An investigation of the influence of varying exposure temperature on chloride ingress in concrete

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Chloride ingress in concrete

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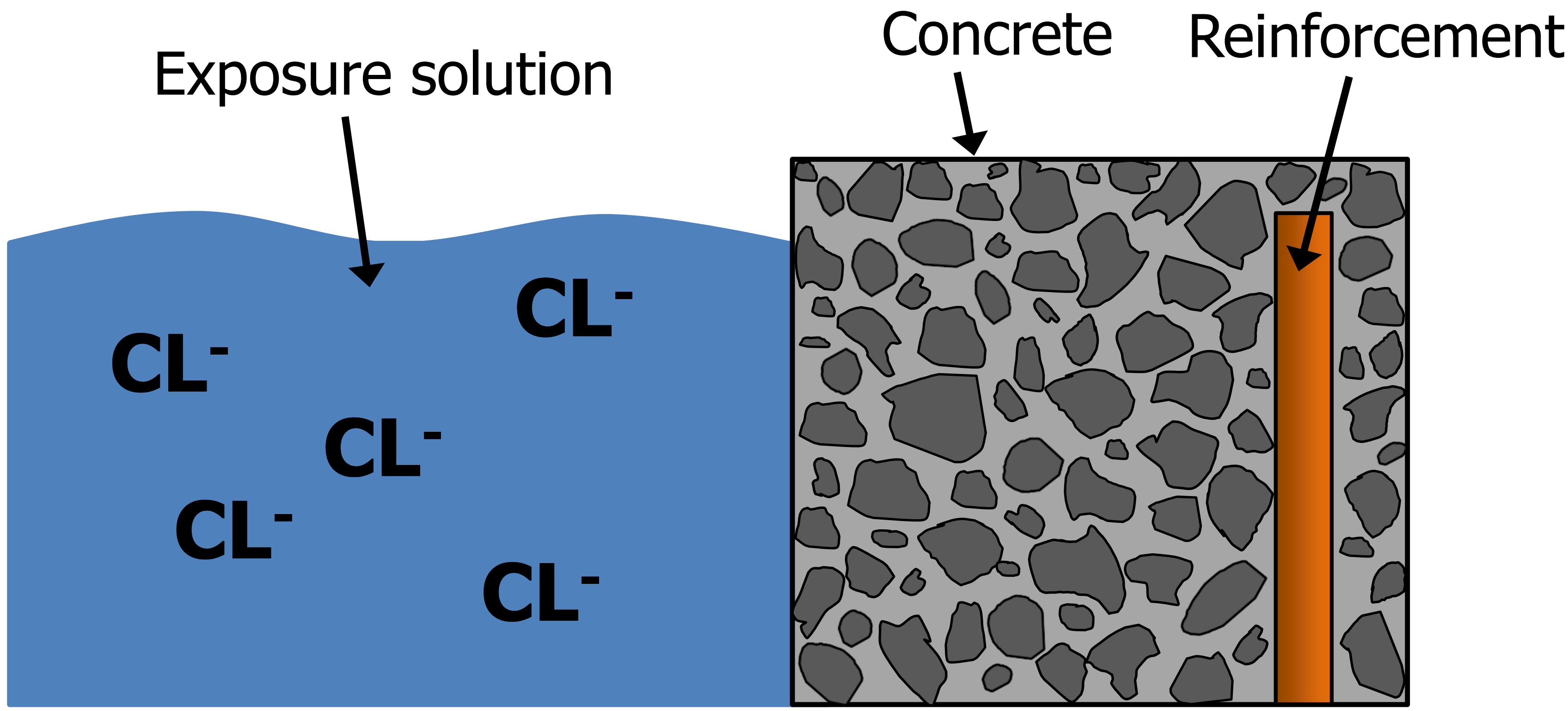

- Initiation of reinforcement corrosion due to chloride ingress.

Chloride ingress in concrete: Effect of temperature conditions

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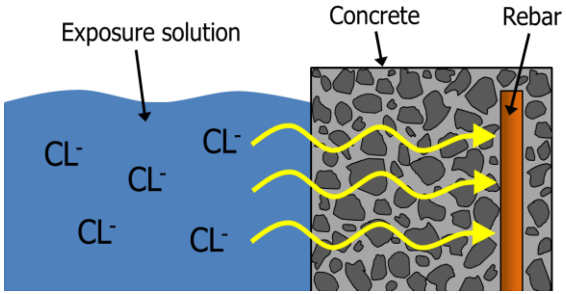
- The transport of chloride ions in concrete and cement-based materials is also affected by the exposure temperature.

- Chloride diffusion and chloride binding are temperature dependent phenomena.

- Effect of increased temperature:
  → Higher chloride diffusion coefficient
  → Reduced chloride binding
  → Acceleration of chloride ingress



Lab experiments

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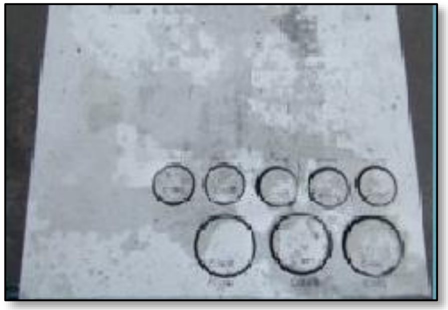
Overall concept of experiments

- Concrete specimens are immersed in chloride solutions and subjected to temperature cycles or constant temperature.



Purpose and relevance of the experiments

- Can we observe a difference in the rate of chloride ingress between the specimens exposed to (a) temperature cycles and (b) constant temperature?

- Real concrete structures are always subjected to some degree of daily and/or seasonal variations in temperature. Most lab experiments at constant temp.

- Temperature is an important input parameter for service life modelling. Constant values for the temperature may result in misleading predictions of the service life.

Sample material

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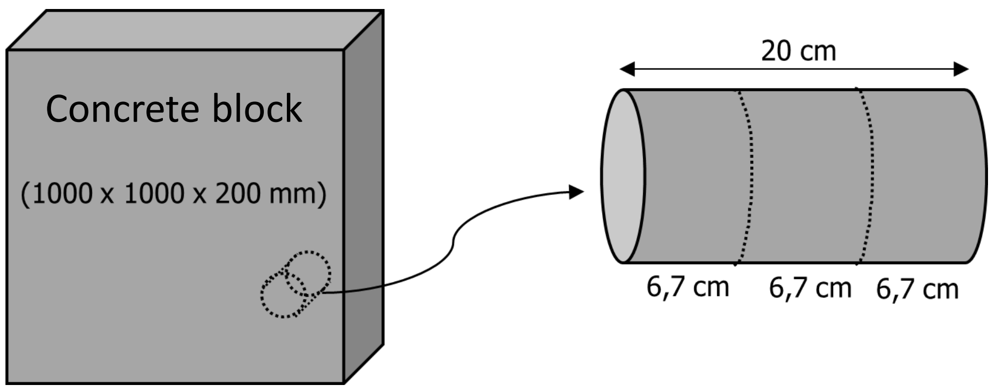
- Concrete specimens drilled as cores from blocks, which had been stored under atmospheric conditions in an outdoor environment for roughly 3.5 years.

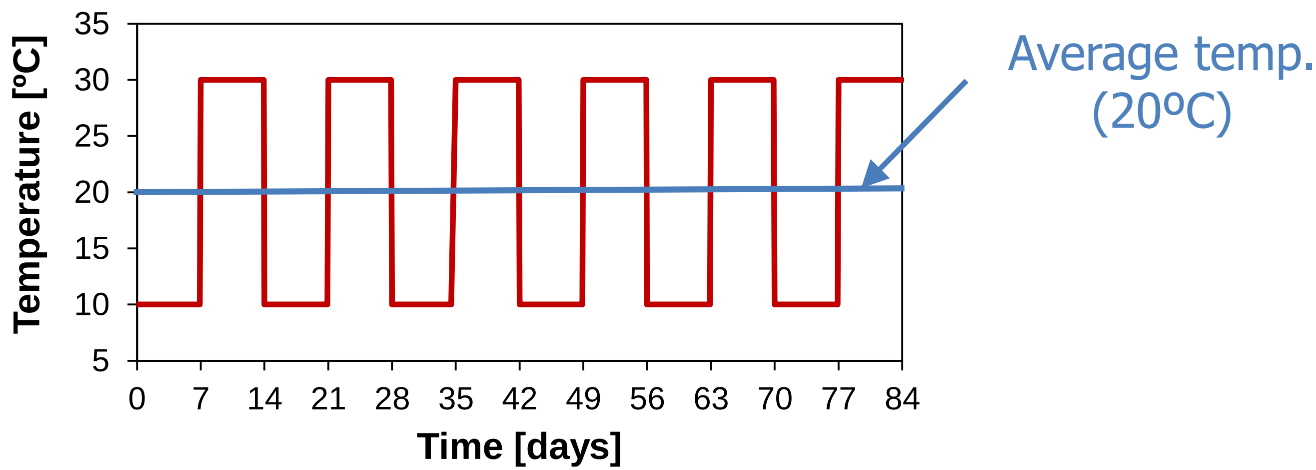


Exposure liquid:
165 g ±1 g NaCl pr. dm^3 solution

- Two concrete types studied:
  - Concrete A: 100% Portland cement (CEM I 42.5 N)
  - Concrete F: 84% Portland cement (CEM I 42.5 N) + 12% fly ash + 4% silica fume.

Experimental setup

- 3 samples of each concrete type subjected to temperature cycles consisting of 7 days at 10ºC followed by 7 days at 30ºC.



- Theoretical average exposure temperature of 20ºC.

- The total duration of the exposure period was 12 weeks (= 6 temperature cycles).

Exposure conditions

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Exposure to cyclic temperature conditions

10°C
Refrigerator

Concrete A

3 specimens + 1 dummy

Concrete F

3 specimens

30°C
Temp. controlled water tank

Concrete A

Concrete F

Exposure at reference temperature

20°C
Temp. controlled room

3 specimens

Measured temperatures

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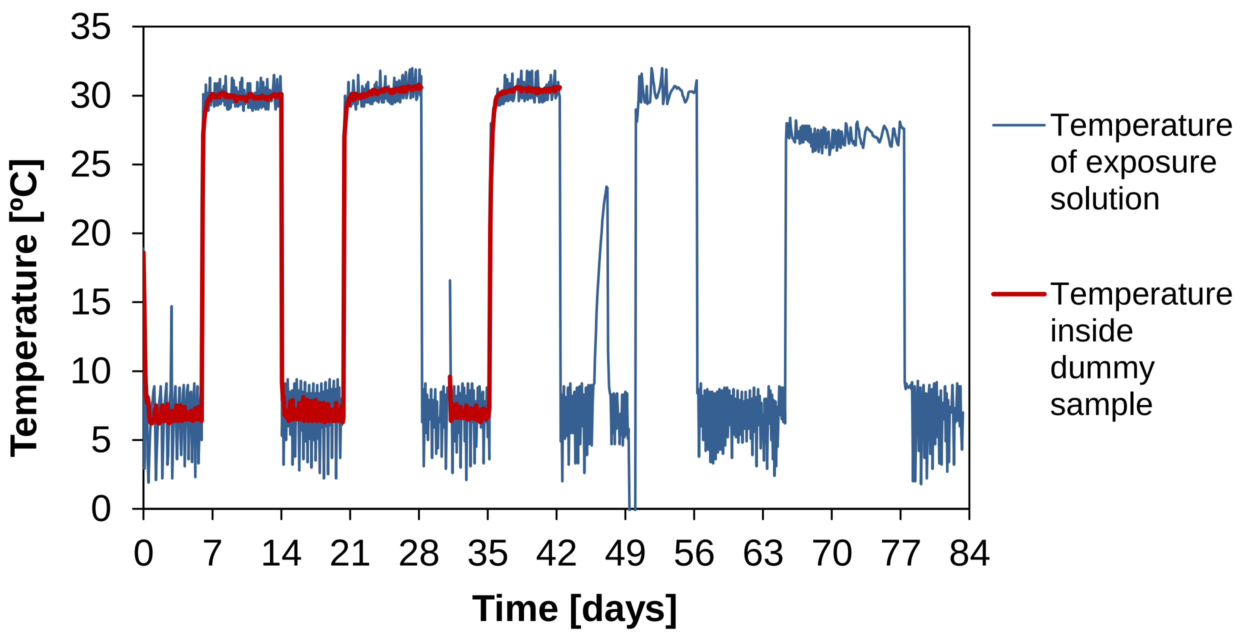

- Measuring of exposure temperature:
  - Thermocouple immersed directly into the exposure liquid.
  - Thermocouple placed inside a dummy sample.

Measured chloride profiles

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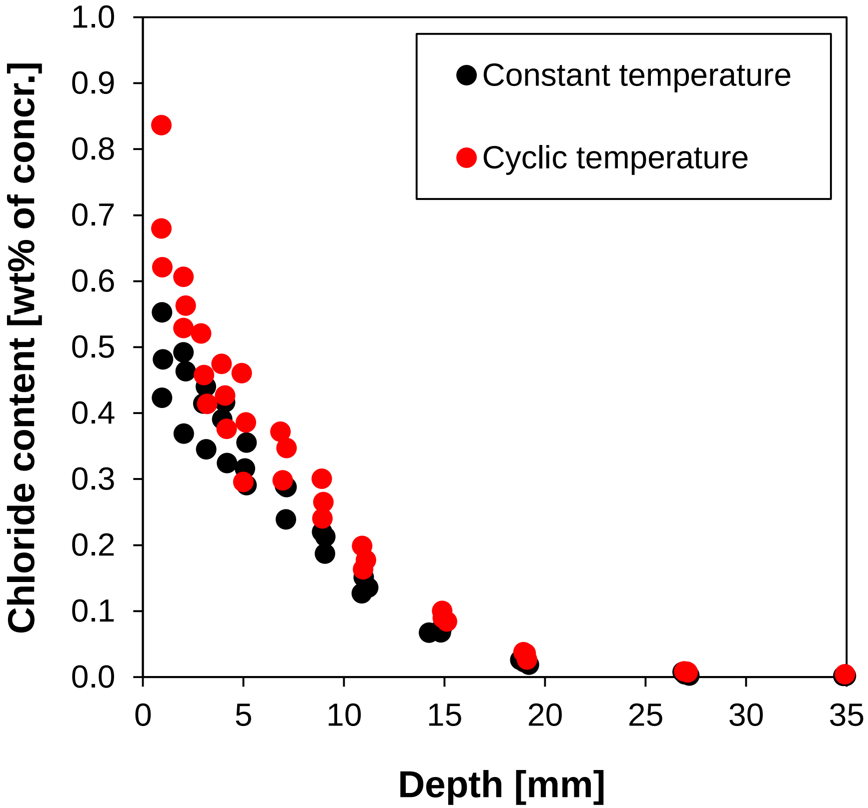
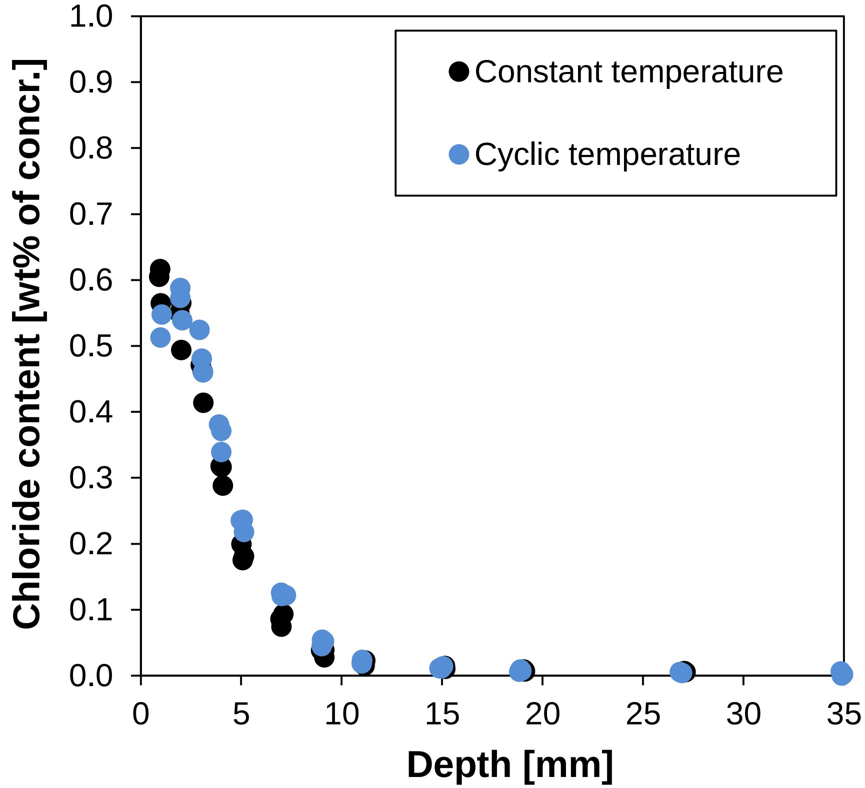
Concrete A

(100% OPC)



Concrete F

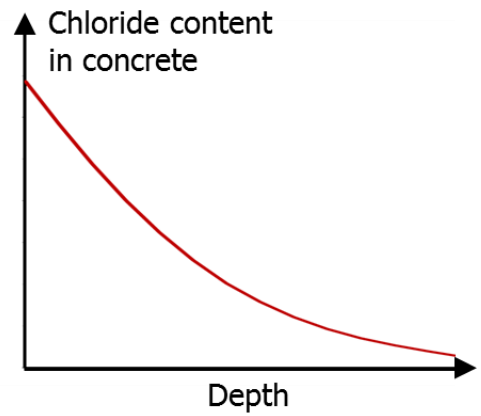
(84% OPC + 12% FA + 4% SF)



Curve fit to measured profiles

- A simple mathematical model for the ingress of chloride in concrete is the error function solution to Fick's second law of diffusion
- This model was fitted to the measured chloride profiles to calculate the parameters D and C_S:

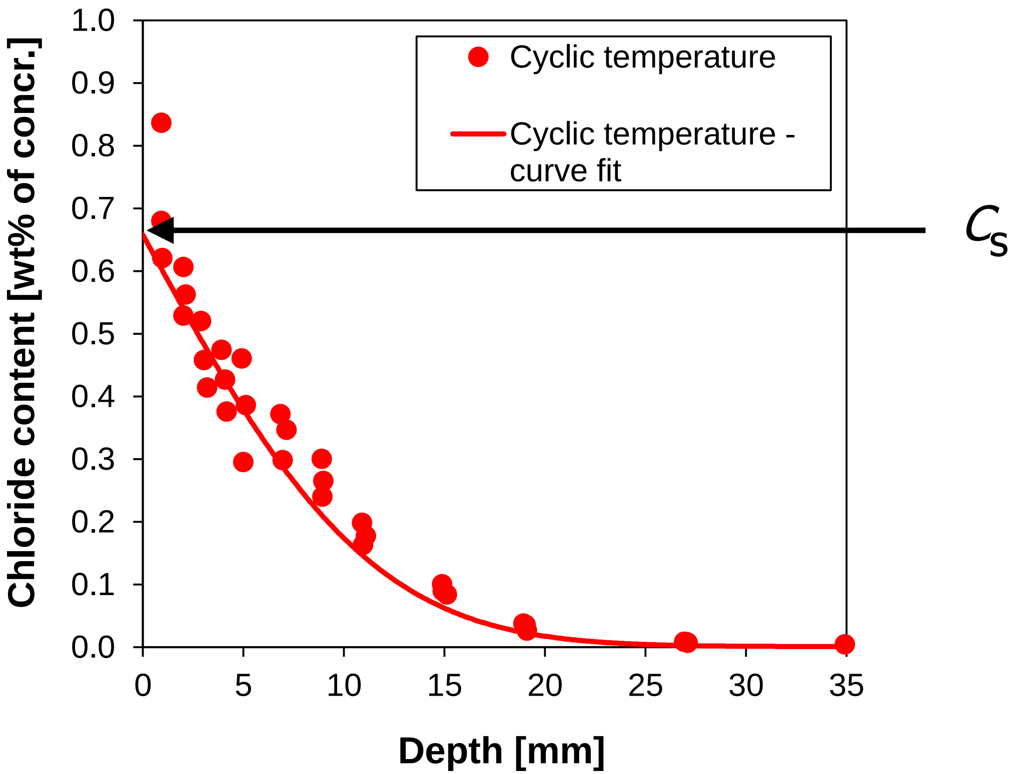
$$C(x,t) = C_i - (C_S - C_i) \cdot erf \cdot \left(\frac{x}{\sqrt{4 \cdot D \cdot t}} \right)$$



$C(x,t)$ = chloride concentration at depth x at time t
C_i = initial chloride concentration
C_S = chloride concnetration at the concrete surface
erf = error function
D = chloride diffusion coefficient

Example of curve fit for specimens of Concrete A

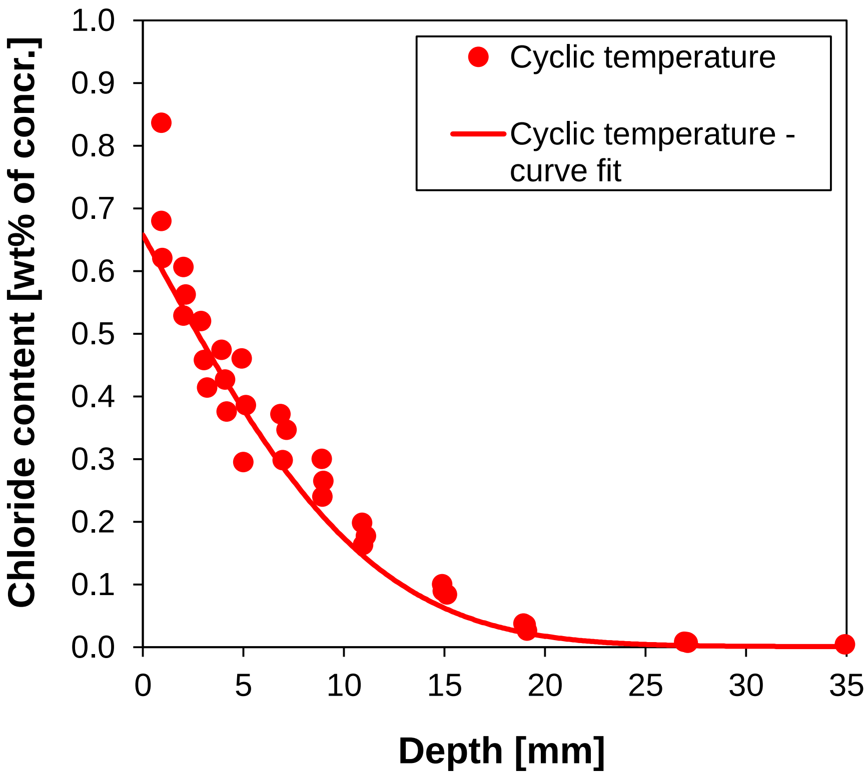
$$C(x,t) = C_i - (C_s - C_i) \cdot erf \cdot \left(\frac{x}{\sqrt{4 \cdot D \cdot t}} \right)$$



Example of curve fit for specimens of Concrete A

$$C(x,t) = C_i - (C_S - C_i)\cdot erf\cdot\left(\frac{x}{\sqrt{4\cdot D\cdot t}}\right)$$

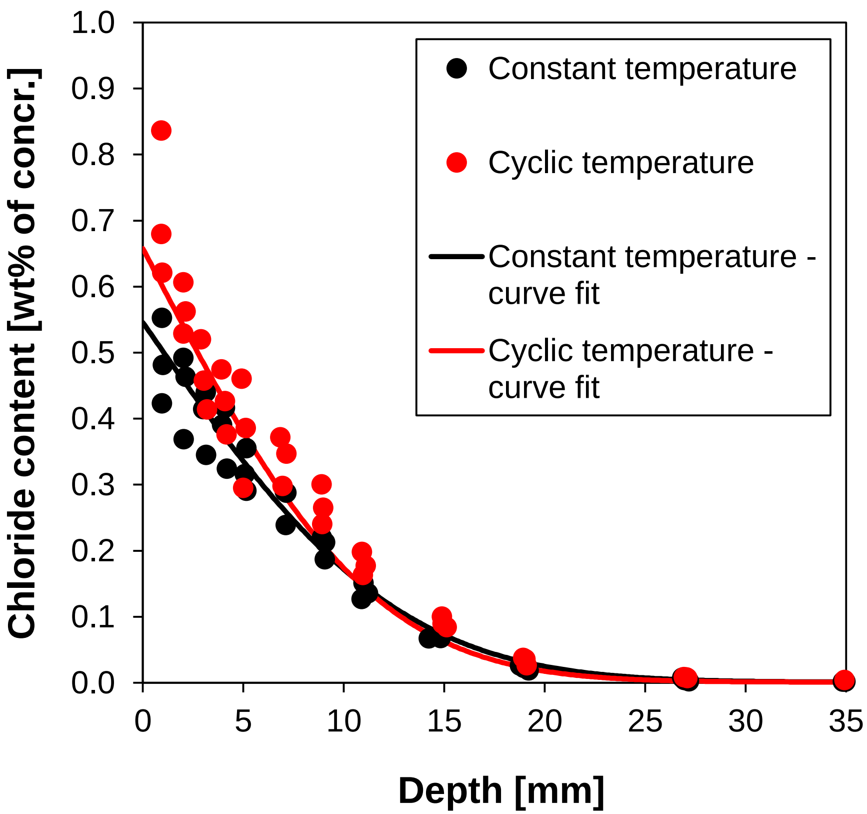
The diffusion coefficient *D* expresses the decay rate of the calculated chloride profile



Resulting curve fits for all measured chloride profiles

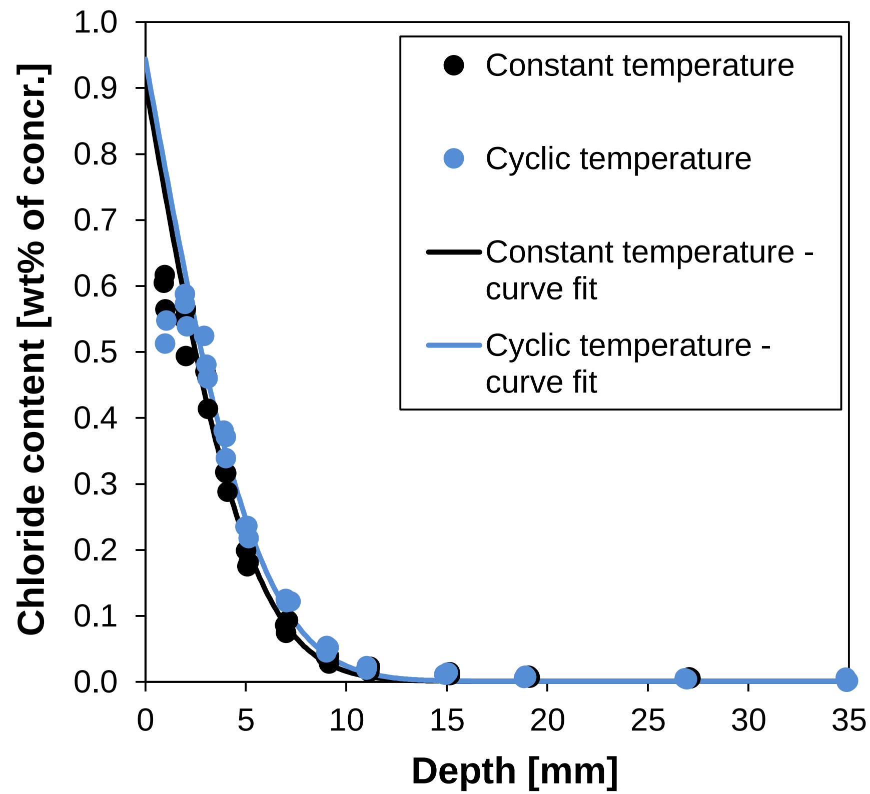
Concrete A

(100% OPC)



Concrete F

(84% OPC + 12% FA + 4% SF)



Ingress parameters from curve fit to measured profiles

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Sample ID	Chloride diffusion coefficient (D) [$m^2/s * 10^{-12}$]	Chloride surface concentration (C_S) [wt% of concrete]
Concrete A - Constant temp.	6.78	0.54
Concrete A - Cyclic temp.	7.09	0.58
Concrete F - Constant temp.	1.20	0.91
Concrete F - Cyclic temp.	1.37	0.94

- Significantly higher chloride diffusion coefficients for Concrete A compared to Concrete F.

Discussion

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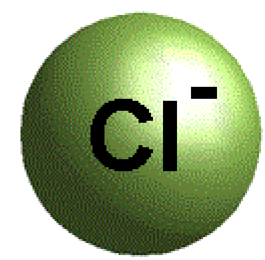
Effect of temperature variations on chloride ingress

- We tentatively suggest that the accelerated chloride ingress at temperature cycles are due to reduced chloride binding during periods with high temperature → increases the concentration of free chloride in the pore solution, which promotes the ingress of chloride.

Effect of binder type on chloride ingress

- The measured profiles revealed that there is a deeper penetration of chloride in Concrete A compared to Concrete F. We ascribe this to the differences in binder composition.

- Fly ash and silica fume in the binder of Concrete F results in a more refined pore structure + enhanced chloride binding → a higher resistance of the concrete against chloride ingress.



Some conclusions

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- An accelerated ingress of chloride was observed in concrete samples exposed to temperature cycles when compared to similar samples exposed at constant temperature.

- Care should be taken if chloride ingress profiles determined at constant temperature conditions in the laboratory are compared to ingress profiles measured on real concrete structures, since such structures are always subjected to some degree of daily and/or seasonal variations in temperature.

- A much deeper chloride ingress was observed in concrete samples with pure OPC compared to samples with blended cement. This is attributed to a more refined pore structure and an enhanced chloride binding capacity for the concrete with blended cement.