Capillary Pressure Controlled Concrete Curing in Pavement Construction

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Capillary shrinkage cracking

Cracks were formed within the first three hours after casting.

Concrete slab on grade (Leipzig, 2006)
Capillary shrinkage cracking

Shrinkage cracks in mud

Airport Berlin-Schönefeld

approx. 40 cm

approx. 40 cm
Capillary shrinkage cracking

Cracked concrete floor (parking structure)
Capillary shrinkage cracking

“Repair“ of early age damage during surface finishing?

Preparing an exposed aggregate surface (concrete road)

Power floating (bridge deck)
Capillary pressure build-up

\[ p = -\frac{2\gamma}{r} \cdot \cos \beta \]
Example of capillary pressure development in cement paste and shrinkage strain versus time
Capillary shrinkage cracking

Fly ash / water suspension observed with an ESEM 100 µm
Capillary shrinkage cracking (Simulation)

Drying suspension

- Water is evaporating.
- Menisci are formed between the particles at the surface.
- Capillary pressure is built up.
- Particles are moving under the action of different forces.
- Strain localization takes place.
- "Cracks" are formed.
particle sizes ranging from 4 µm to 32 µm
Capillary pressure measurement

Conic tip (transparent plastic), filled with degassed water, diameter of the opening at the end approx. 1.0 mm

Concrete

Depth approx. 4…5 cm

Curing agent or plastic foil

Pressure transducer

Connecting tube

Sensor case

Contactless charging device

Radio module (2.4 GHz)

Antenna

Status LED

Magnetic switch

Rechargeable battery

Cable to recording device

Contactless charging device

Magnetic switch

Rechargeable battery
Capillary pressure measurement
Capillary pressure measurement

1. Wireless capillary pressure sensors 1...n
2. Radio transmission of measured values
3. USB

Base station

Computer for data recording, visualisation, and controlling

Capillary pressure controlled curing

Image of equipment with steam.
Influence of curing measures

Capillary pressure versus time measured in a cured and in an uncured concrete specimen
Controlled concrete curing

Fogging system
Capillary pressure dependent surface rewetting

Upper threshold of capillary pressure

Capillary pressure [kPa]

Time after casting [min]
Practical applications

Concrete road construction (highway)
Practical applications

Airfield construction
Practical applications

Exposed aggregate concrete (highway construction)
Practical applications

Capillary pressure development in concrete (highway construction)

Time after casting [h]

Capillary pressure [kPa]

Sensor application
No curing (reference)
Application of the curing agent
Cured concrete (curing agent)
End of measurement
Conclusions

• Plastic shrinkage of concrete is mainly caused by the build-up of a capillary pressure in the pore system of the material.
• Early age cracks resulting from plastic shrinkage may have an unfavorable effect on the durability of concrete structures.
• The capillary pressure can be easily measured under site conditions with special pressure transducers.
• On the basis of the measured capillary pressure, it is possible to make decisions concerning the timing of curing measures and to evaluate the effect of such measures. This allows to reduce the early age cracking risk.
• The measured capillary pressure may serve as a feedback signal for a closed-loop controlled concrete curing.
Outlook

Enhanced capillary pressure sensor

Air temperature, relative air humidity

Capillary pressure, concrete temperature

Solar radiation
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On-site capillary pressure measurement

Highway bridge, Zwickau, Germany
On-site capillary pressure measurement

- Estimated capillary pressure increase
- Influence of surface finishing
- Surface covered with plastic foil
- Capillary pressure break-through

(Bridge deck, Zwickau 2006)
Wireless capillary pressure sensors

www.capillary-pressure-sensors.com
www.Kapillardrucksensoren.de
Controlled concrete curing

Laboratory

- Identify the air entry point and the related capillary pressure (air entry value)
- Define a “critical capillary pressure”

Construction site

- Capillary pressure measurement
- Surface rewetting before reaching the critical capillary pressure
Capillary pressure measurement

Capillary pressure measurement (laboratory)

Capillary pressure measurement (construction site)
Experimental set-up for constrained shrinkage tests
Stress development

Stress development (Concrete, 440 kg/m³ CEM I 32.5 R, w/c=0.41, Temp. 25°C, RH 35%, Wind 5.0 m/s)

(Concrete, 440 kg/m³ CEM I 32.5 R, w/c=0.41, Temp. 25°C, RH 35%, Wind 5.0 m/s)
Stress development

Stress development over time after casting. The graph shows the development of capillary pressure and stress over time. The capillary pressure (cured) decreases rapidly and stabilizes at around 0 kPa after about 60 minutes. The stress (cured) also decreases but remains below the capillary pressure curve.

The stress (wind) shows a more gradual decrease, while the capillary pressure (wind) increases initially and then decreases more slowly.

The graph illustrates the interplay between capillary pressure and stress as the material cures over time.
Controlled concrete curing
Controlled concrete curing

![Graph showing capillary pressure and loss of water over time after casting.](graph.png)

- Capillary pressure [kPa]
- Loss of water [kg/m²]
- Time of day [h:min]
- Time after casting [min]

**Slab without curing**

**Cured slab**

Loss of water
Controlled concrete curing

→ Crack pattern after 24h

Cured concrete slab

Concrete slab without curing
Capillary pressure measurement

Concrete for road construction (top layer), 420 kg/m³ cement, very stiff

![Graph showing capillary pressure measurement over time after casting. The graph compares no curing, curing immediately after casting (slight bleeding film), and correct curing. The x-axis represents time after casting in minutes, ranging from 0 to 720, and the y-axis represents capillary pressure in kPa, ranging from -60 to 0.]
Evaporation

![Graph showing evaporation over time for different curing conditions.]

- **No curing**
- **Curing immediately after casting (slight bleeding film)**
- **Correct curing**

<table>
<thead>
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<th>Time after casting [min]</th>
<th>Evaporated water [kg/m²]</th>
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<tr>
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</tbody>
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Capillary shrinkage cracking

Environmental Scanning Electron Microscope (ESEM)
Capillary shrinkage cracking

Fly ash / water suspension observed with an ESEM 100 µm
Capillary shrinkage cracking

Fly ash / water suspension observed with an ESEM

Local air entry

Cross section (schematic)

A

B

C

D

100 µm
Capillary shrinkage cracking

Fly ash / water suspension observed with an ESEM  100 µm
Capillary shrinkage cracking
Publications


