The Economics, Performance, and Sustainability of Internally Cured Concrete, Part 1

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Objectives

• To understand why low w/c, high cement content mixes are susceptible to cracking
• To understand how internal curing reduces autogenous shrinkage & increases capacity
• To understand how internal curing improves transport properties
• To quantify the combined effect of reducing cracking and reducing fluid transport with internal curing

Outline

• Shrinkage and Stress Development
• Benefits for Thermal Shrinkage
• Restrained Shrinkage Slab Testing
• Corrosion Testing in Restrainted Elements
• Chloride Ingress
• Comparison with Field Case
• Summary
Residual Stress Development

Initial Specimen
Shrinkage Effect
Restraint Effect
Creep/Cracking Effect
Stress Relaxation
Final Stress State

Effect of LWA Shrinkage

LWA Paste

Residual Stress Development

IC to Mitigate Cracking and Improve Corrosion Performance

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Temperature Plus Autogenous Shrinkage

Coil system used to regulate sample temperature from 60°C to -10°C
**Effect of Internal Curing on Thermal Stress Development**

Plain Mortar (w/c = 0.30)
Not Internally Cured

Internally Cured Mortar (w/c = 0.30)

\[ \Delta T \text{ crack } = 10.3°C \]
\[ \Delta T \text{ crack } = 27.1°C \]

**Simultaneous Shrinkage/Corrosion**

- IC is effective in reducing shrinkage, shrinkage cracking and transport properties
- This research uses a full-scale slab geometry and instrumented rebar to study in-situ corrosion behavior of steel reinforced concrete with internal curing.
- The results of this investigation are aimed at understanding the impact that IC concrete may have on improving the service life of steel reinforced concrete structures.

**Effect of Internal Curing On Reserve Capacity Curve**

Plain Mortar (w/c = 0.30)
Not Internally Cured

Internally Cured Mortar (w/c = 0.30)

**Restrained Shrinkage**

- Plain and IC in a 5 m restrained slab (14 days section cut and exposed to NaCl)
- Instrumented steel rebar was embedded in each specimen was monitored for corrosion

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**Restrained Shrinkage**

- 4.34m (14.25ft.) long, 0.330m (13in.) wide, and 114mm (4.5in.) thick
- Instrumented W12×210 beam – Widened at ends
- Steel beam restrains concrete from moving freely as the concrete shrinks.
- threaded rods were used to anchor the specimen at beam ends
- wedges - 1.5mm (1/16in.) wide tip and widened to 10mm (3/8 in.)
Instrumented Rebar

- #6 grade-60 rebar
- Central section: 380mm (15in.)
- Hollowed out
- Rebar threaded to a solid section
- Connections sealed using marine-epoxy
- Minimum steel as specified by ACI318
- 28 sensors, 25 mm

Reference Electrode

- A reference electrode - 6mm (1/4in.) dia., 90mm (3.5in.) long, stainless steel (A316)
- Positioned midway between the rebar and the side face of the slab
- Separate tests performed to assess the stability of the stainless steel reference bar.
- Stainless steel remained stable for short testing period as compared with a standard saturated calomel electrode

Corrosion/Transport Testing

- Corrosion sensing using the instrumented rebar section, corrosion mapping using half-cell potential, and chloride ingress testing
- Open circuit potential (OCP) was monitored upon exposure of specimens to NaCl wrt SS
- Different distances of corrosion sensors to the reference electrode, resulted in the OCP
- A OCP drop of 100 mV was used to signal the onset of corrosion activities for a sensor.

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Corrosion/Transport Testing

- Corrosion potential was greatly influenced by crack proximity of the crack around at the steel-mortar interface.
- Sensors #1, 3, 5, 15, 17, 21, 25, and 27 on the top surface of the rebar and started to corrode immediately
- ASTM C876 (-275 mV after 4 days) 90% of the plain sample
IC to Mitigate Cracking and Improve Corrosion Performance

Raoufi, K., and Weiss J.

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Conclusions

• Low w/c, high paste mixtures are susceptible to cracking – autogenous, drying, thermal shrinkage
• Internal curing reduces autogenous shrinkage, increases capacity, reduces transport
• Large scale samples were prepared to simultaneously investigate cracking and transport
• instrumented rebar to determine the age of corrosion and distribution along the interface
• plain mixture - cracked at several locations and corroded quickly over a large debonded area
• IC mixture – did not crack

Chloride Ingress

• chloride ingress in mortar cylinders at 14 days
• 3% NaCl solution at the age of five weeks.
• 0.1-N silver nitrate solution (AgNO₃)
• IC shows less penetration due to dense cement paste microstructure and less porous/connected ITZ

Visual Inspection of the Bridge Decks after 20 Months

Plain bridge – 3 cracks

IC bridge – no cracks