to determine the order of resistance to general corrosion. Linear Polarization Resistance measurements are an accurate and rapid way of measuring general corrosion rate.

2. EXPERIMENTAL INVESTIGATION

2.1. Test variable and material used

Four concrete mixes were used in this investigation, the major test variables was the cement type. The different types of cements used in experimental work were OPC (Ordinary Portland cement), PPC (Pozzolanic Portland Cement), PSC (Pozzolanic Slag Cement)and KRIA (Anti-corrosive cement) [4],[5],[6]

<table>
<thead>
<tr>
<th>Sr.No</th>
<th>Cement Type</th>
<th>Grade of Cement</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ordinary Portland cement</td>
<td>53</td>
<td>Ambuja Cements</td>
</tr>
<tr>
<td>2</td>
<td>Pozzolanic Portland Cement</td>
<td>53</td>
<td>Ambuja Cements</td>
</tr>
<tr>
<td>3</td>
<td>Pozzolanic Slag Cement</td>
<td>53</td>
<td>JSW Cements</td>
</tr>
<tr>
<td>4</td>
<td>Anti-corrosive cement</td>
<td>53</td>
<td>Krishna Conchem Products Pvt Ltd</td>
</tr>
</tbody>
</table>

2.2. Preparation of specimen of steel specimen and concrete moulds

Concrete cylinders of dia 100mm and length of 200mm as per IS 516 were casted. The centre on the cylinder was marked and TMT 12mm dia bar was inserted in the cylinder with aluminium casting with hole drilled in centre and C-clamps were used to maintain the verticality of TMT bar then concrete was poured into the mould. TMT bar was coated with epoxy coating. The concrete cylinder moulds with TMT bar were immersed in chloride solution 3.5% NaCl for 168 hours.[3]

2.3. Experimental Procedure

2.3.1. Instrument and Electrochemical cell description

The electrochemical tests were performed on TMT bar (without Epoxy coating) using a versatile instrument BIOSONIC SP-50. This instrument is capable of performing various electrochemical tests as LPR Tests and Tafel Plots etc [9]. The instrument is capable of processing the data and plotting graphs automatically.
The electrochemical cell consisted of bucket, cylinder with TMT bar was placed in the bucket. A hole of about 15-20mm was drilled at a distance of 20mm from TMT bar. There are connections for connecting working electrode, reference electrode and auxiliary electrode. The reference electrode used throughout was saturated calomel electrode (SCE). The solution used for all specimens was 3.5% NaCl.

2.3.2. Electrochemical testing of steel

Electrochemical testing was carried out on potentiostat (BIOSONIC SP-50) where working electrode was steel, reference electrode was saturated calomel electrode (SCE) and auxiliary electrode was mesh. The following input values were entered for calculating the corrosion rate and for estimating the polarization resistance ($R_p$)[9]

The scan rate $E_{sc}$ was 0.166mV/sec. The cell description input values were as follows, electrode material was 12mm diameter tor steel embedded in concrete, electrolyte solution used was 3.5% NaCl. The diameter of bar was cross checked using vernier caliper and then the actual surface area was worked out, electrode surface area was $66\text{cm}^2$; equivalent weight and density were $28\text{g/eq}$ and $7.880\text{g/cm}^3$ respectively. The measurements were recorded using EC-LABS software and graphs were plotted automatically. The graphs indicated the cathodic and anodic zones.

2.3.3. Determination of pH of samples.

The electrolyte solution of each sample was tested for estimating the pH levels. Digital pH meter was used to determine the pH level, following are the values recorded.

<table>
<thead>
<tr>
<th>Sr.No</th>
<th>Sample Identification Mark</th>
<th>pH reading</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>OPC-1</td>
<td>12.32</td>
</tr>
<tr>
<td>2.</td>
<td>PPC-1</td>
<td>12.42</td>
</tr>
<tr>
<td>3.</td>
<td>KRIYA-1</td>
<td>13.05</td>
</tr>
<tr>
<td></td>
<td>PSC-1</td>
<td>12.04</td>
</tr>
</tbody>
</table>

3. RESULTS AND DISCUSSIONS

The LPR measurement plots and tafel plots are plotted directly by using software EC-LAB.

![Figure 1](http://www.iaeme.com/IJCIET/index.asp)
Figure 2: Potential vs. Current of concrete sample with PPC-1, TMT steel specimen

Figure 3: Potential vs. Current of concrete sample with KRIA-1, TMT steel specimen

Figure 4: Potential vs. Current of concrete sample with PSC-1, TMT steel specimen
**Table 3** Linear Polarization Resistance values of the sample

<table>
<thead>
<tr>
<th>SR.No</th>
<th>SAMPLE CODE</th>
<th>Ecorr (mV)</th>
<th>Icorr (µA)</th>
<th>Rp (Ohms·Ω·cms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>OPC-1</td>
<td>-615.5</td>
<td>37.02</td>
<td>705</td>
</tr>
<tr>
<td>2</td>
<td>PPC-1</td>
<td>-550.07</td>
<td>110.62</td>
<td>236</td>
</tr>
<tr>
<td>3</td>
<td>KRIA-1</td>
<td>-640.97</td>
<td>22.85</td>
<td>1142</td>
</tr>
<tr>
<td>4</td>
<td>PSC-1</td>
<td>-661.42</td>
<td>37.85</td>
<td>689</td>
</tr>
</tbody>
</table>

Similarly, tafel plots are plotted using EC-LAB software.

**Figure 5** Potential vs. Current density concrete sample with OPC-1, TMT steel specimen

**Figure 6** Potential vs. Current density concrete sample with PPC-1, TMT steel specimen
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Figure 7: Potential vs. Current density concrete sample with KRIA-1, TMT steel specimen

Figure 8: Potential vs. Current density concrete sample with PSC-1, TMT steel specimen

Table 4: Tafel plot values for each sample

<table>
<thead>
<tr>
<th>SR.No</th>
<th>SAMPLE CODE</th>
<th>E_corr (mV)</th>
<th>I_corr (µA)</th>
<th>CR (mpy)</th>
<th>betaA (mV)</th>
<th>betaC (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>OPC-1</td>
<td>-758.64</td>
<td>104.04</td>
<td>0.742</td>
<td>59.5</td>
<td>3278.1</td>
</tr>
<tr>
<td>2</td>
<td>PPC-1</td>
<td>-647.53</td>
<td>104.64</td>
<td>0.725</td>
<td>84.4</td>
<td>314.9</td>
</tr>
<tr>
<td>3</td>
<td>KRIA-1</td>
<td>-700.42</td>
<td>55.48</td>
<td>0.384</td>
<td>380.7</td>
<td>99.3</td>
</tr>
<tr>
<td>4</td>
<td>PSC-1</td>
<td>-756.17</td>
<td>90.15</td>
<td>0.625</td>
<td>1618.6</td>
<td>65.9</td>
</tr>
</tbody>
</table>
Fig.1 to Fig.4 indicate linear polarization curves. In LPR measurement it can be clearly observed that Rp values of the sample are varying. It can be noted that Rp value of concrete sample with KRIA cement was 1142 ohms-cms with Icorr value of 22.05 µA. Similarly it can be noted that the Rp value of concrete sample with OPC, PPC and PSC cements were 705 ohms-cms, 236 ohms-cms, 689 ohms-cms respectively with corresponding Icorr values 37.02 µA, 110.62 µA and 37.85 µA. The resistance is inversely proportional to corrosion rate. This can be verified by applying Ohm’s Law, mathematically represented by

\[ R = \frac{V}{I} \]

Where, \( R \) is resistance
\( V \) is Voltage
\( I \) is Current.

The results of LPR test indicate that resistance of KRIA cement to corrosion is around 10 to 15 times greater than other cements. In other words, it can be pointed that the samples with high current values (Icorr) the resistance to corrosion is less. The results indicate that resistance of OPC cement to corrosion is better than concrete sample with PSC. The results of concrete sample with PPC cement indicate high current value therefore the resistance to corrosion is low.

The fig.5 to fig.8 indicate the tafel plots, in tafel plot the values are extrapolated to zero by producing the co-ordinate sets relating to X-axis (Ecorr) and Y-axis (Icorr). The tafel constants are obtained ba (anodic constant) n bc (cathodic constant) from which the corrosion rate can be estimated by using the following formulation

\[ \text{Icorr} = \text{ecorr} \left( \frac{ba + bc}{Rp} \right) [11] \]

The results of tafel plot indicate that the corrosion rate for sample with KRIA cement has less corrosion rate of 0.384 mpy (mils per year) which is low compared to samples with OPC, PPC and PSC cement. In fig.7 it is clear from the graph that passive zone is more prominent compared to other cement samples. It is evident that the anodic and cathodic zones of KRIA cement are balancing the anodic zone as well as cathodic zone. In tafel plot results the sample containing PSC cement fairs better than sample with OPC and PPC cement.

4. CONCLUSION
The concrete is an heterogeneous material, if we compare it to metals. The metals have definite values and can be compared with the standards. In concrete, all the materials used have their own significance and interpretation. However, the LPR measurements indicate the corrosion rate or resistance to corrosion. In tafel plots various zones of corrosion can be identified as anodic zones, cathodic zones and passive zone [12]. It can be concluded that KRIA cement has better corrosion resistance properties than OPC, PPC and PSC. The blended cements have their own significance because of the materials by which they are blended.

REFERENCES


