EFFECT OF WATER-CEMENT RATIO ON CORROSION OF REINFORCED CONCRETE

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Abstract

Corrosion of reinforced concrete is one of the major problems in the construction industry causing premature deterioration of concrete structures well before their service life. This has placed incredible financial burden on many projects and also placed safety of users at risk. A research work was carried out to evaluate the effect of water cement ratio on corrosion of steel in reinforced concrete structures. Eighteen samples in three groups of six samples each with three different water cement ratios were prepared and tested. The size of each sample was kept as 40x40x160 mm and water cement ratios was 0.45, 0.60 and 0.75 for the three groups respectively. The test results indicated that by using an appropriate amount of mixing water, penetration of main corrosion causing agents like chloride ions and atmospheric carbon dioxide could be significantly reduced. It is also observed that a water-cement ratio of less than 0.6 shall give better corrosion resistance with increased compressive strength.

Key words: deterioration, corrosion, steel, chloride ions, water cement ratio.

1. Introduction

Corrosion of reinforcement is an electrochemical process. Chloride ingress & carbonation are the two major causes. Chloride may penetrate by salt spray, seawater or present inside concrete and carbonation occurs due to the penetration of atmospheric carbon dioxide [1]. The adverse effects are cracking & spalling of concrete, reduction in cross sectional area and even breaking of reinforcement as shown in figure-1[5]. Several electrochemical and non-electrochemical methods are available for corrosion detection & monitoring in the existing concrete structures which must be used to determine the type and extent (severity level) of corrosion [3].

There are various techniques available that can be used to control reinforcement corrosion in the concrete structures e.g. in existing structures it may be controlled by providing a barrier on the surface of existing concrete, cathodic protection or electrochemical chloride extraction and in new structures
by increasing concrete cover on reinforcement, controlling water cement ratio, adding corrosion inhibiting admixtures, using coated mild steel bars, bars made of corrosion resistant materials or use of highly impermeable concrete [2,6].

![Diagram of concrete corrosion process](image)

**Figure-1:** Cracking and spalling of concrete cover due to corrosion of reinforcement.

Method of controlling water-cement ratio (w/c ratio) is more simple, economical and important as by using an appropriate amount of mixing water, less porous concretes could be obtained easily and effectively which reduce the tendency of penetration of chloride ions and atmospheric carbon dioxide. For a developing country like Pakistan where shortage of funds is a major problem, simple and cost effective methods are needed to cope with this problem. Keeping in view these things an experimental work was carried out under controlled conditions given here as under.

2. **Experimental work**

Three types of samples of size 40 x 40 x 160 mm each with #8 bar embedded and different w/c ratios were casted in C:S :: 1:3 and 5% of CaCl₂ [4]:

<table>
<thead>
<tr>
<th>Sr.#</th>
<th>Sample-ID</th>
<th>Samples casted</th>
<th>W/C-ratio</th>
<th>C:S ratio</th>
<th>Cement (gm)</th>
<th>Sand (gm)</th>
<th>Water (ml)</th>
<th>CaCl₂ (gm)</th>
<th>Sample tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>6</td>
<td>0.45</td>
<td>1:3</td>
<td>333</td>
<td>1000</td>
<td>150</td>
<td>17</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>6</td>
<td>0.60</td>
<td>1:3</td>
<td>333</td>
<td>1000</td>
<td>200</td>
<td>17</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>6</td>
<td>0.75</td>
<td>1:3</td>
<td>333</td>
<td>1000</td>
<td>250</td>
<td>17</td>
<td>4</td>
</tr>
</tbody>
</table>

**Table-1:** Table of testing samples

![Diagram of 1:3 cement sand samples](image)
Cement (Fauji cement) and oven dried sand (Lawrencepur sand) were mixed evenly on an impermeable platform and divided in three equal portions. Three types of samples of size 40 x 40 x 160 mm were prepared with w/c ratio of 0.45, 0.60 and 0.75 and #8 bar embedded in each type as shown in the figure-2. Six samples of each type were prepared and four tested as detailed in the table-1.

After hardening in twenty-four hours, samples were cured for first three days in the moulds and after demoulding cured at alternative days for a period of forty-one days. The temperature during curing was ambient temperature ranging from 19°C to 25°C. The experiment time was forty-five days.

Electrical resistance of embedded bars was taken after every five days and mean value is calculated for each type of sample as shown in the table-2. A consolidated graph of each type of sample b/w electrical resistance and time was plotted as shown in the figure-3. Compressive strengths of mortar samples casted in C:S :: 1:3 with w/c ratio 0.45, 0.60 and 0.75 were taken at three and seven days at ambient temperature ranging from 19°C to 25°C as given in the table-3 and graph was plotted to compare the strengths of each type of sample as shown in the figure-4.

Visual inspection of corrosion testing samples was also carried out to observe the surface cracks and corrosion stains. After the completion of the whole testing program, samples were broken for the observation of the state of embedded steel i.e. to check its corrosion condition and reduction in cross sectional area.

3. Results and discussions

Following are the tables of electrical resistances and compressive strengths taken for each type of sample:

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>DAYS</th>
<th>ELECTRICAL RESISTANCE-(MICRO OHM)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>SAMPLE-A (W/C=0.45)</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>34</td>
</tr>
<tr>
<td>3</td>
<td>15</td>
<td>40</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>45</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>60</td>
</tr>
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<td>6</td>
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</tr>
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<td>7</td>
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<td>80</td>
</tr>
<tr>
<td>8</td>
<td>40</td>
<td>102</td>
</tr>
<tr>
<td>9</td>
<td>45</td>
<td>112</td>
</tr>
</tbody>
</table>

Table-2: Table of electrical resistance of each type of sample

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>DAYS</th>
<th>COMPRESSION STRENGTH (Psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>SAMPLE-A (W/C=0.45)</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>3100</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>4150</td>
</tr>
</tbody>
</table>

Table-3: Table of compressive strength of each type of sample
Following are the electrical resistance and compressive strength graphs.

Figure 3: Resistance graph of sample-A ($w/c = 0.45$), B ($w/c = 0.60$) & C ($w/c = 0.75$)
Figure-4: Compressive strength graph of all samples
Analysis of the behavior of samples shows that

- Corrosion rate slowed down when water-cement ratio kept over and below the ratio of 0.6.
- Compressive strength increased by the decrease of water-cement ratio.
- Cross-sectional area of the reinforcement reduced due to the formation of corrosion products.
- Increased volume of reinforcement due to the formation of corrosion products resulted in the cracking of cover.

4. Conclusions

Controlling water cement ratio for corrosion resistance is the easiest and cost effective method. Therefore it should be given prime consideration both at the design and construction stage. A water-cement ratio of less than 0.6 shall give better corrosion resistance as well as good compressive strength; therefore it should be kept to the lowest possible value depending upon the type of construction. A water-cement ratio of more than 0.6 may also be helpful in reducing corrosion rates but with its increase, compressive strength decreases. The impact of increase in the water cement ratio (as is used in a number of construction projects in Pakistan) may be investigated further for its effect in reducing corrosion rates considering different environmental conditions.

5. References

Dr. M. Tullmin “Rebar Corrosion”, 589 Millwood Dr., Kingston, Ontario, Canada, K7M 8Y3.