Corrosion in concrete

The most important protective coating for reinforced concrete is the concrete itself

Getting it right first time is a good starting point!

Corrosion Engineering Division ICORR
IMechE Engineering Training Centre
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Glenfinnan Viaduct

• Built in 1897
• 21 spans
• Largest span 15m
• Height 30m
• Constructed by Robert McAlpine using unreinforced concrete
What can corrode in concrete?

- Iron pyrites
- Steel reinforcement
Why is the prevention of corrosion so important?
There are two fundamental problems with reinforced concrete.

1. Concrete that is restrained has a tendency to crack.

2. Iron and steel want to oxidise to form iron oxide or “rust”.
What causes corrosion?

Low cover, porous concrete or surface defects allow corrosive agents to enter the concrete, break down the protective passive layer and create a galvanic cell causing corrosion and spalling of the concrete as the products of corrosion expand.
Why put steel in concrete?

To improve the tensile or flexural strength of concrete for bigger, longer, higher, thinner, lighter and more cost effective construction.

Concrete while good in compression does not perform so well in tension or flexure. A concrete typically only achieves around 8 to 12% of compressive strength when subjected to these types of stresses.

Additionally without being reinforced, the concrete possess little strength after failure.

Vasco da Gama Bridge
The design dilemma

1. We need to prevent corrosion
2. We need more durability from the concrete
3. Designs needs to be commercially and technically viable

1. The concrete is difficult to batch
2. The concrete is difficult to use
3. Elements of structures are difficult to build

1. Service life is not as required
2. Ongoing maintenance and cost issues
Overall the same aims but different individually!

Designer
- Durability
- Strength
- Service life
- Finish
- EN 1992

Producer
- Material costs
- Supply chain
- Conformity
- Transport
- Plant maintenance and running costs
- EN 206

User
- Cost
- Delivered on time
- Correct consistence
- Ease of use
- Workability retention
- Strength for early striking
- EN 13670
Successful concrete

Value Engineering

Specified

Specification

Producer
(Ready-mixed supplier)

Suppliers

Production

Conformity

User

Placing

Compaction

Finishing

Curing

Exchange of information

Producer

Suppliers

Production

Conformity

Value Engineering

Specifier

Successful concrete

Exchange of information

Specifier

Successful concrete
BS 8500 Tables A4 and A5 provide a matrix for essential mix design requirements for achieving durability in differing exposure conditions based on intended working life, depth of cover and cement type. Similar tables are included in BS 6349 for maritime structures.
Concrete either buried or in contact with the ground will have additional requirements for resistance to sulfate attack and may need additional protective measures.

- Enhance concrete quality (APM1)
  
  Increase the design chemical class by one class
- Use controlled permeability formwork (APM2)
- Provide surface protection (APM 3)
- Provide a sacrificial layer (APM4)
  
  Increase the depth of cover to provide a sacrificial layer
- Address drainage of site (APM5)
The biggest problem with the use of reinforced concrete is the failure to position the reinforcement with the correct cover of concrete, and the durability suffers as a result. The Building Research Establishment estimated that this type of failure costs £550 million each year in the UK alone, (more than £1.5 million a day).

As an example, for external concrete sheltered from the rain 30mm of cover will give 135 years of protection to the reinforcement, but 10mm of cover will give only 10 years of life.
All curing compounds are the same, right?

Even when the correct curing agent has been applied, research suggests that it is often not applied at the correct rate of application!

75% Curing efficiency

90% Curing efficiency
Think of concrete as a coating to the reinforcement:

It has to be of the correct composition for durability in the environment to which it will be exposed, like to choosing the correct type of coating;

Correct cover is like achieving a specified film-thickness;

And it has to be cured properly like protective coatings.

Failure to provide any of these will effect performance, reduce service life and give significant maintenance issues to the end user!
When it goes wrong

Measuring the depth of carbonation

Testing resistivity to determine the potential for corrosion

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Corrosion rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.5 µA/cm²</td>
<td>Negligible</td>
</tr>
<tr>
<td>0.5 - 5 µA/cm²</td>
<td>Slow</td>
</tr>
<tr>
<td>5 - 15 µA/cm²</td>
<td>Moderate</td>
</tr>
<tr>
<td>&gt; 15 µA/cm²</td>
<td>High</td>
</tr>
</tbody>
</table>
Repairing corrosion damaged concrete

Cathodic protection

Standard patch repairs may be possible but great care is needed to ensure that all corrosive agents are removed otherwise galvanic cells may be created at either end of the repair!
Enhancements for aggressive environments

- Stainless steel
- Epoxy coated steel
- Waterproofing coatings and pore blocking additives
- Integral and migratory corrosion inhibitors
Going forward - 1

Before

After

Self-healing concrete

Cathodic protection
Basalt fibre reinforcement

Synthetic macro and micro fibres
With the complexities of construction, and the future costs of repairs, is the reliance solely on concrete to provide long term durability and the specified design life the best solution?
Thank you