Model for binding of chlorides

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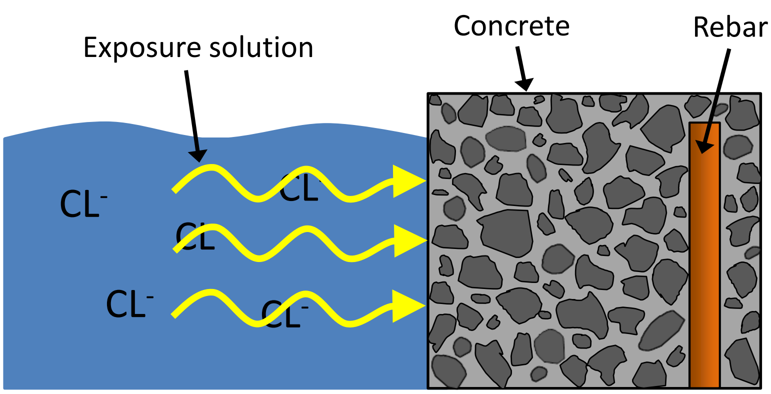
Ingress of chloride in concrete



- Partial fixation of chloride ions by the hydrate phases through processes collectively known as **chloride binding.**

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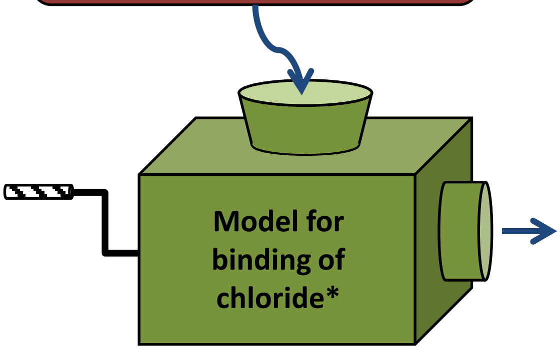
Model for binding of chloride in cement paste

Input

- Chemical composition of system



Output

- Quantification of chloride binding.
- Chemical composition of pore solution: $[Cl^-]$, $[Na^+]$, $[OH^-]$, $[Ca^{2+}]$.
- Phase assemblage of hydrated system.

** Nielsen, E.P. The durability of white Portland cement to chemical attack. PhD thesis R-084, DTU·BYG, 2004.*

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Model for binding of chlorides

- Thermodynamic model based on Gibb's Phase Rule.
- Model verified by chloride binding experiments carried out on six binder compositions + two 25 year-old pastes and experimental data from DTU projects.
- As a result of work carried out at the Expert Centre the model has been expanded to include a wider range of binder compositions.

Binding of chlorides

- Binding of chlorides in:
  - C-S-H phase.
  - AFm solid solution phase*:* Monocarbonate – Fridel's salt.

- Well-defined distribution between the content of chloride bound by the C-S-H phase and that bound by the AFm solid solution phase.

- The content of alkalis in the binder has a pronounced effect on its chloride binding capacity: Decrease in alkali content → increased chloride binding capacity.

Expansion of model for chloride binding

- Typical Ca/Si ratio of C-S-H in plain Portland cement paste: 1.75.

- In binders containing significant amounts of slag, fly ash or silica fume: Ca/Si < 1.75.

- The Ca/Si ratio in the C-S-H phase has a significant effect on the distribution of alkalis between the pore solution and the C-S-H phase, which consequently affects the chloride binding capacity of the C-S-H.

- Expanded version of the model, which takes the variation of Ca/Si in the C-S-H phase into account: Ca/Si ratio is allowed to vary between: 0.8 and 1.75.

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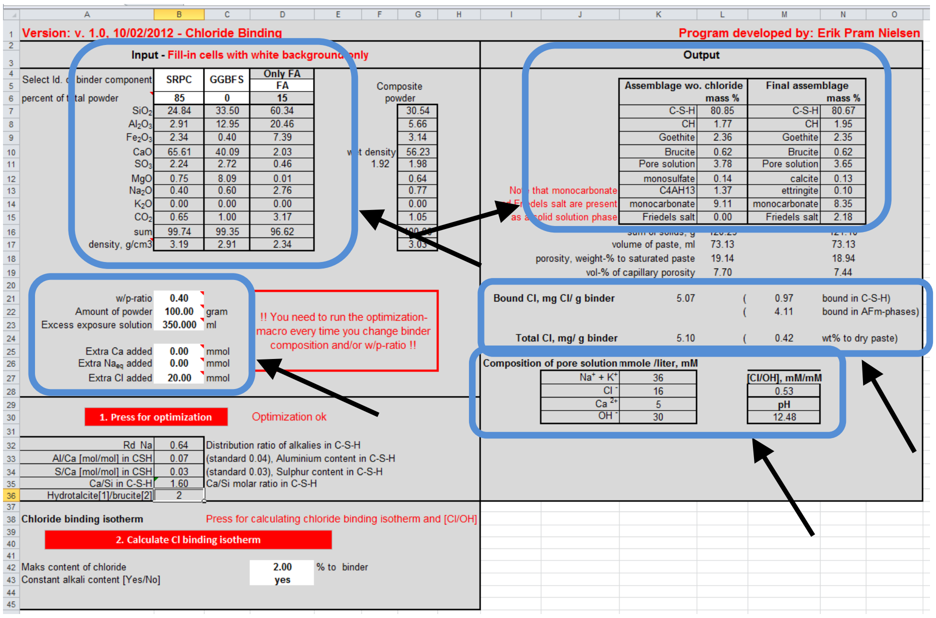
Model for binding of chloride



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Crushed concrete in artificial pore solution

- Crushed concrete samples (grain size Ø < 4 mm) exposed to artificial pore solutions.
- The test method allows a raking of different binders with regard to resistance against chloride induced reinforcement corrosion.
- [Na^+] in the artificial pore solution was adjusted to that expected in the "unexposed" concrete by adding NaOH to the solution. Calculated by the model.
- [Cl^-] was set at 6 levels covering an interval around the expected chloride threshold value, based on the assumption that a [Cl^-]/[OH^-] ≈ 0.6 triggers reinforcement corrosion. Calculated by the model.

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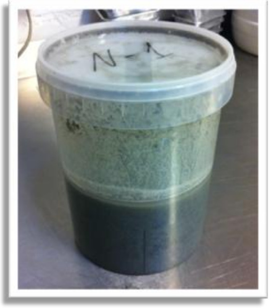
Crushed concrete in artificial pore solution

- 6 types of concrete:
  - Sulfate resitant Portland cement (SRPC)
  - SRPC + 15% fly ash
  - SRPC + 25% fly ash
  - SRPC + 12% fly ash + 4% microsilica
  - Rapid Portland cement (RCP) + 70% slag
  - RCP + 25% fly ash



- Age of concretes: 1.5 years.
- 1000 g crushed concrete + 350 ml solution in each plastic container.
- Specimens kept sealed and stored at 20°C for 3 months in order to obtain equilibrium.
- After storing the solutions were analyzed for $[Cl^-]$ and $[OH^-]$.

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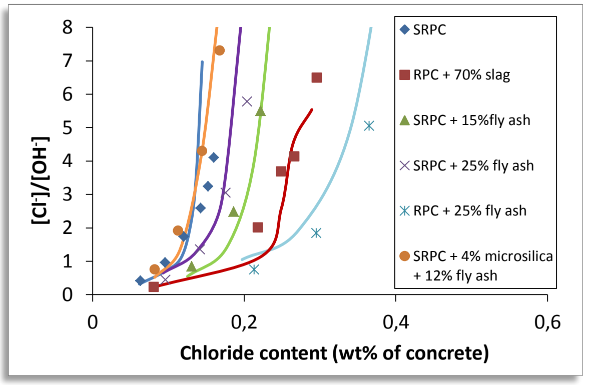
Crushed concrete in artificial pore solution



- The artificial pore solutions were prepared with too much alkali for the binders containing slag and fly ash. Apparently, only a minor proportion of the alkalis in the fly ash and the slag becomes available during hydration.
- Data was used to modify the model.

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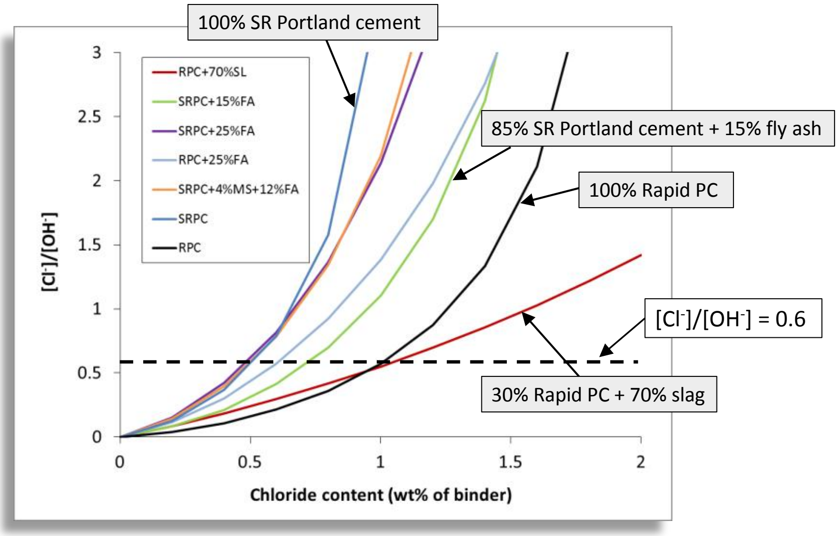
Prediction of [Cl⁻]/[OH⁻] ratios



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Crushed concrete in artificial pore solution

- Small pieces of reinforcement steel have been exposed to artificial pore solutions to test the ability of the solutions to initiate corrosion.
- The steel was cleaned in citric acid and passivated in saturated $Ca(OH)_2$ solution prior to the exposure.
- No signs of reinforcement corrosion in any of the specimen containers after 4 weeks of exposure.
- It appears that even very high [Cl⁻]/[OH⁻] ratios will not necessarily result in the onset of reinforcement corrosion. Other triggering factors?

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New test series with crushed concrete

- New test series with crushed concretes in artificial pore solutions will be carried out. Same procedure and same concretes, but with correct concentration of alkalis in the artificial pore solutions.
- The was developed for conditions at 20°C. New test series on the same concretes, but at a lower temperature.

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Thank you for your attention