Corrosion of Concrete
Design, Prevention and Repair
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※Some figures and pictures are taken from ‘Practical Guideline for investigation, Repair and Strengthening of cracked concrete Structures -2009- published by JCI.’
Importance of crack control for prevention of corrosion

✓ The surface of rebar is protected by high alkaline solution.

✓ Carbonation often progress along the wide crack.

✓ Steel corrosion starts under a pH 11.0

Therefore it’s necessary to control the cracks of concrete for prevention of corrosion.
Drying shrinkage is one of the general factor of concrete cracks.

Concrete can’t contract freely, cause the minute cracks.
2. Design of concrete for crack control
   ◆ ‘Expansive concrete’
**Length change of concrete**

![Diagram showing length change of concrete](image)

**Surface tension** → shrinkage

**Expansion**

**Shrinkage**

**Time (week)**

**Expansion control the cracks of concrete**

- **Expansive Concrete**
- **Normal**

- **Hydrates**
- **Water**
- **Surface tension**

Reduction of water by drying

0 5 10 15

Crack

Expansion control the cracks of concrete

Denka

Think Globally...Act Locally...™
How does expansion contribute to concrete?

**Mechanism of shrinkage compensation**

**Strain**

- Expansion: Positive
- Shrinkage: Negative

**Stress**

- Tensile strength: Positive
- Compressive stress: Negative

Normal concrete vs. CSA concrete

- Cracking in normal concrete
- Expansion in CSA concrete
Expansive additive for concrete

Control

Expansive Concrete

Control the crack
Production of Expansive Concrete

- Normal concrete + Expansive additive = Expansive concrete

- Mixed at the ready mixed concrete plant.

- Precast Concrete

- Construction site
Example of expansive concrete

Slab concrete in a plant

Formulation (24MPa)

【Power-CSA】

Cast-in-place Power CSA concrete

<table>
<thead>
<tr>
<th>No</th>
<th>Slump (cm)</th>
<th>Air (%)</th>
<th>Unit weight (kg/m³)</th>
<th>Admixture (kg/m³)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cement</td>
<td>Water</td>
</tr>
<tr>
<td>A-1</td>
<td>16.0</td>
<td>5.0</td>
<td>302</td>
<td>175</td>
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<tr>
<td>A-2</td>
<td>16.5</td>
<td>5.0</td>
<td>282</td>
<td>175</td>
</tr>
</tbody>
</table>

➢ CSA is replaced to Portland cement.
Example of the Expansive Concrete

Slab concrete in a plant

➢ Strain gage was attached to the steel bar.
➢ Compared to the concrete without CSA.
Example of the Expansive Concrete

The effect of CSA has continued over 5 years.

Expansion

Strain of concrete

Difference of strain between CSA and Plain

CSA concrete

Normal concrete

The effect of CSA has continued over 5 years.

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Application of Denka CSA Viaduct

Past 20 years

CSA was used for concrete rail reducing crack.
3. Prevention and repair
◆ ‘Desalination’ and ‘Re-alkalization’
Desalination, Re-alkalization

Electrolyte solution $\text{Ca(OH)}_2, \text{Li}_3\text{BO}_3$

Direct current $1\text{A/m}^2$ as standard (8 weeks)

- A temporary anode with $\text{Ca(OH)}_2$ is attached on the concrete.
- The direct current move the chloride ions to the concrete surface.
- This method contribute to the diffusion of alkaline solution.
Desalination, Re-alikalization method

Installation of temporary anode

High way pillars in the sea
Osaka castle
3. Prevention and repair
   ◆ ‘Chloride ion fix agent’
Chloride ion Fix agent

Rebar corrosion by chloride attack

Standard mortar

With Chlorfix

Mechanism

Chlorfix + Cement

5~10%

Generate the hydro-calmite

3CaO·Al₂O₃·Ca(OH)₂·12H₂O

Fix the Cl⁻ in between the layer

Prevent Corrosion

World first additive technology to achieve the long service life of reinforced concrete.

<Operation>

① Replace Chlorfix to Cement.

② Generate the hydro-calmite

③ Fix the Cl⁻ in between the layer

World first additive technology to achieve the long service life of reinforced concrete.
What is salt damage of Concrete Structures?

If the corrosion of rebar proceed,

Rust fluid and crack

Surface float, and peel off

In this case we have to repair and replace.
Chloride ion attack

Pore structure of hardened paste

\[ \text{Ca(OH)}_2 + 2\text{Cl}^- \rightarrow \text{CaCl}_2 \]

High Solubility (59.5 g/100 g H\(_2\)O)

Leaching of Ca(OH)\(_2\) ⇒ Accelerate the Cl\(^-\) intrusion.

Free Chloride:
move in the pore solution freely ⇒ Reacts with rebar, cause the corrosion.

Bound Chloride:
present in the cement hydrates⇒ it is not related to the corrosion.
Chloride binding mechanism of calcium aluminates

Chloride ion is bounded as Friedel’s salt.
XRD pattern of paste at 28 days

Normal cements
OPC100%

OPC 90% + CF: 10%

Paste with CF generated hydro-calmite (HC)
Resistant to external salt

1. Permeability of chloride ions
2. Corrosion of steel bar
Chloride penetration depth was controlled by the additive.
Accelerated corrosion test

40°C dry atmosphere

14cm

10% NaCl solution

Rebar state after accelerated corrosion 1 year by external salt

Corrosion ratio: 18.6%

OPC

6.5%

Nitrite type hydrocalumite 10%

0%

CF 7%
Production line up

Chlore fix shot
Chlore fix patch
Chlore fix grout
Concrete wall was repaired by patching mortar.

construction example in Japan
Conclusion

- Design of concrete for crack control `Expansive concrete`
  ⇒ Contribute the extension of service life.

- The repair method and material taking into account durability
  ⇒ Reduction of cost for maintenance.

Reducing the speed of deterioration will enhance the authenticity to extend the service life of concrete structure.
Thank you for your attention!