CORROSION RESISTANCE OF CONCRETE
SPECIMENS SUBJECTED TO
SULPHATE SOLUTION

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Abstract:
The problem of corrosion has reached major proportions in many
parts of the world. This problem has also been encountered in Egypt,
especially in the coastal areas.

The present work was undertaken to compare between corrosion
resistance of three types of locally produced cements (ordinary
Portland, blast furnace, and Sulphate resisting cement). Four
concrete mixes from each cement were chosen to cover most of the
practical mixes which are currently used in many structures in Egypt.

Compressive strength and splitting tensile strength were
evaluated after 28, 60, 90 and 120 days for specimens attacked by
sulphate as well as for similar control specimens cured by fresh water
to be as comparison levels. The variation of strengths gives an idea
about the influence of sulphate on concrete specimens.

As a result of this research, some useful conclusions and
practical recommendations have been reached for concrete protection
against corrosion.

1. INTRODUCTION:

It is well known that most damages of reinforced concrete
structures are due to the gradual growth of corrosion of concrete
elements by sulphate attack.

Calcium, sodium, and magnesium sulphates usually exist in
soils with concentrations up to 5% (50 gm/l.). Unprotected concrete
foundation elements such as deep piles, isolated footings and raft
foundations placed in the ground at depths varying mostly from 1 to
6 m are highly susceptible to deterioration and corrosion by
sulphate attack.
Indeed, in the last few years, better understanding and reliable knowledge concerning corrosion criteria of concrete was strongly needed for both economical and safety considerations. So, the corrosion of concrete structures has been engaging the activities of workers all over the world. (1)(2)(3)(5)

The aim of this paper is to compare corrosion resistance of three types of locally produced cements (Ordinary Portland cement (OPC), Blast Furnace slag cement (BFC), and Sulphate resisting cement (SRC)), and also to provide more knowledge for both designers and site engineers about the extent to which these cements may stand against sulphate corrosion.

2. EXPERIMENTAL PROGRAM:

Three types of cement were used (OPC), (BFC), and (SRC). Four concrete mixes were prepared from each type of cement using two cement contents (250 and 450 kg/m³) and two slump values were chosen for each cement content (80 mm and 10 mm). Table (1) summarizes detailed values for the weights, volumes, and mix proportions of concrete constituents used in this investigation.

2-1. Preparation of attacking solution:

Magnesium sulphate (MgSO₄·7H₂O) with purity 99% was chosen to represent the corrosive media which attack the concrete specimens. In order to obtain rapid and correct information about the rate of corrosion, rapid methods of corrosion testing should be performed. The rate of corrosion was accelerated by increasing the concentration of attacking sulphate solution. This concentration was chosen to be 80 g/m³ (80 000 ppm).

2-2. Preparation of specimens:

Concrete mixes were designed, treated, and controlled under similar conditions. The constituents were mixed in dry state for one minute to ensure the uniformity of the mix. Mixing water was added gradually and the contents were mechanically mixed for a period of ten minutes. The slump and compacting factor tests were carried out on all concrete batches.

Vibrating table and hand tamping were used during placing of concrete to ensure full compaction. Specimens were removed from the moulds after 24 hours from casting then cured in water until tested.

All concrete specimens which were planned to be attacked by Mg SO₄ were taken from curing water after 28 days, then marked, and weighed. For each mix, three specimen groups were prepared according to the following programme:

1. For first group, routine tests were carried out to obtain the original strength value after 28 days.
2. For second group, control specimens were cured under water for various age periods (60, 90, and 120 days).
3. The third group, specimens were stored under Mg SO₄ solution (50 g/1) for corresponding age periods (60, 90, and 120 days) similar to control group specimens which were cured by fresh water.

2-3. Testing of hardened concrete:

Compression test as well as splitting tensile test were carried out on cube specimens 10X10X10 cm. The splitting tensile strength was computed using the following formula:

\[ F_s = \frac{2P}{\pi L^2} \]

where:
- \( F_s \) = Splitting tensile strength (kg/cm²)
- \( P \) = Max. compressive load (kg)
- \( L \) = Side length of cube (cm)
3. RESULTS AND DISCUSSION:

The obtained results about the influence of corrosion on the mechanical properties of plain concrete specimens will be analyzed and discussed. Mechanical properties included in this study are compressive strength and splitting tensile strength. Strengths were obtained at various ages for both control specimens stored under water and identical specimens attacked by sulphate solution.

The main results of this experimental work and the overall average reductions in strengths which resulted from the chemical attack of magnesium sulphate on concrete specimens may be summarized in Figs. (1 to 3) and Tables 2 & 3. From the figures and tables the following observations may be obtained:

1) Specimens attacked by sulphate showed lower strength than similar ones cured by fresh water. The percentage reduction in strength due to sulphate attack varied between 1.3% and 36% with average value 21%.

2) The average percentage reductions in compressive strength are 22%, 11% and 14% for OPC, [BFC] and [SAC] respectively. The corresponding reductions in splitting strength are 27%, 19.5% and 26% respectively. These reductions in strength may be due to the chemical reaction between magnesium sulphate and cement which leads to significant expansion and disintegration of concrete elements.

3) The rate of disintegration is influenced by the C3A (Tri-calcium aluminate) content of the cement. Cements containing less than 6 percent C3A exhibit strong resistance. However when C3A content exceeds 12 percent the concrete is liable to suffer from attack by sulphates no matter what is the density of the concrete.

4) The rate of attack by sulphate solution is affected by:
   a) the condition of concrete and the possibility of such water to penetrate through it, and
   b) the chemical composition of the concrete. However dense rich concrete with low permeability will be much more resistant to infiltration by the sulphate water than lean concrete.

5) The good resistance of blast furnace slag cement may be due to the fact that 35% of its constituents are chemically nonreactive materials i.e. the adverse reactive materials are 65% only.

4. Mechanism of sulphate attack:

The mechanism of sulphate attack can be explained as:

1- Sulphates react chemically with calcium and aluminum ions in cement paste to form calcium sulphate (gypsum) and calcium sulpha aluminate hydrate (ettringite) according to the following equations:

\[ \text{Ca(OH)}_2 + \text{MgSO}_4 \cdot 10\text{H}_2\text{O} \rightarrow \text{CaSO}_4 \cdot \text{2H}_2\text{O} + \text{Mg(OH)}_2 + 8\text{H}_2\text{O} \]

Calcium hydroxide + Magnesium sulphate \rightarrow gypsum + Magnesium hydroxide.

\[ \text{CaO} + \text{Al}_2\text{O}_3 \cdot 19\text{H}_2\text{O} + 3(\text{CaSO}_4 \cdot 2\text{H}_2\text{O}) + 7\text{H}_2\text{O} \rightarrow 3\text{CaO \cdot Al}_2\text{O}_3 \cdot 3\text{Ca SO}_4 \cdot 31\text{H}_2\text{O} \]

3\text{H}_2\text{O} + \text{Ca(OH)}_2 \rightarrow \text{Calcium hydroxide hydrate} + \text{gypsum} \rightarrow \text{ettringite + calcium hydroxide.}

2- The formed products have considerably greater volume than the compound they replace. This leads to significant expansion and disintegration of concrete element, e.g. the increase in volume due to gypsum is equivalent to 17.7% of the original volume. While the "ettringite" is accompanied by an increase in volume equivalent to 227% of the original volume, so the
Formation of gypsum and ettringite is the main reason for the detrimental sulphate action.

9. CONCLUSIONS
The main conclusions of this experimental work may be summarized as follows:
1) The choice of attacking material (magnesium sulphate) with (SO₃) concentration 50 g/l was very reliable in quick determination of the corrosion rate within few days of sulphate attack.
2) Locally produced ordinary Portland cement (OPC) response to corrosion attack of concrete specimens with the same role and efficiency for both two strengths (compressive and splitting tensile). It indicated the maximum percentage reductions in strengths.
3) Blast furnace slag cement (BFC) showed high corrosion resistance especially in compressive strength.
4) Sulphate resisting Portland cement (SRC) showed medium role in resisting corrosion attack.
5) The best concrete mix for resisting corrosion was given by the rich concrete mix (cement content 450 kg/m³, W/C = 0.37) prepared from (BFC). This mix was able to resist sulphate for 92 days and lose 1% only of its original compressive strength during the overall age period of attacking process. This appreciates the use of (BFC) over all other types.
6) One more important conclusion is that the effect of the attacking material does not begin before 28 days of curing for all three tested cement types. This can be noticed from all the curves presented in this work (Fig. 1) to Fig. 6.)

REFERENCES
Table 1: Some properties of concrete

<table>
<thead>
<tr>
<th>Aggregate (kg)</th>
<th>Coarse (kg)</th>
<th>Water (L)</th>
<th>Mix</th>
<th>No. of specimens</th>
<th>Variability</th>
</tr>
</thead>
<tbody>
<tr>
<td>644</td>
<td>189.3</td>
<td>128.8</td>
<td>750</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>645</td>
<td>189.3</td>
<td>128.8</td>
<td>750</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>544</td>
<td>187.2</td>
<td>156.9</td>
<td>150</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>565</td>
<td>191.3</td>
<td>135.8</td>
<td>150</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

- L = Loose Volume

Table 2: Average values of experimental results of compressive and splitting tensile strengths for concrete specimens prepared from various types of cement (OPC, PPC, PPC)

<table>
<thead>
<tr>
<th>Cement Type</th>
<th>Compressive Strength (N/mm²)</th>
<th>Splitting Strength (N/mm²)</th>
</tr>
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<tbody>
<tr>
<td>OPC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28 days</td>
<td>52</td>
<td>2.5</td>
</tr>
<tr>
<td>56 days</td>
<td>75</td>
<td>3.2</td>
</tr>
<tr>
<td>112 days</td>
<td>90</td>
<td>3.8</td>
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</table>

Note: 'f' represents the strength.
Table 3: Comparison between strength reductions for concrete specimens.

<table>
<thead>
<tr>
<th>Mix proportion</th>
<th>Strength Reduction</th>
<th></th>
<th></th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>Compression</td>
<td>BFC</td>
<td>SRC</td>
<td>Compression</td>
<td>BFC</td>
</tr>
<tr>
<td>HK (250, 0.65)</td>
<td>36</td>
<td>12</td>
<td>0</td>
<td>30</td>
<td>6</td>
</tr>
<tr>
<td>H7 (200, 0.55)</td>
<td>46</td>
<td>14</td>
<td>11</td>
<td>27</td>
<td>20</td>
</tr>
<tr>
<td>H3 (150, 0.47)</td>
<td>35</td>
<td>10</td>
<td>17</td>
<td>24</td>
<td>23</td>
</tr>
<tr>
<td>HK (400, 0.55)</td>
<td>26</td>
<td>9</td>
<td>21</td>
<td>25</td>
<td>27</td>
</tr>
<tr>
<td>Average</td>
<td>20</td>
<td>14</td>
<td>16</td>
<td>27</td>
<td>17.5</td>
</tr>
</tbody>
</table>

Fig. 1: Effect of admixture content (0%–90%) on compressive strength of concrete cube specimens prepared from ordinary Portland cement (OPC).
Fig. 2: Influence of aggregate roughness (59, 79 g/cm²) on compressive strength of concrete with air entrainment (low bleed). (Same as Fig. 1 for 100 kg/m³ cement.)

Fig. 3: Influence of aggregate roughness (59, 79 g/cm²) on compressive strength of concrete made with 100 kg/m³ cement.
Fig. 4: Influence of aggregate sulfates (AS) on split tensile strength of concrete cube specimens prepared from ordinary Portland cement (OPC).

Fig. 5: Influence of aggregate sulfates (AS) on split tensile strength of concrete cube specimens prepared from high-fines cement (HFC).
Fig. 6.3 Influence of expansive sulfate (SO₃, 60 g/m³) on 28-day cube strength of concrete cube specimens prepared from sulfoaluminate cement (SAC).

Fig. 6.4 Relationships between change of compressive strength of concrete specimens exposed to sulfoaluminate effect (SO₃, 60 g/m³) and type of cement at various ages.