Numerical and Experimental Study of Chloride Ion Transport in Recycled Aggregates Concrete

NoMaD 2022

Arthur FANARA – 16 November 2022

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University of Liège, ArGEnCo Department, UEE Research Unit

Background

Environmental Concerns

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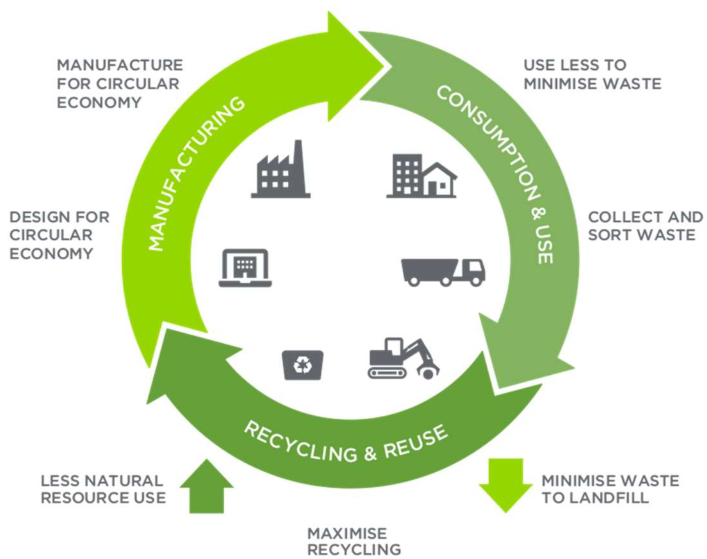


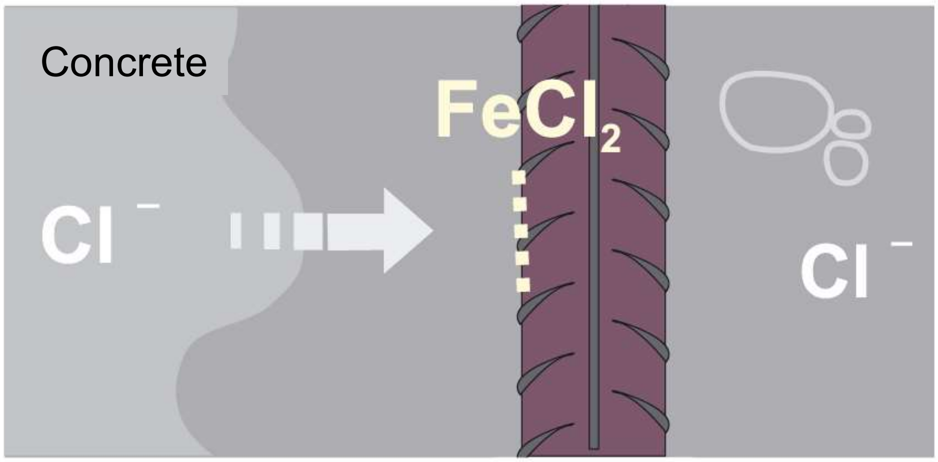
[https://www.futurerecycling.com.au/sustainability/circular-economy/,2020]

Background

Chlorides Attacks

[Ployaert, 2008]

Sea water,
sea wind,
deicing salts,
mixing
constituents,
…



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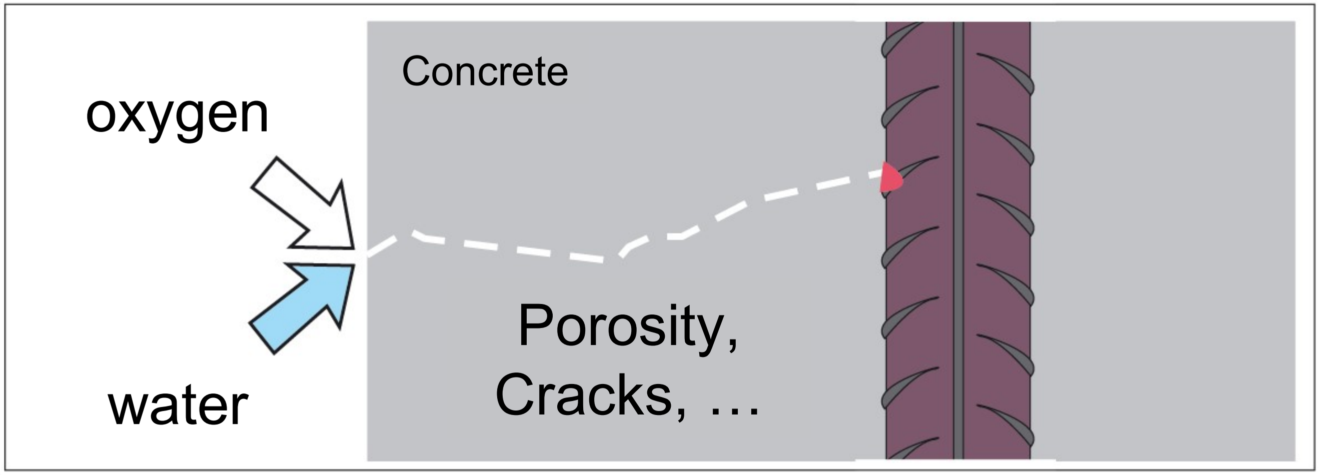

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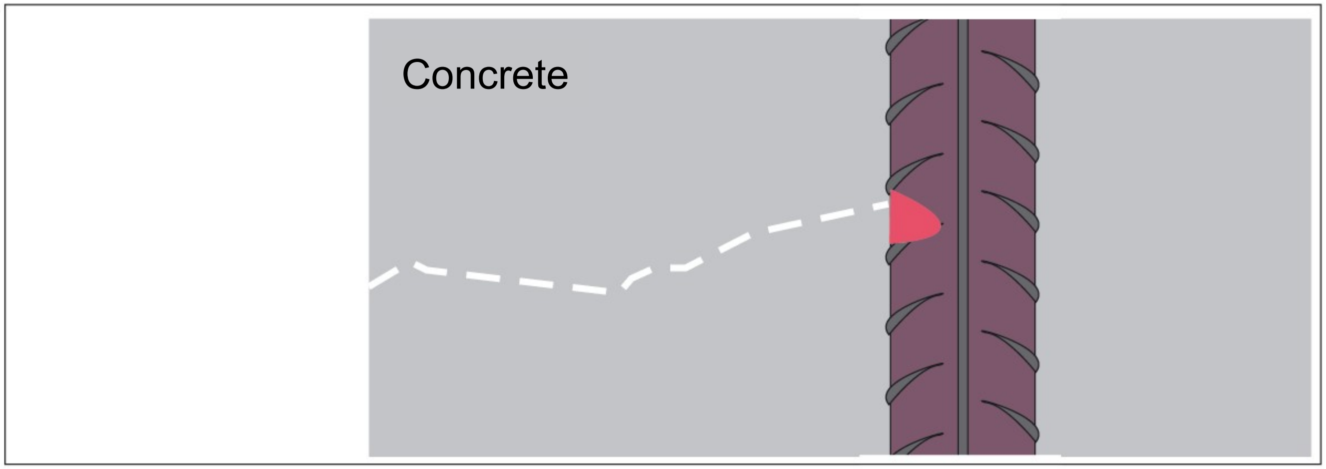

Corrosion by
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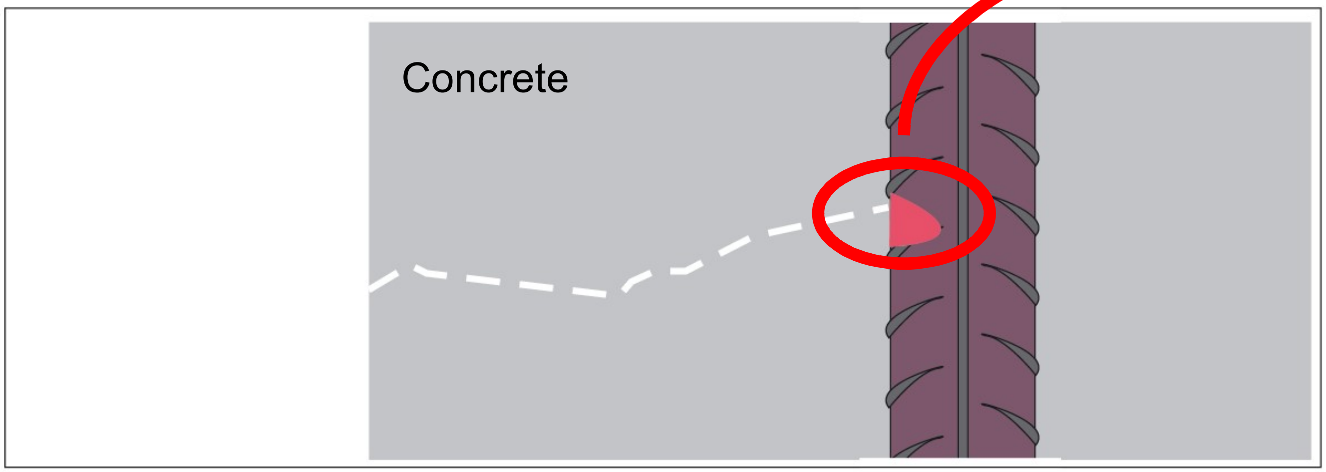

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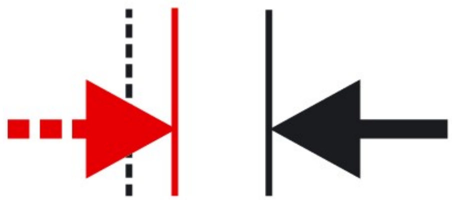
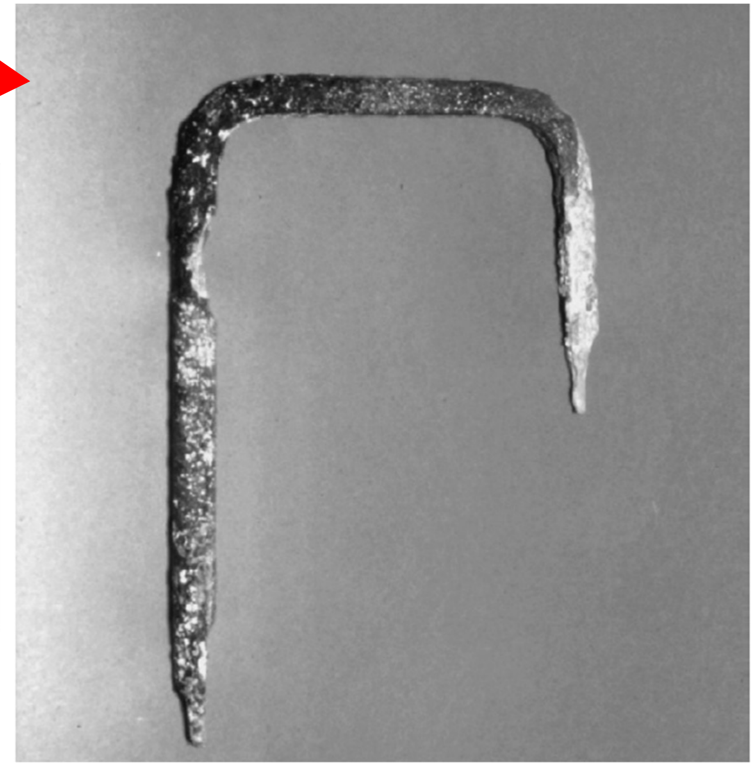
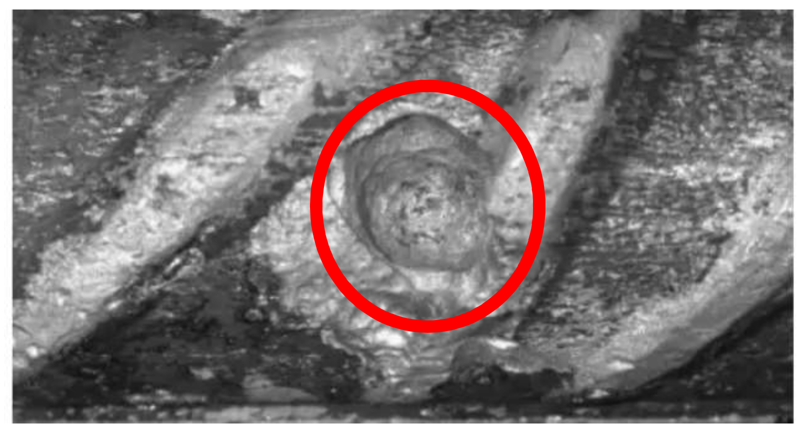




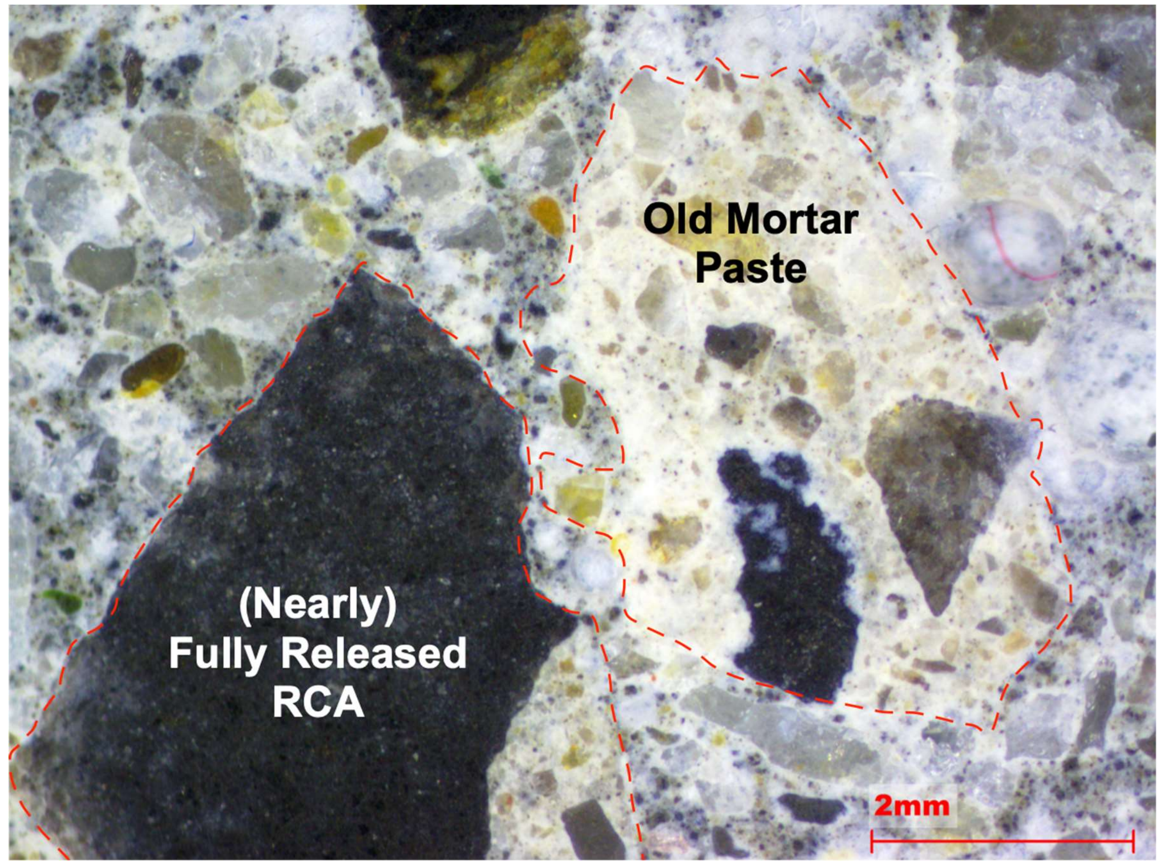
[Raupach & Büttner, 2014]



[Raupach & Büttner, 2014]

Background

Influence of RCA

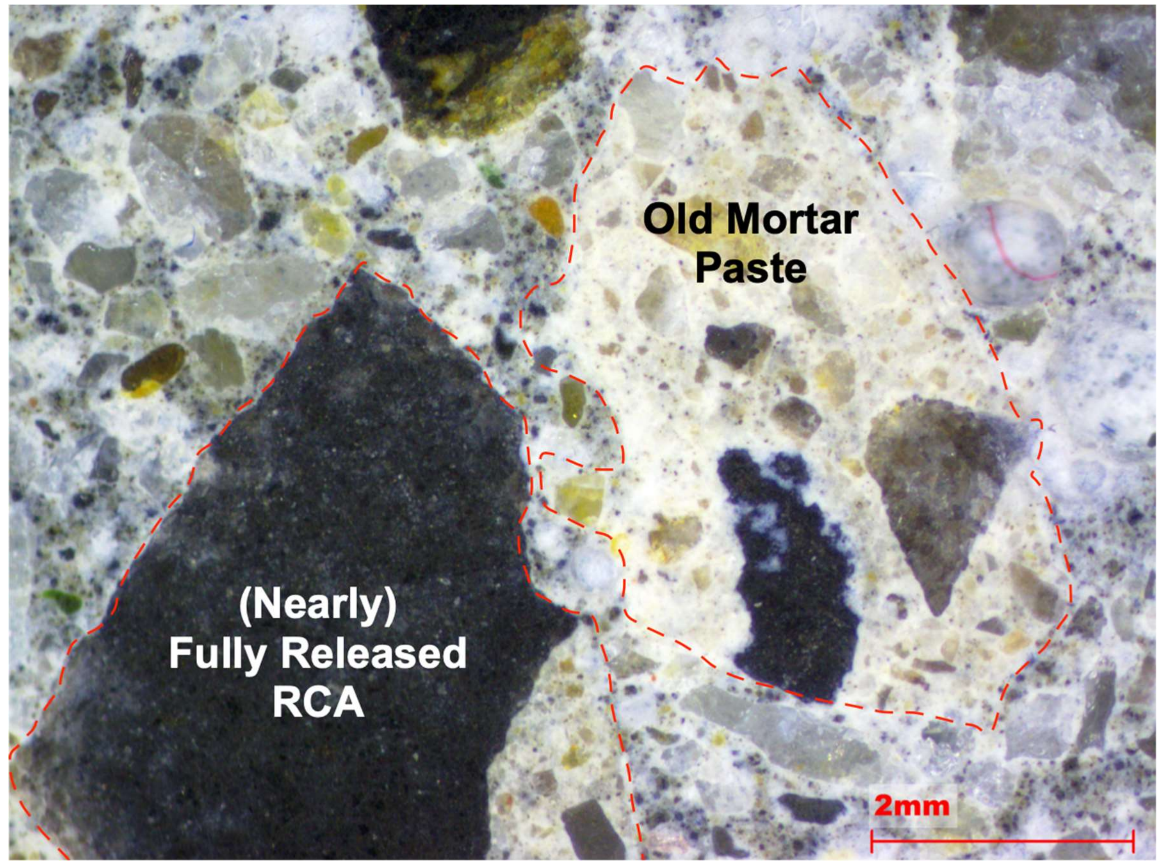


[Fanara, 2020]

Background

Influence of RCA

- RCA: increased porosity and water absorption



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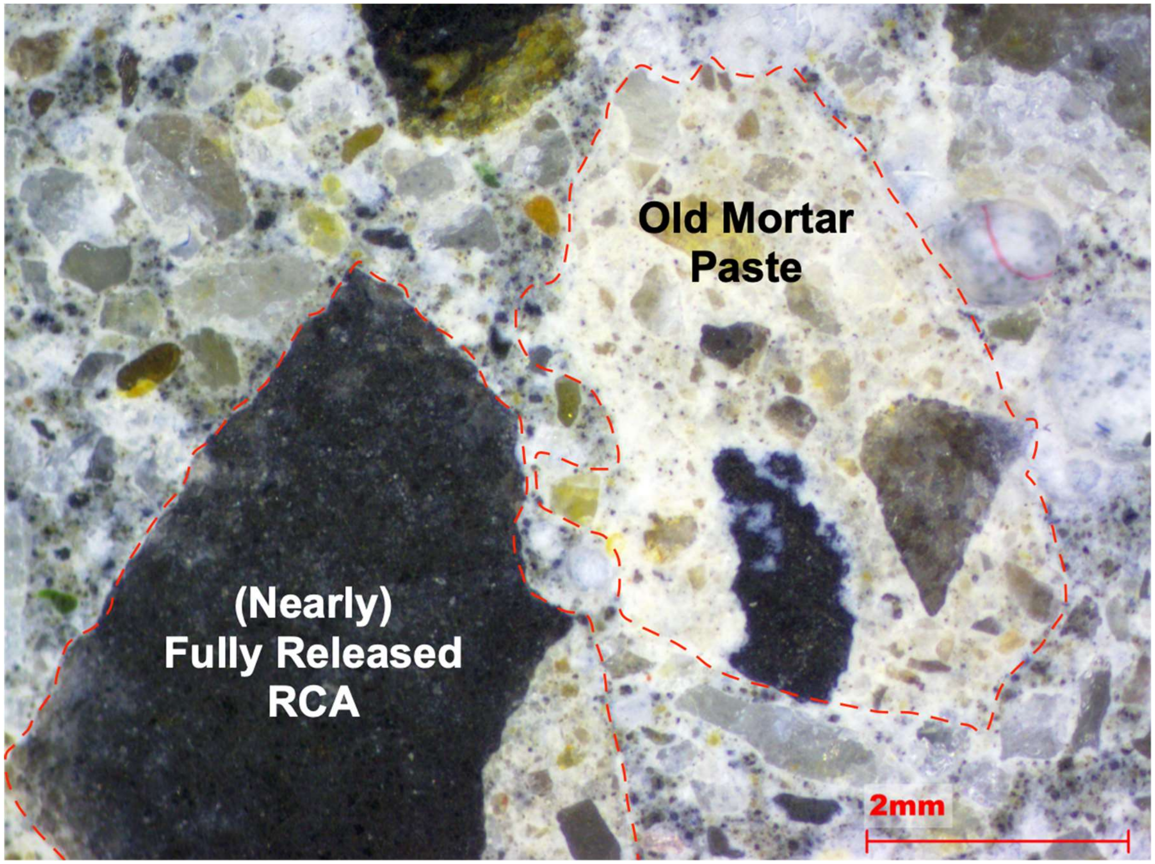
- Water is the cause of most of degradations processes



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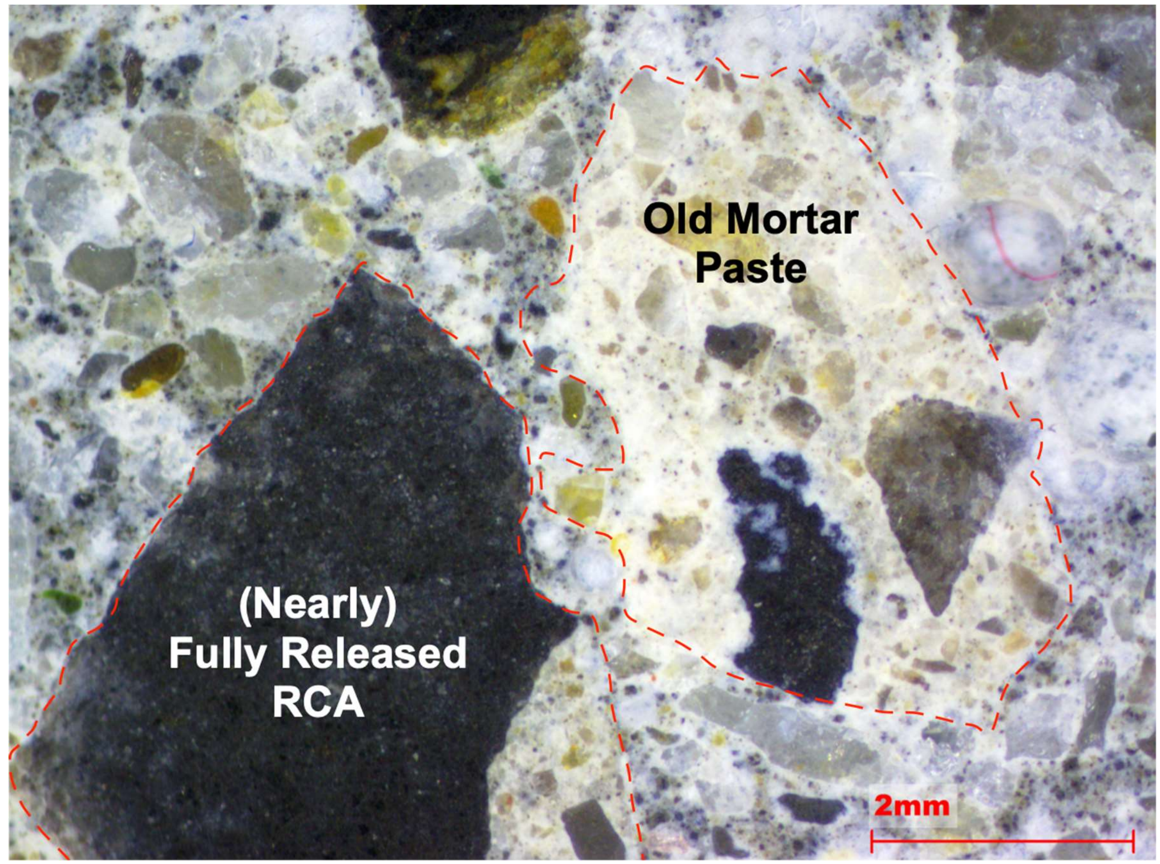
- The chloride corrosion rate is maximum at around 85% RH



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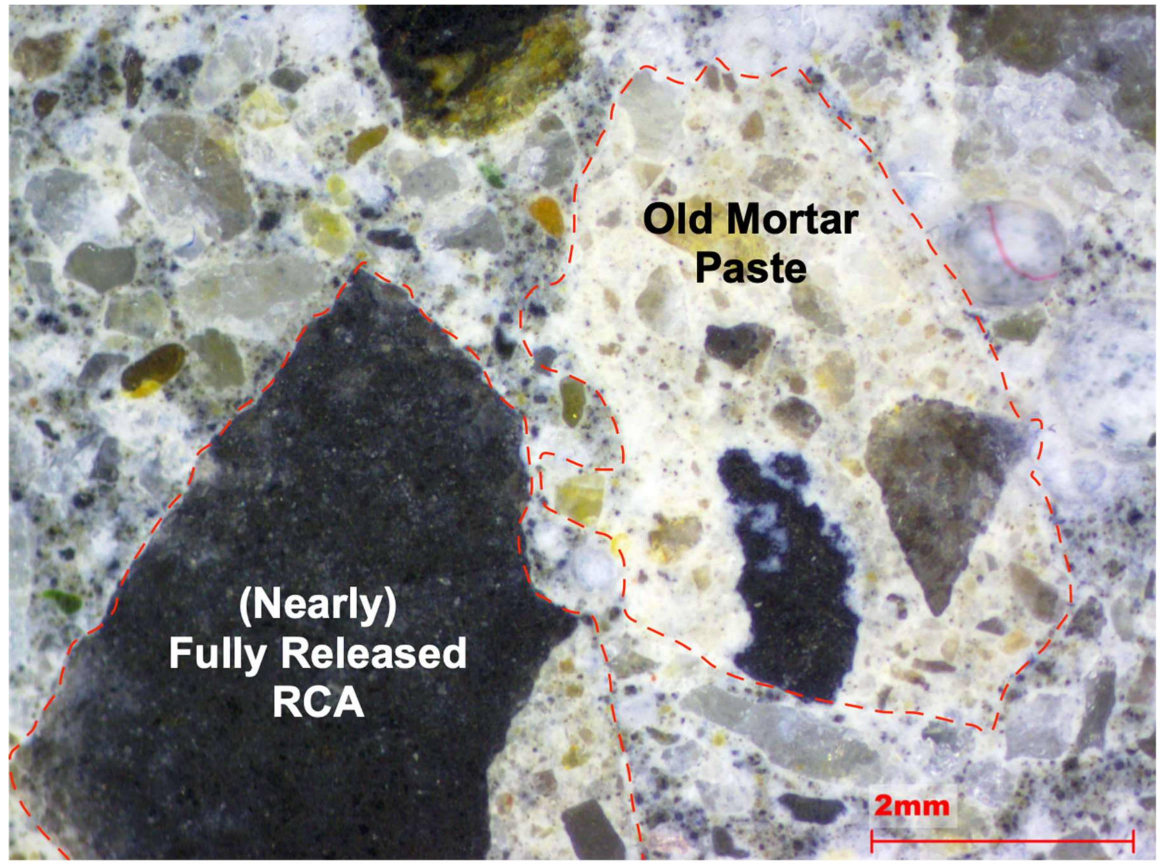
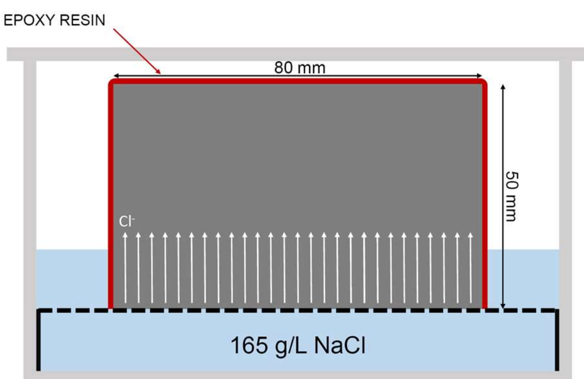


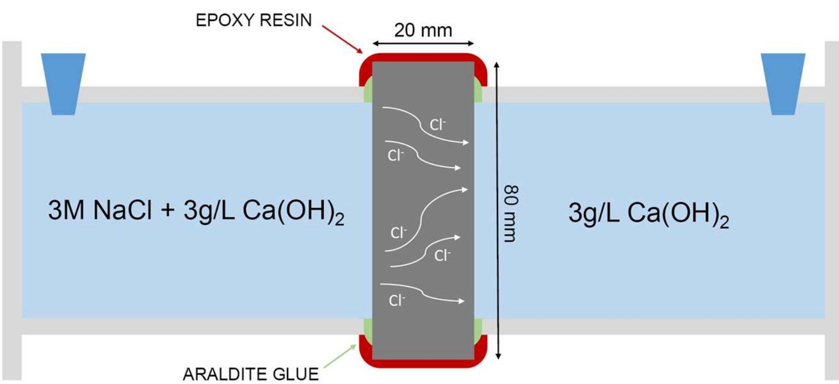
[Fanara, 2020]

→ Influence of RCA on chloride attacks ?

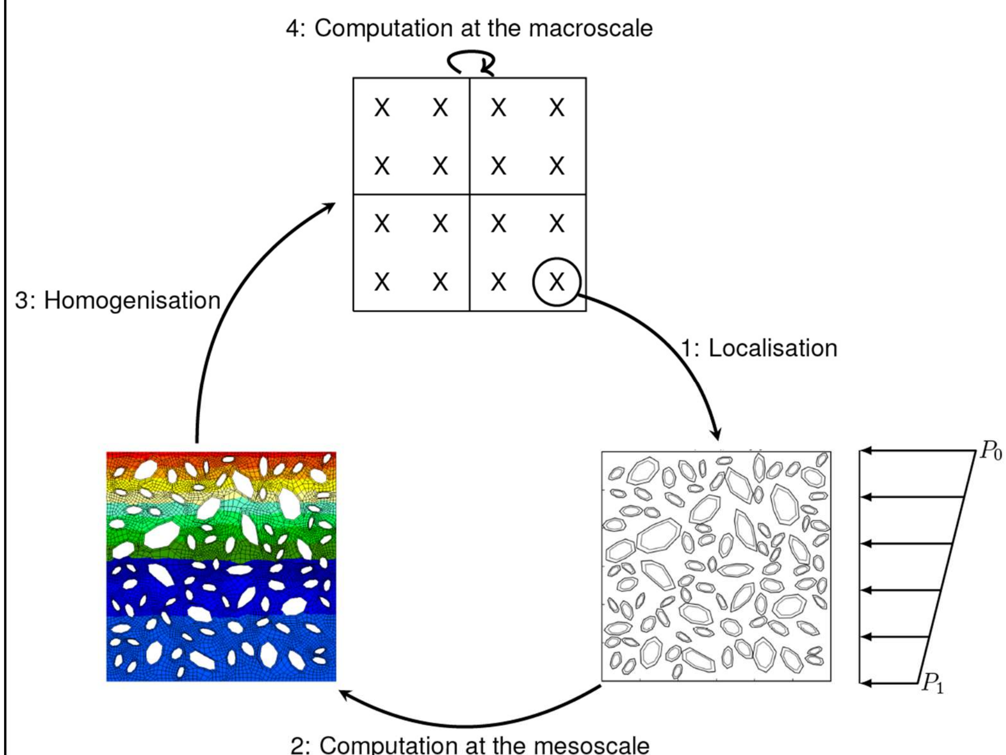
Goals of this study

Experimental





Numerical



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1. Introduction

2. Materials

3. Experimental Plan
4. Experimental Results
5. Numerical Validation with Experimental Results
6. Conclusion

Materials

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- 3 main materials:

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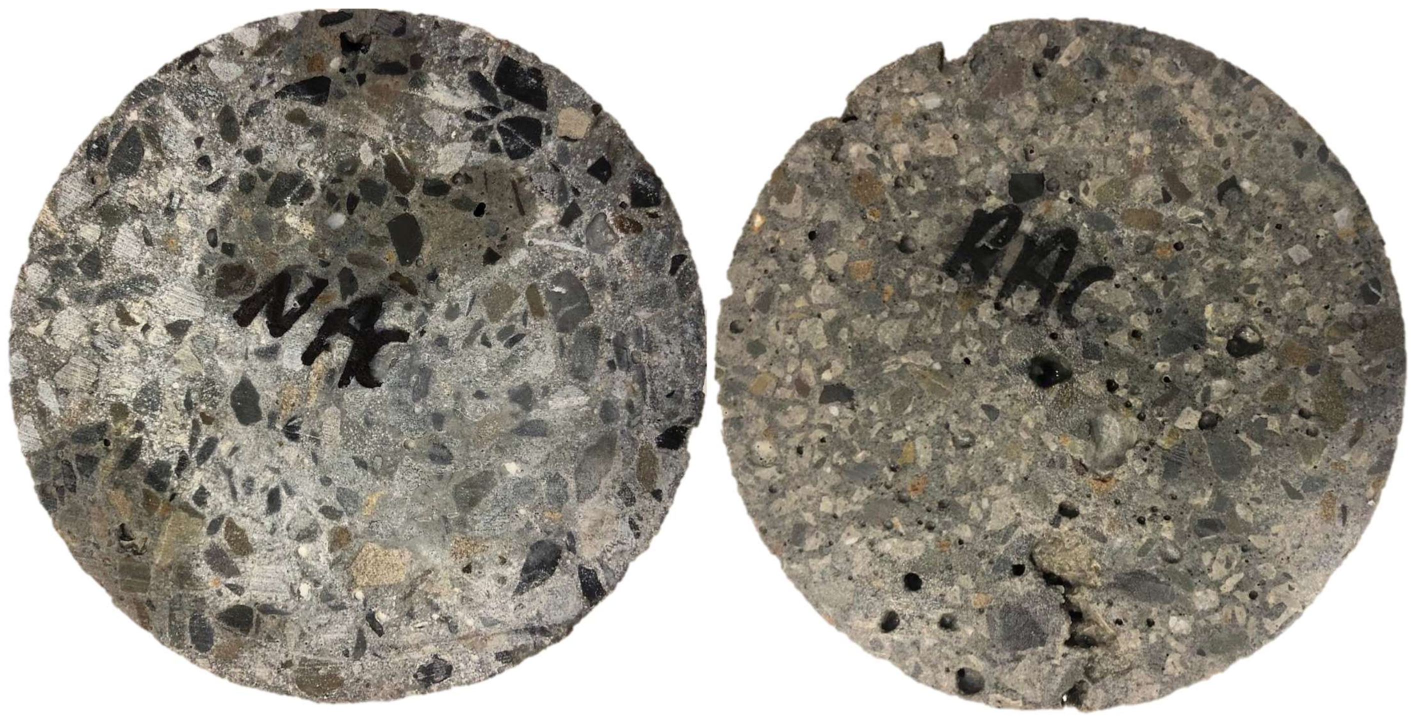
  - **RAC**: concrete with 2/7 RCA (constant volume fraction and reconstructed PSD)



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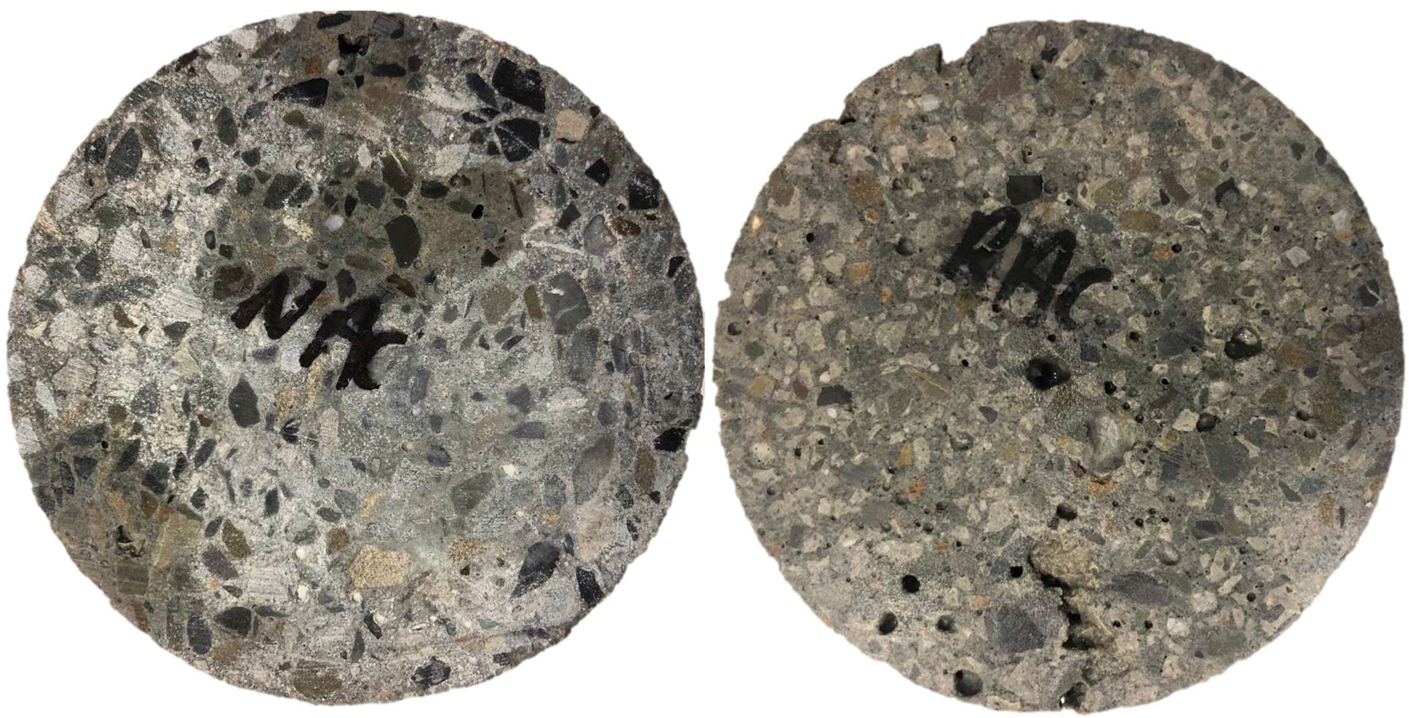

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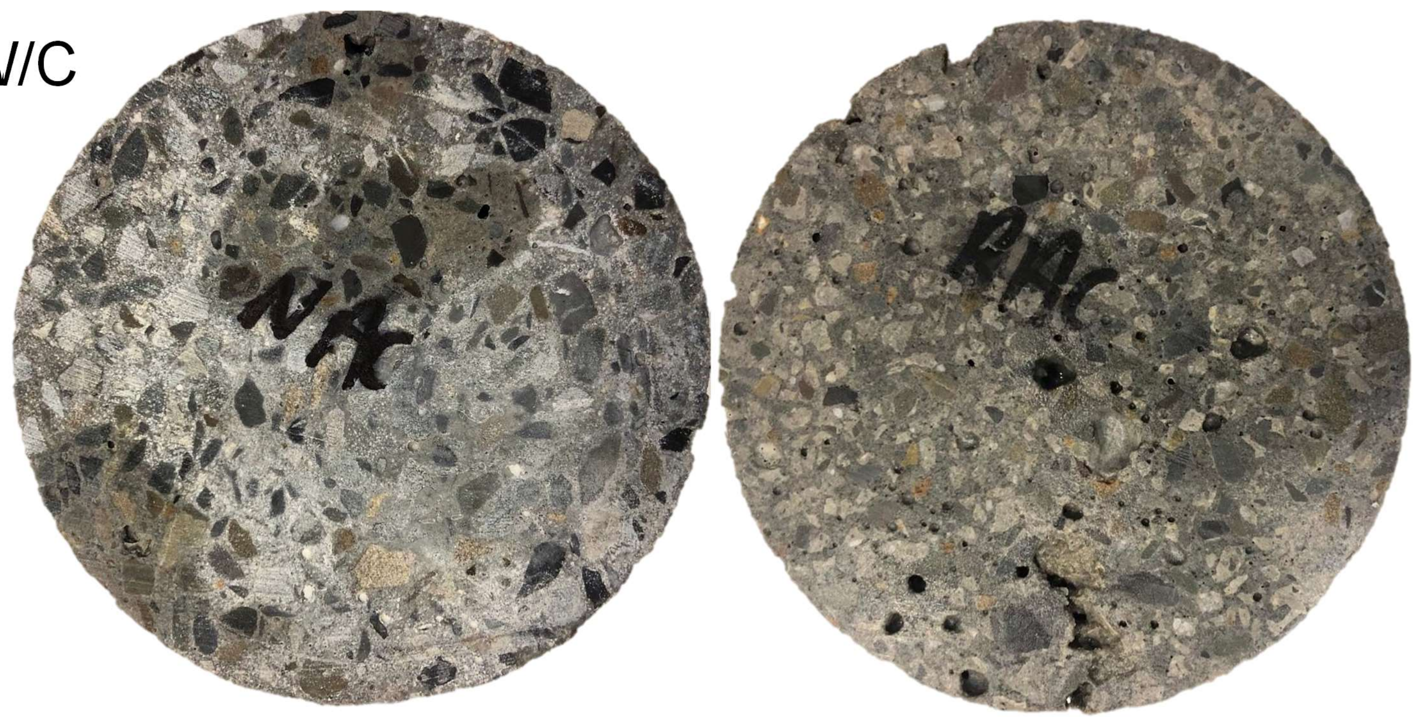

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Experimental Plan

Water transfer properties

- Water Absorption by Immersion (NBN B 15-215:2018 and NBN EN 772-4)
  - Dry and humid densities, water absorption and water accessible porosity

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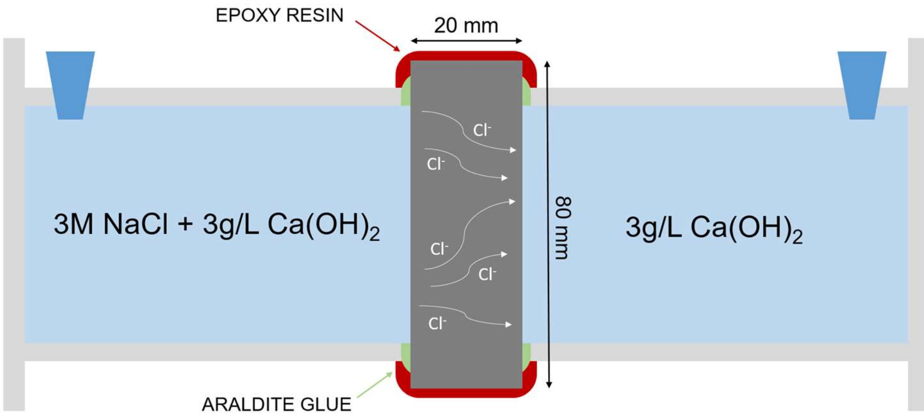
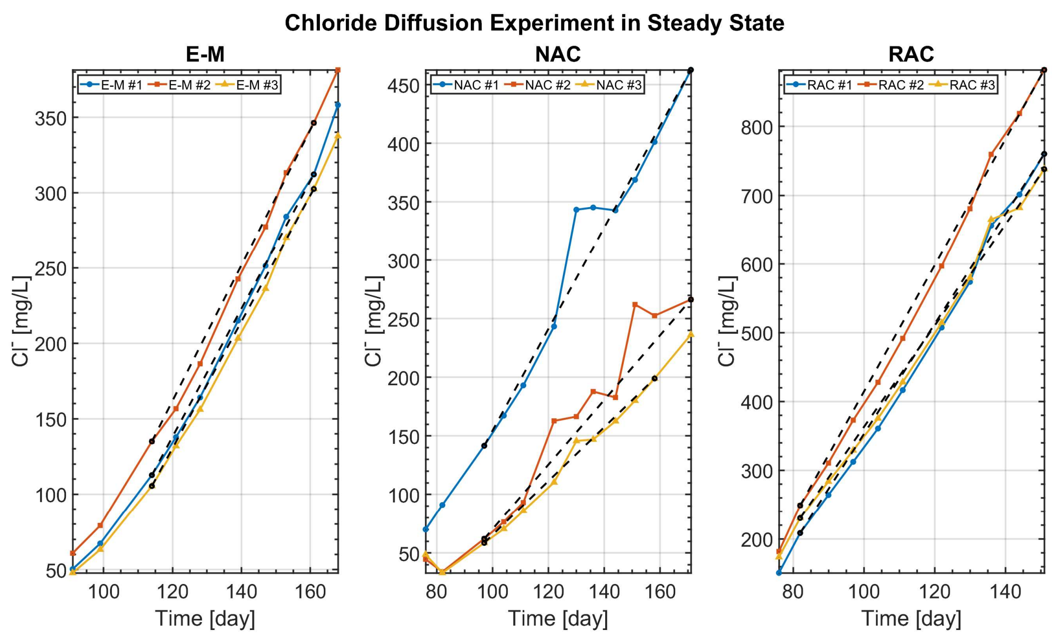
- Static sorption and desorption
  - Water Retention Curves

Experimental Plan

Chloride ions transfer properties

- **Chloride Diffusion under steady-state**





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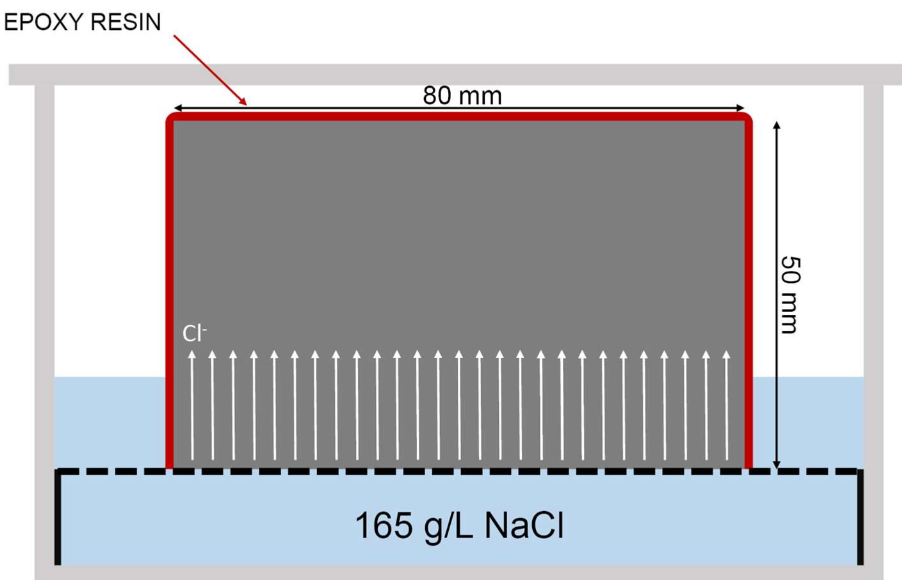

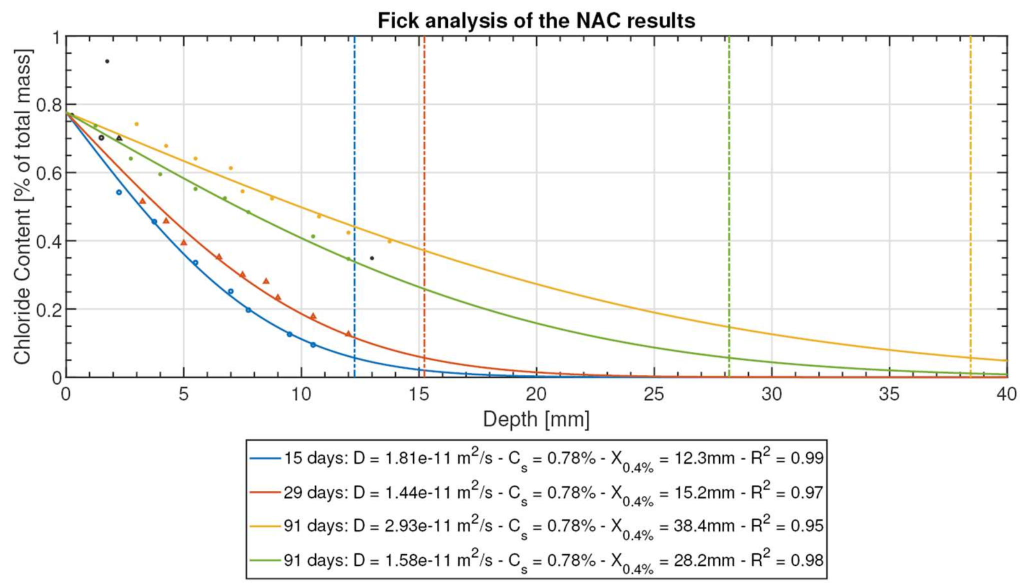

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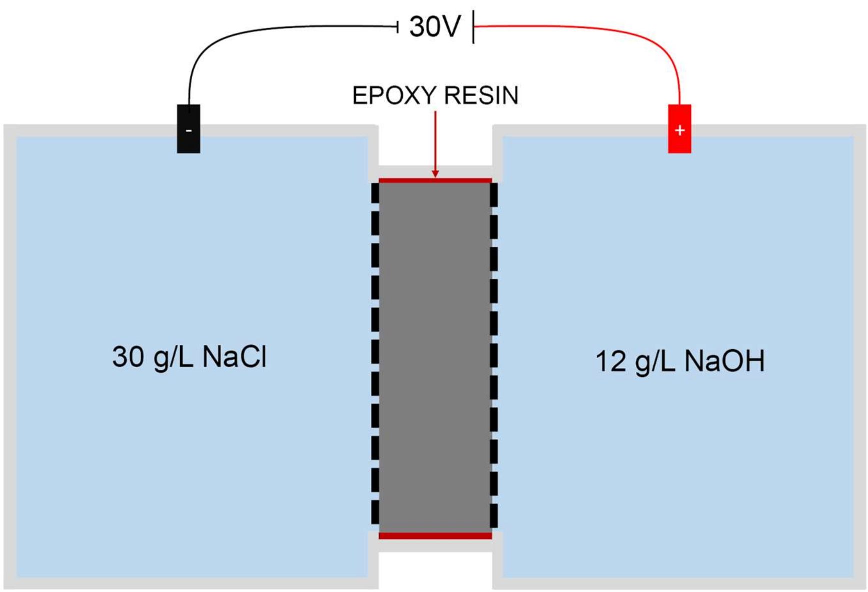

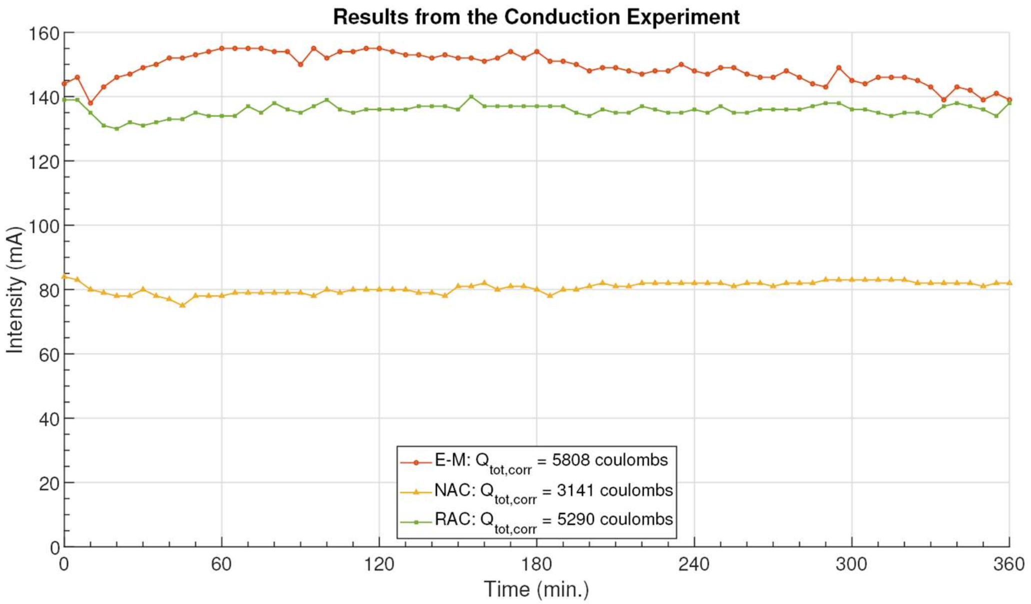

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Water transfer properties

- n, WA: E-M (22.83%V, 11.27%M) > RAC (20.5%V, 9.95%M) > NAC (14.16%V, 6.26%M)
    - The porosity is induced by the mortar matrix (aggregates and sand rather not porous)

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- WRC: RAC ~= E-M > NAC
  - The RAC has a greater exchange rate of moisture with its environment than the NAC.

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Chloride Ions transfer properties

- Diffusion under steady-state:
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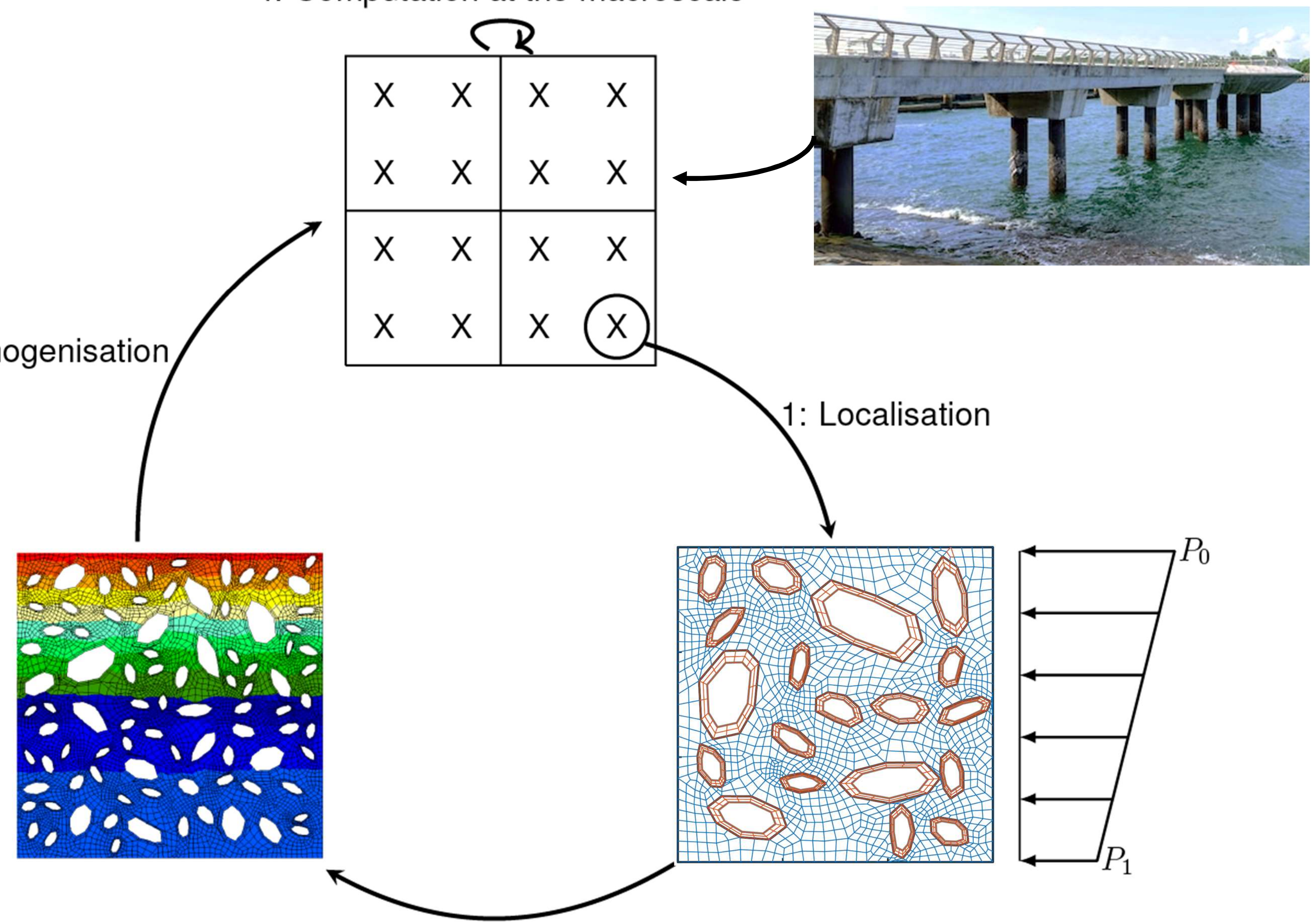
- Conduction: E-M (5808 Coulombs) > RAC (5290 Coulombs) > NAC (3141 Coulombs)

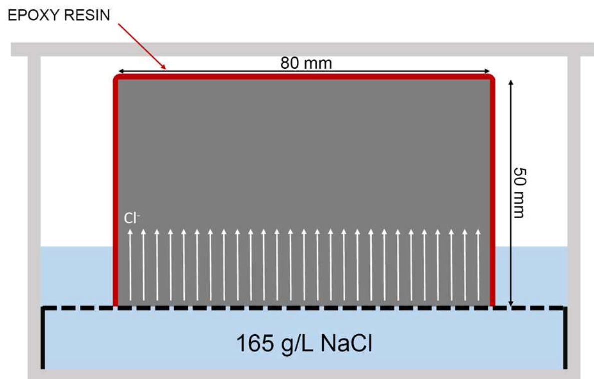
5. Numerical Validation with Experimental Results

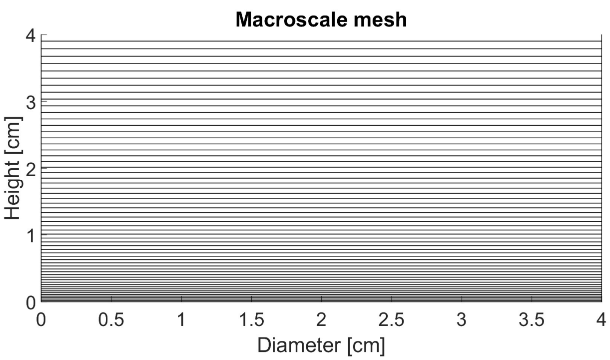
Multiscale modelling

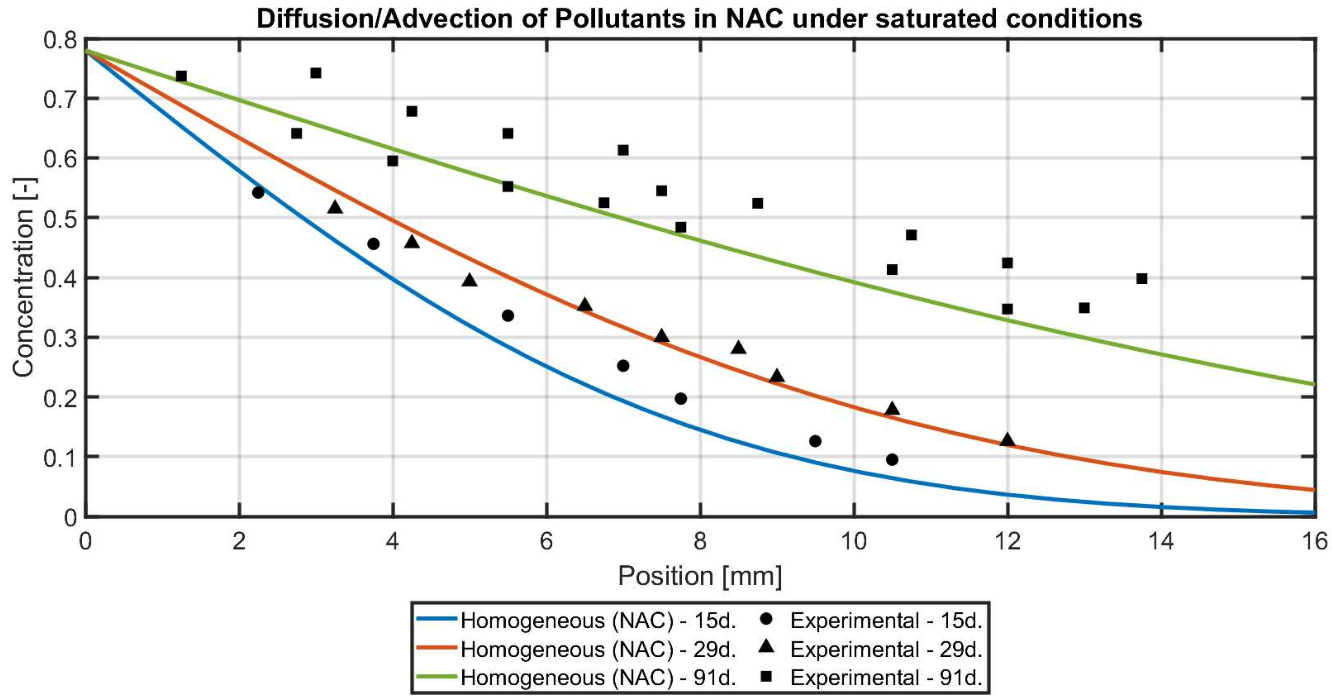


*Our microscale
is in the order of
the centimetre

Experimental modelling - NAC







- For NAC microstructure with EM+30% Diffusion Coefficient, the numerical results are close enough to the experimental (and analytical) analysis. Other studies have found an increase of up to 40% of the diffusion in 3D compared to 2D *[Nilenius, 2014]*

Experimental modelling - NAC

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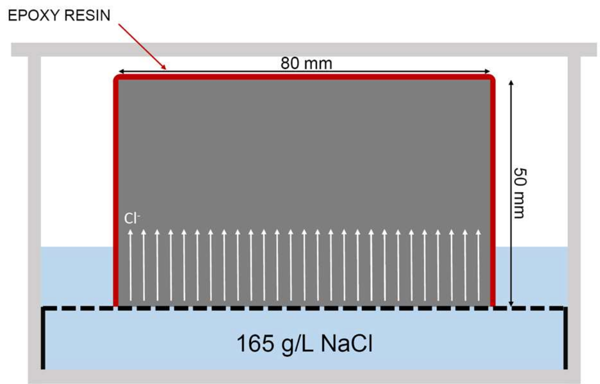

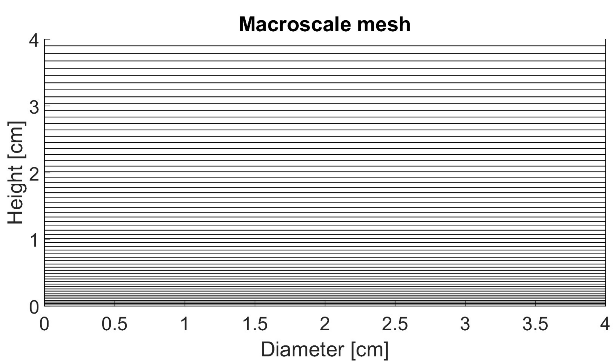

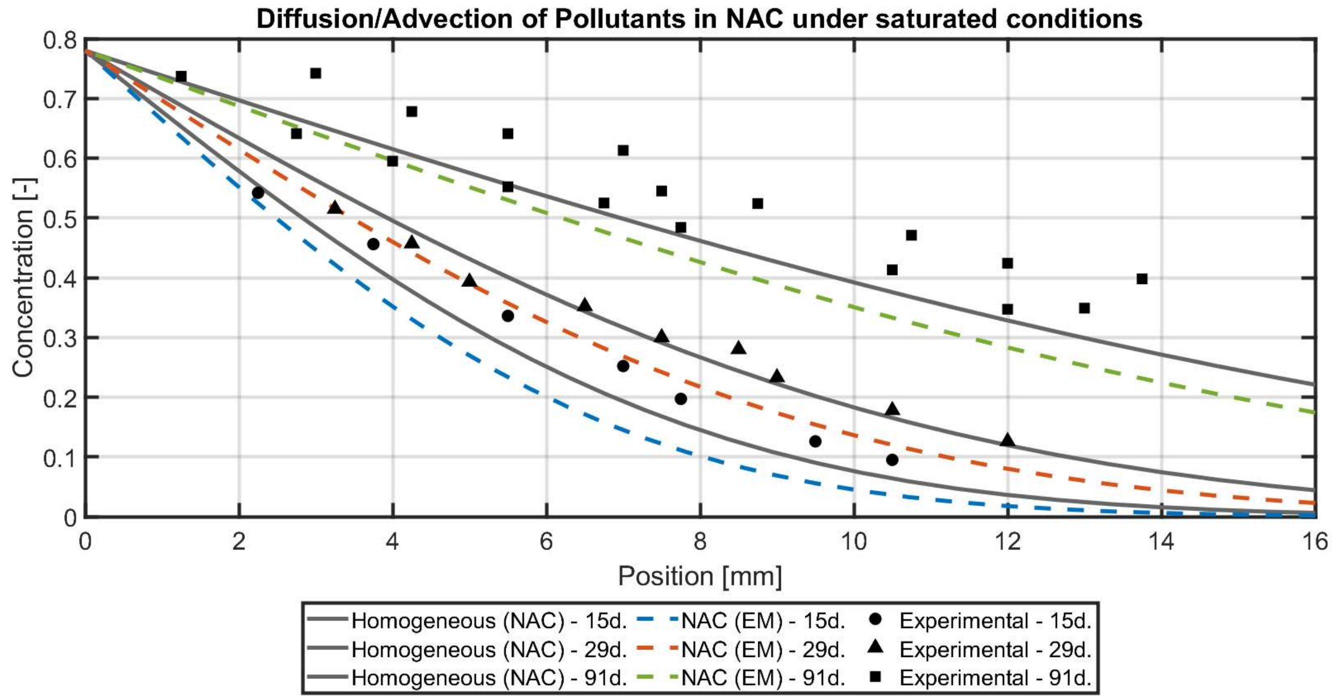

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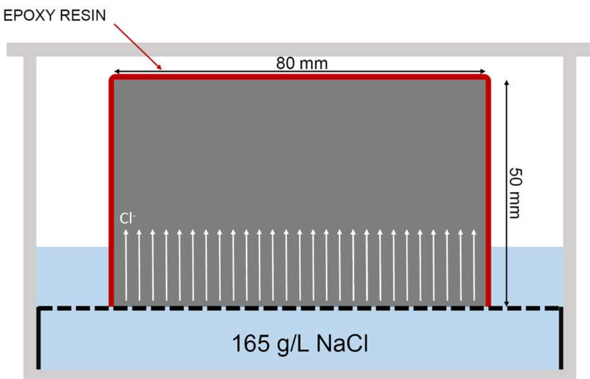

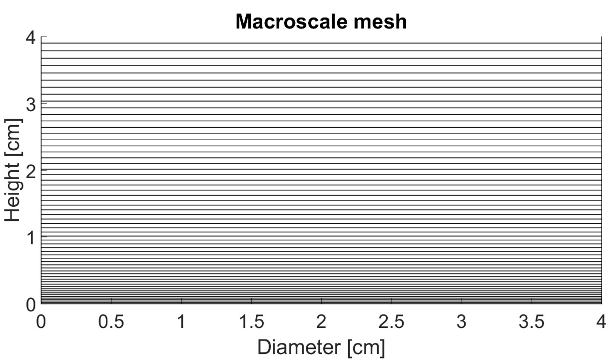

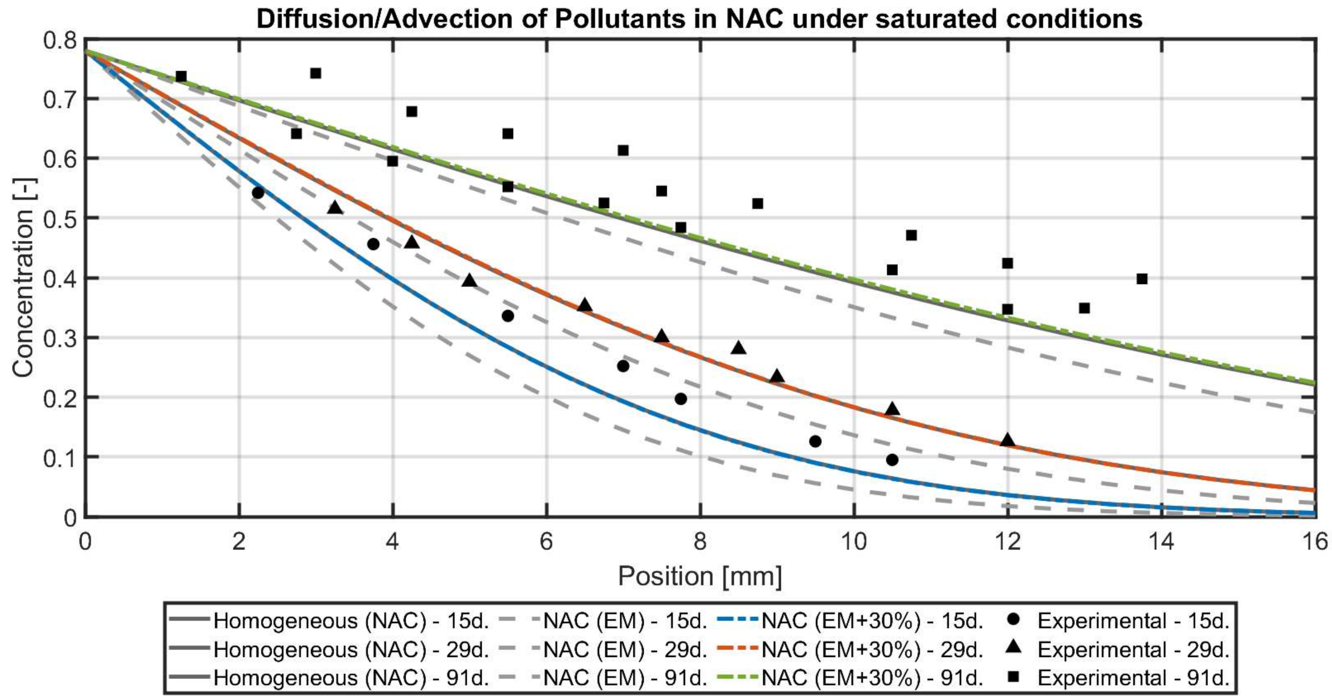

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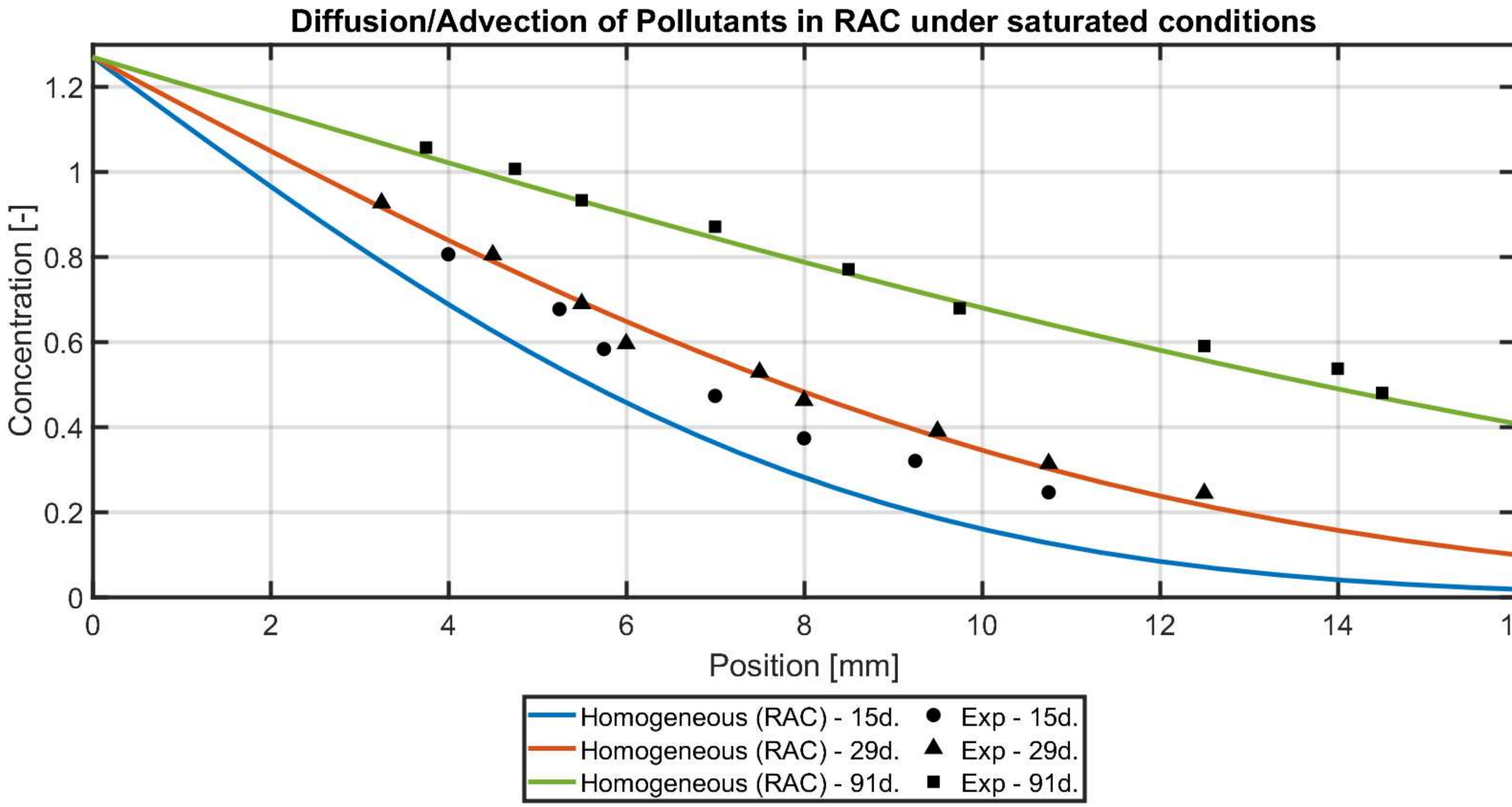
Experimental modelling - RAC



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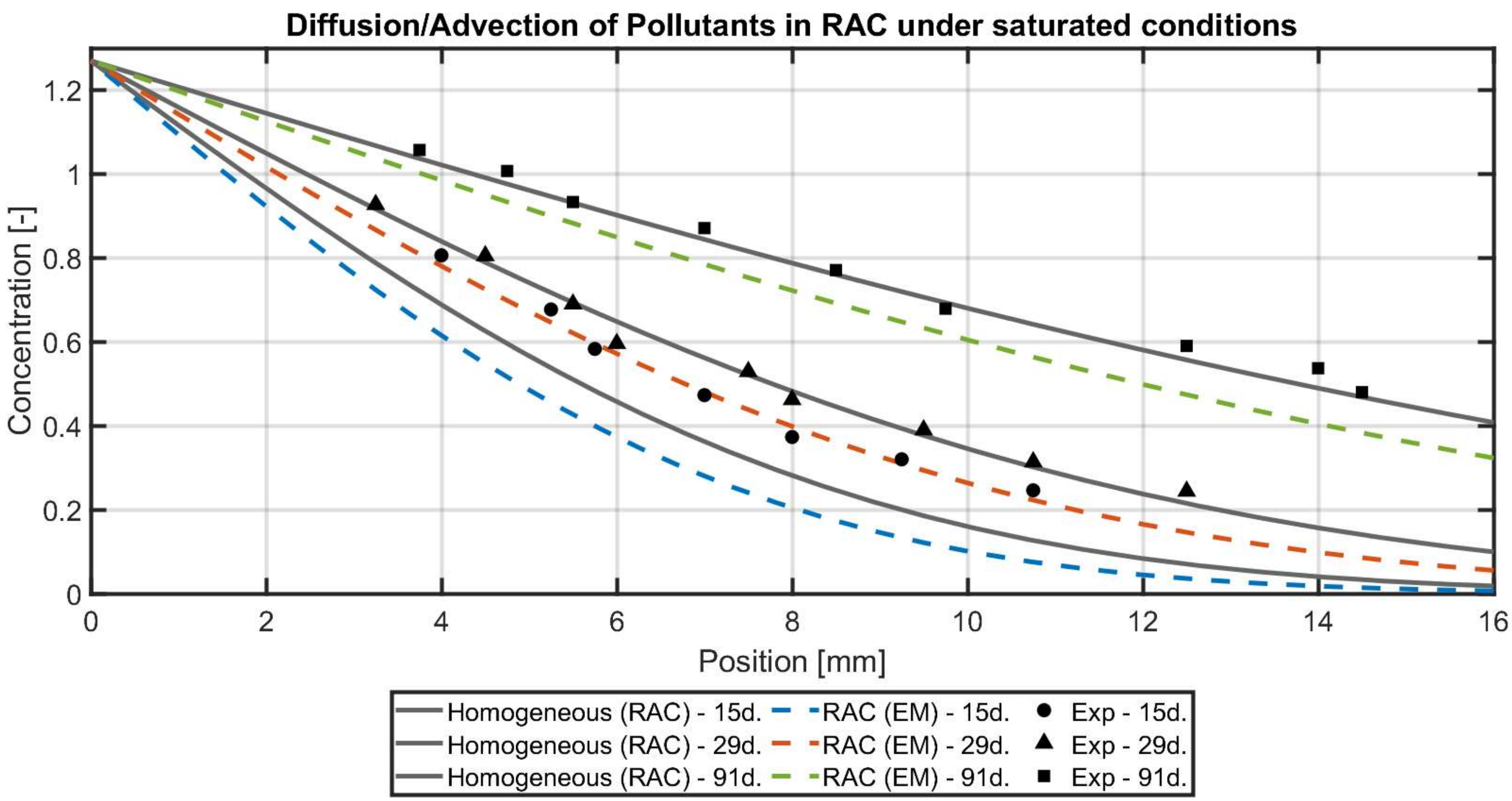

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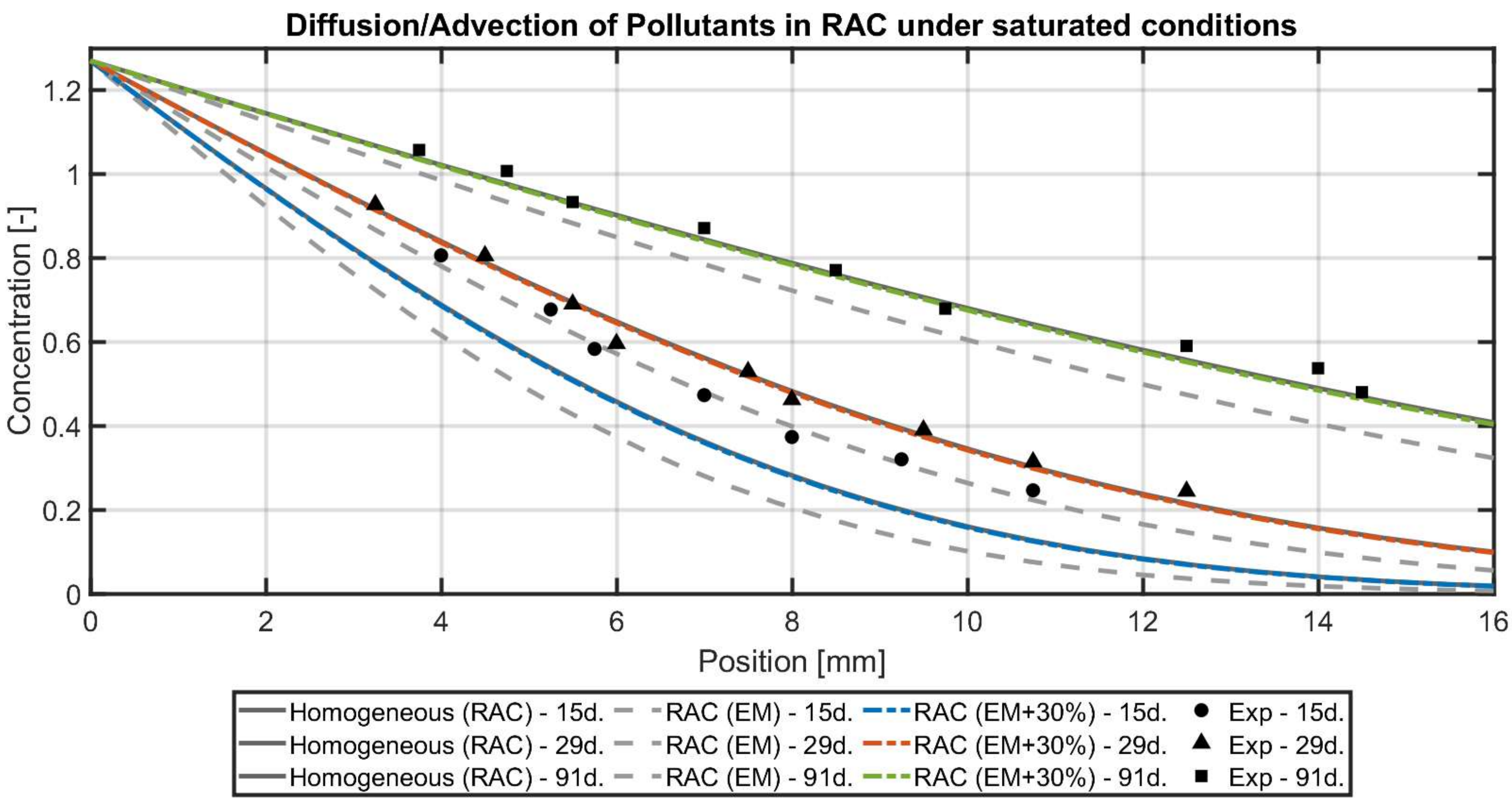

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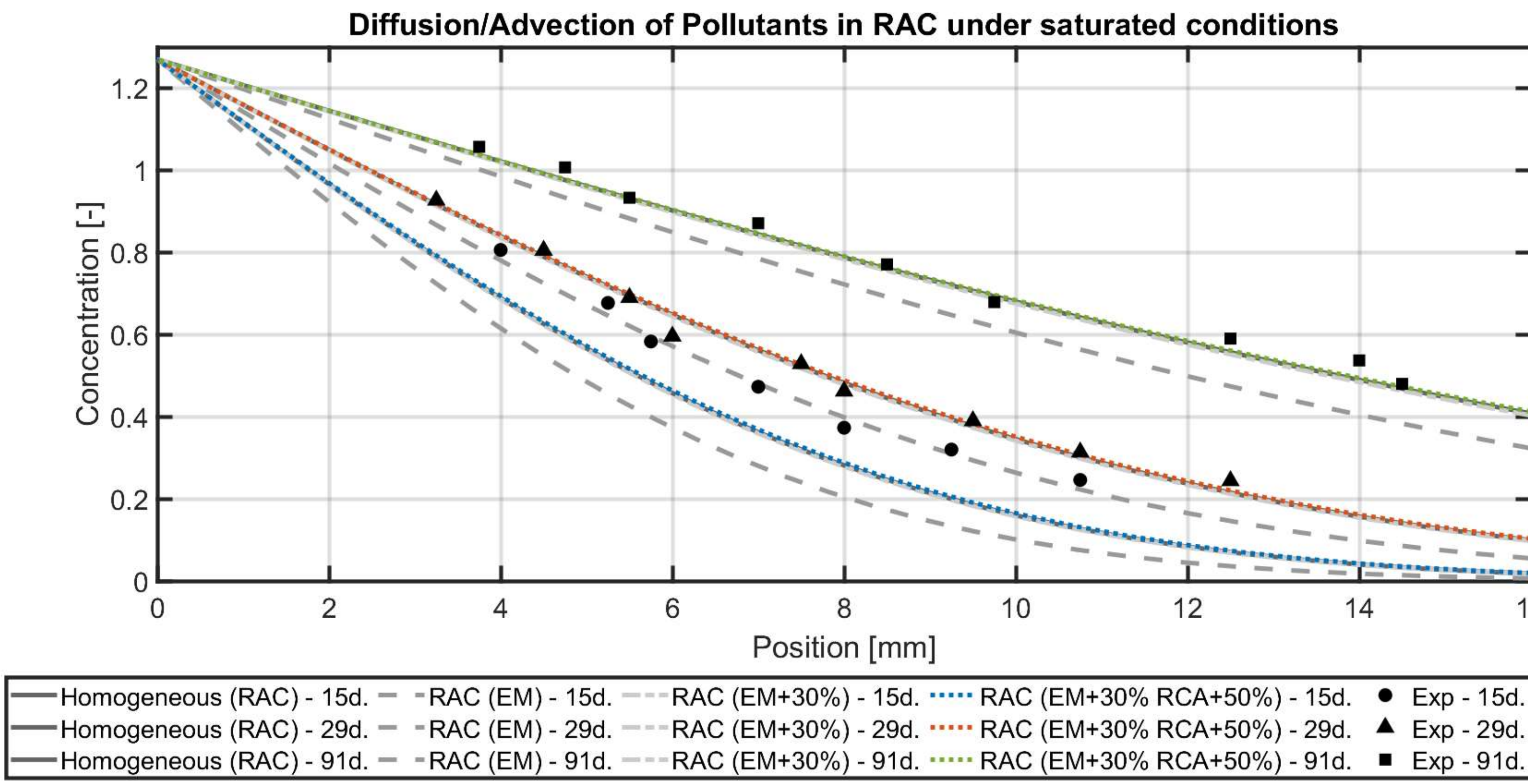

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Thank you for your attention.

This work is co-funded by the FNRS and the Wallonia Regional Government in the framework of a FRIA grant.

RVE: parameters/results

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- PSD: 2-4mm 48%, 4-5mm 22.9%, 5-6.3mm 20%, 6.3-8mm 9.1%
- SF: 41% Volume/Surface for both NAC and RAC (mix hypothesis)
- AR: between 1.5 and 2.5
- % Adherent mortar in RCA (+-5%) : 50% for 2-4mm, 45% for 4-5mm, 40% for 5-6.3mm, 35% for 6.3-8mm *[de Juan & Gutiérrez, 2009][Akbarnezhad et al.,2013][Florea & Brouwers, 2013].*

RVE: parameters/results

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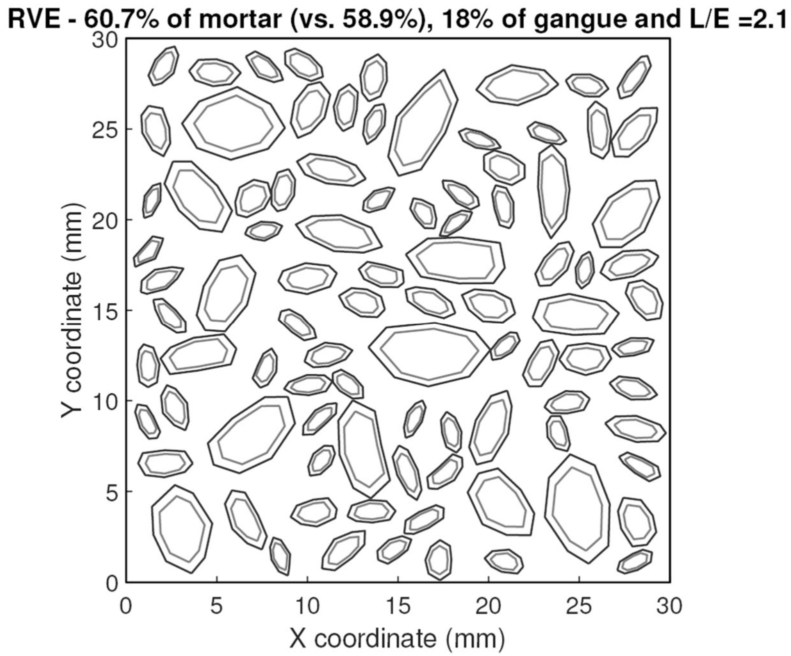
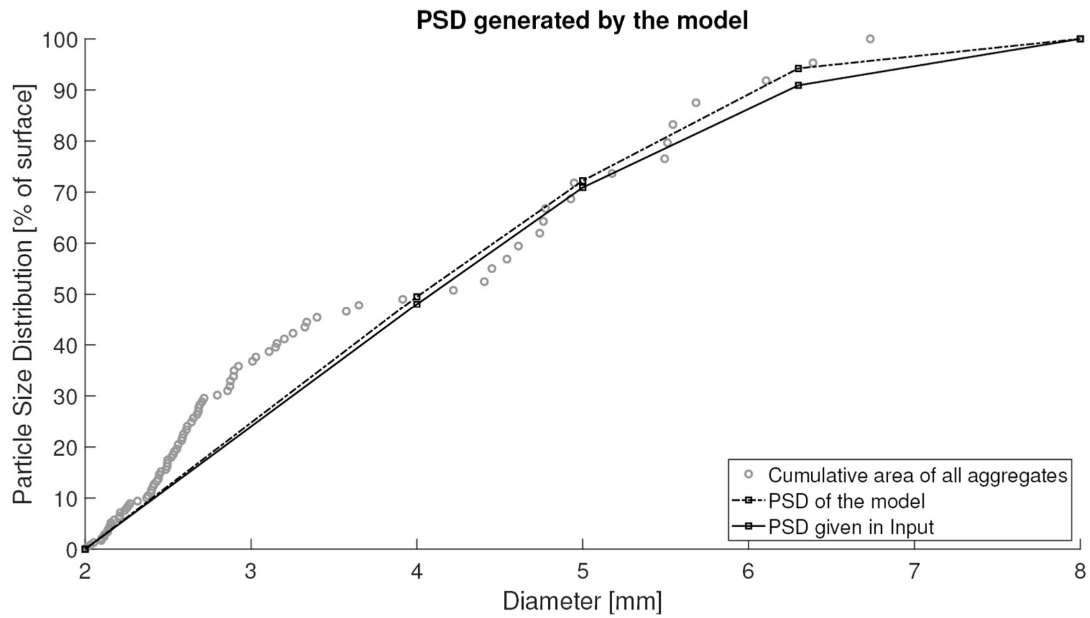
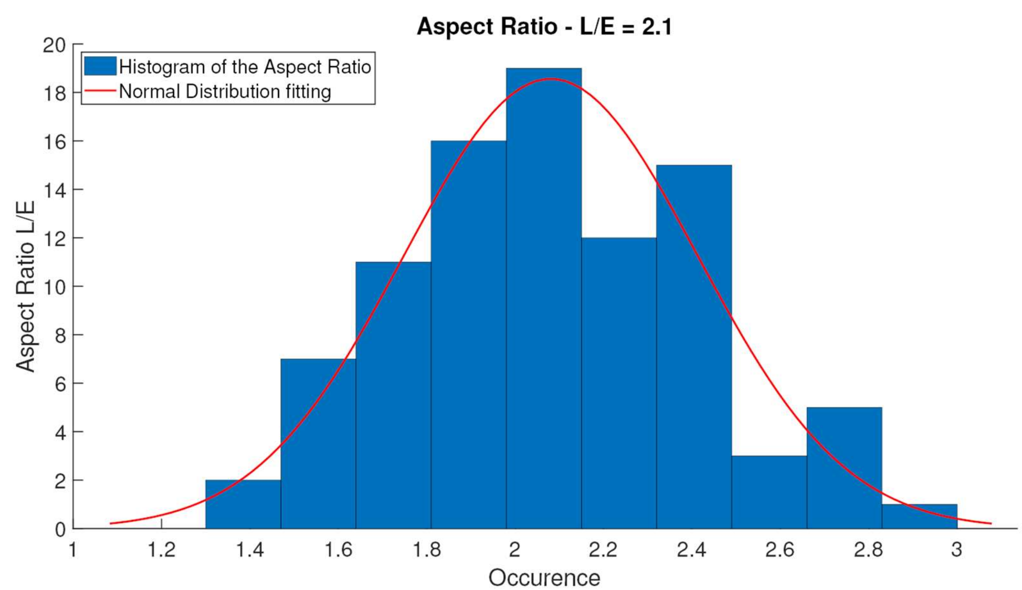
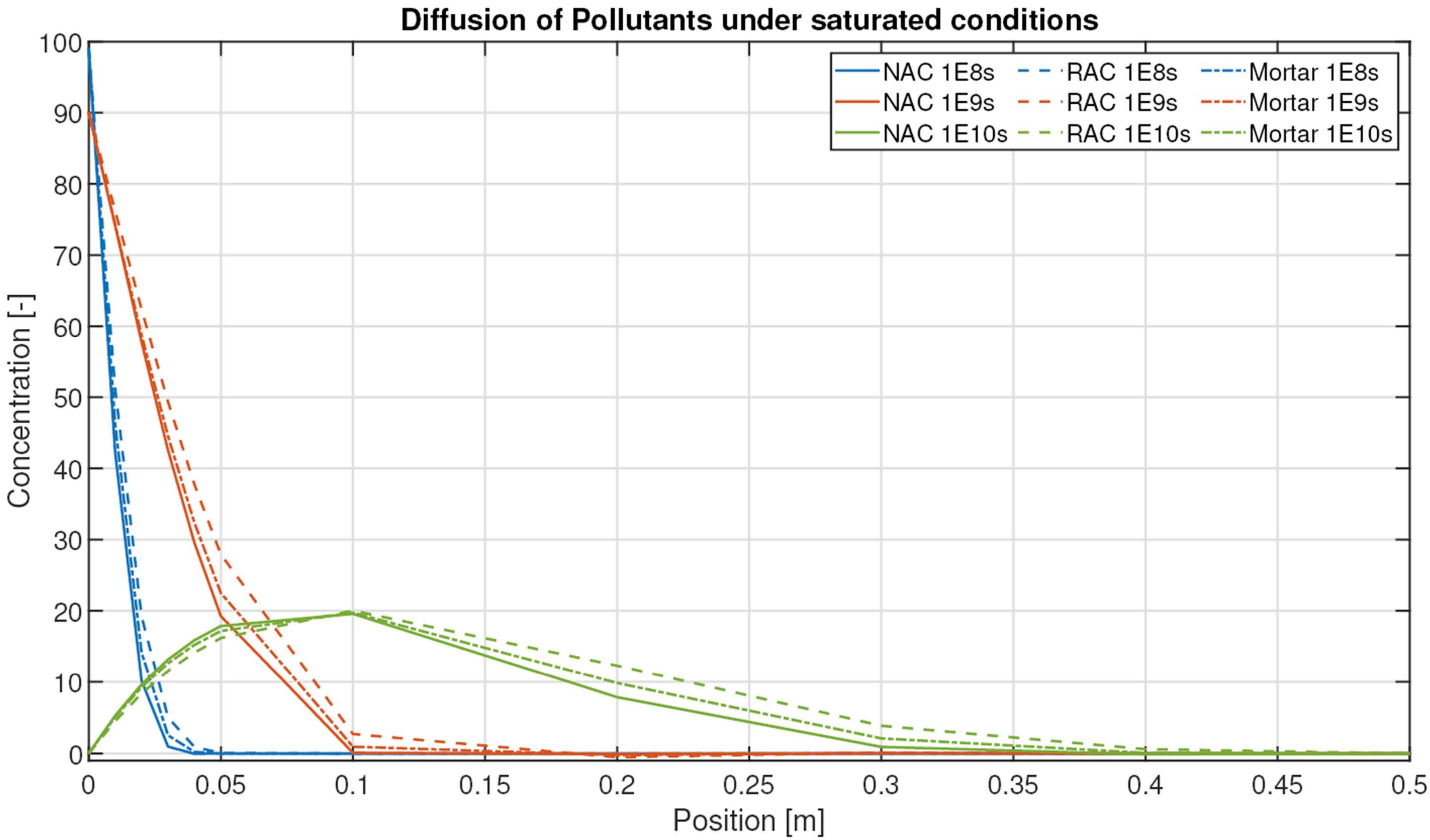






RVE: RCA influence



- Equal properties, except for RCA: 5x more diffusive

Analytical Validation

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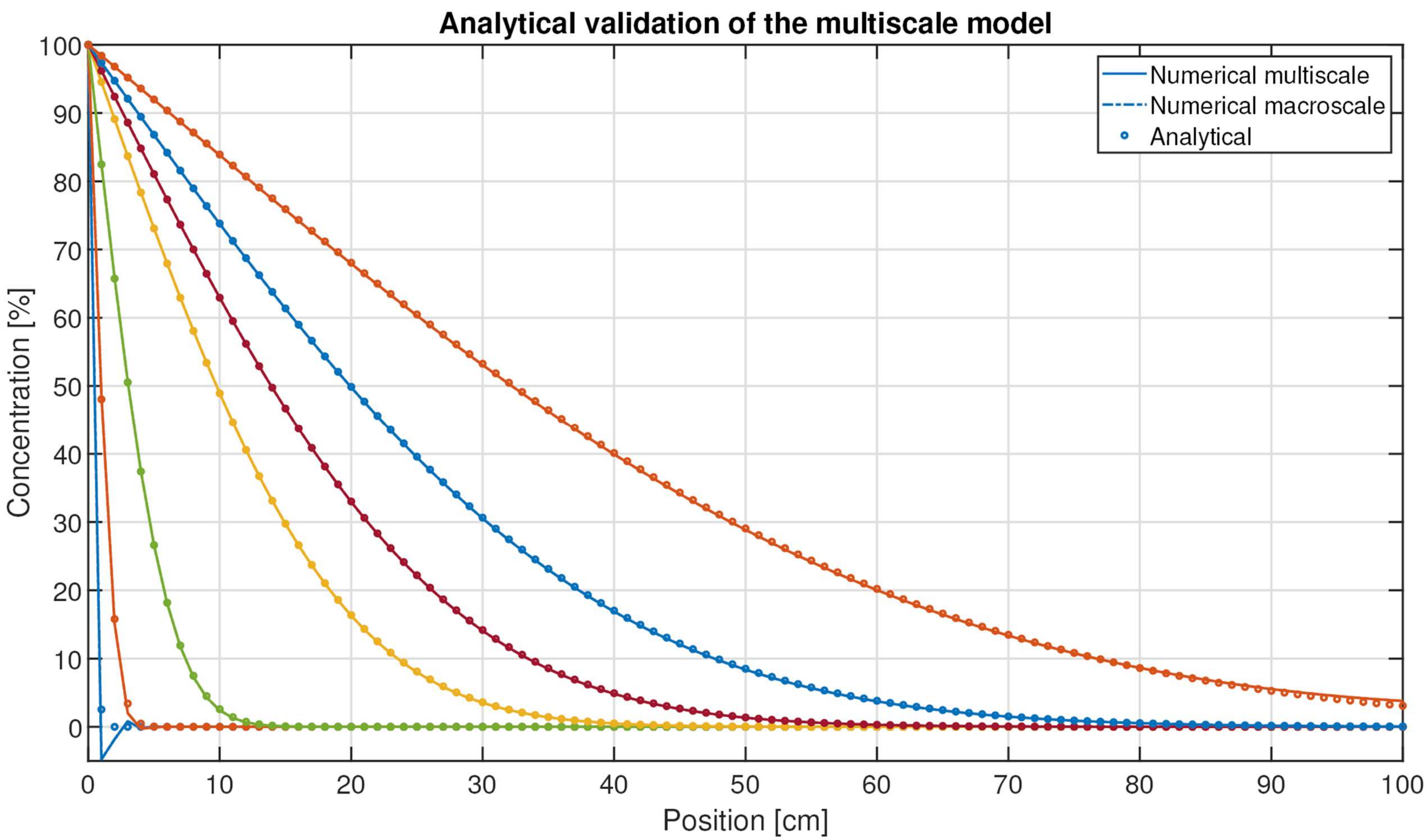
Analytical solution for a 1D semi-infinite medium [Biver,1993]:

$$C(x,t) = \frac{C_0}{2}\ \exp\left(\frac{ux}{2D}\right)\left[\exp\left(-x\frac{u}{2D}\right)\operatorname{erfc}\left(\frac{x}{2\sqrt{Dt}} - \sqrt{\frac{u^2t}{4D}}\right) + \exp\left(x\frac{u}{2D}\right)\operatorname{erfc}\left(\frac{x}{2\sqrt{Dt}} + \sqrt{\frac{u^2t}{4D}}\right)\right] \quad ($$



Case	C_0 [mg/ml]	D [cm^2/s]	u [cm/s]
$u \neq 0$	100	1E-8	4E-11

$$u = \frac{k_{int}}{\mu_w}\frac{\partial P_w}{\partial x} = \frac{10^{-19}}{10^{-3}}\frac{105325 - 101325}{1} = 4 * 10^{-11}\ \text{cm/s} \quad (4)$$

Experimental compositions

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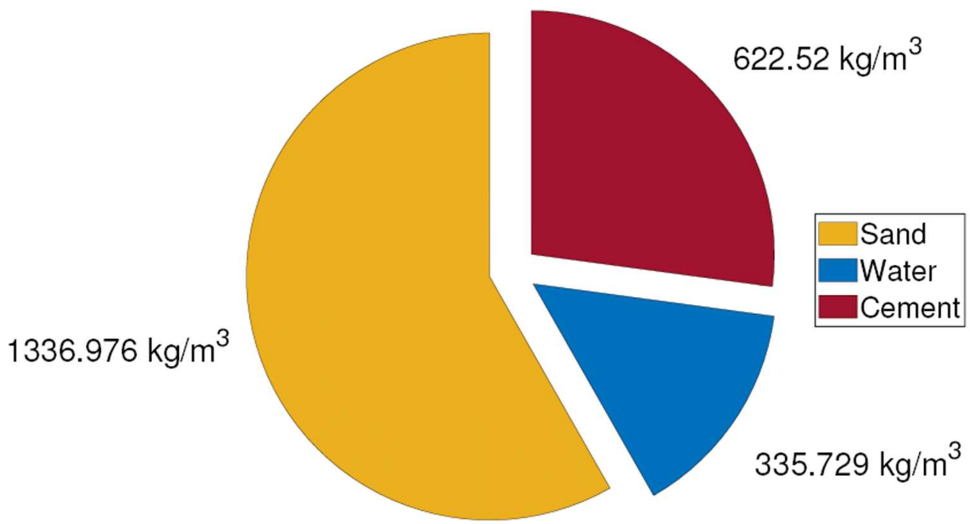
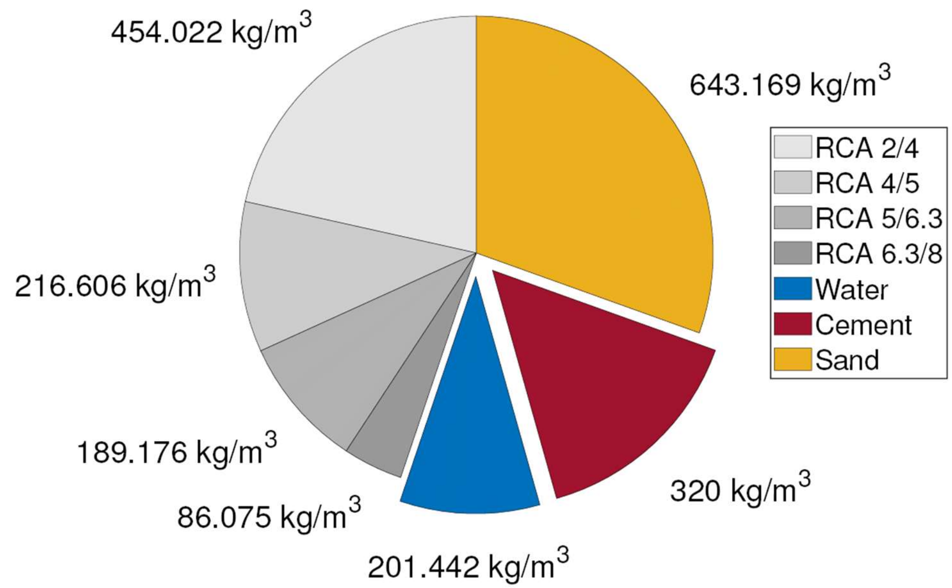
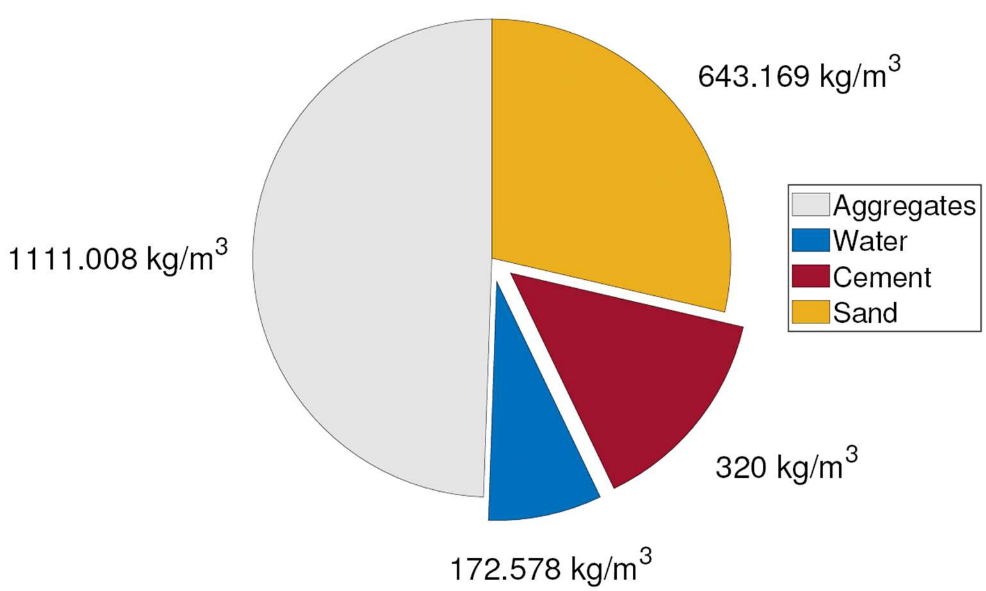
Composition of the E-M (W/C = 0.54)



Composition of the RAC (W/C = 0.63)



Composition of the NAC (W/C = 0.54)



Experimental results

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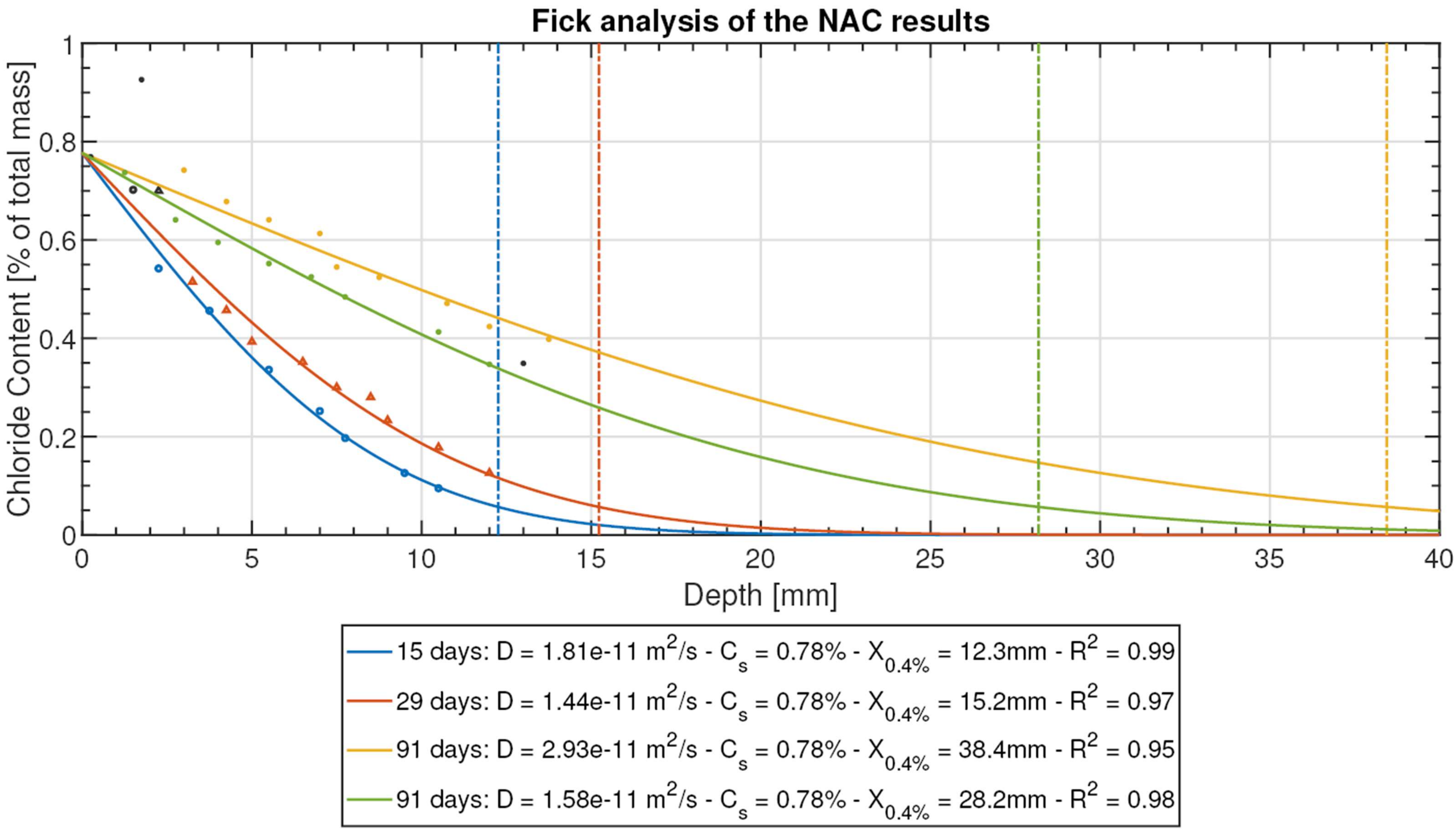
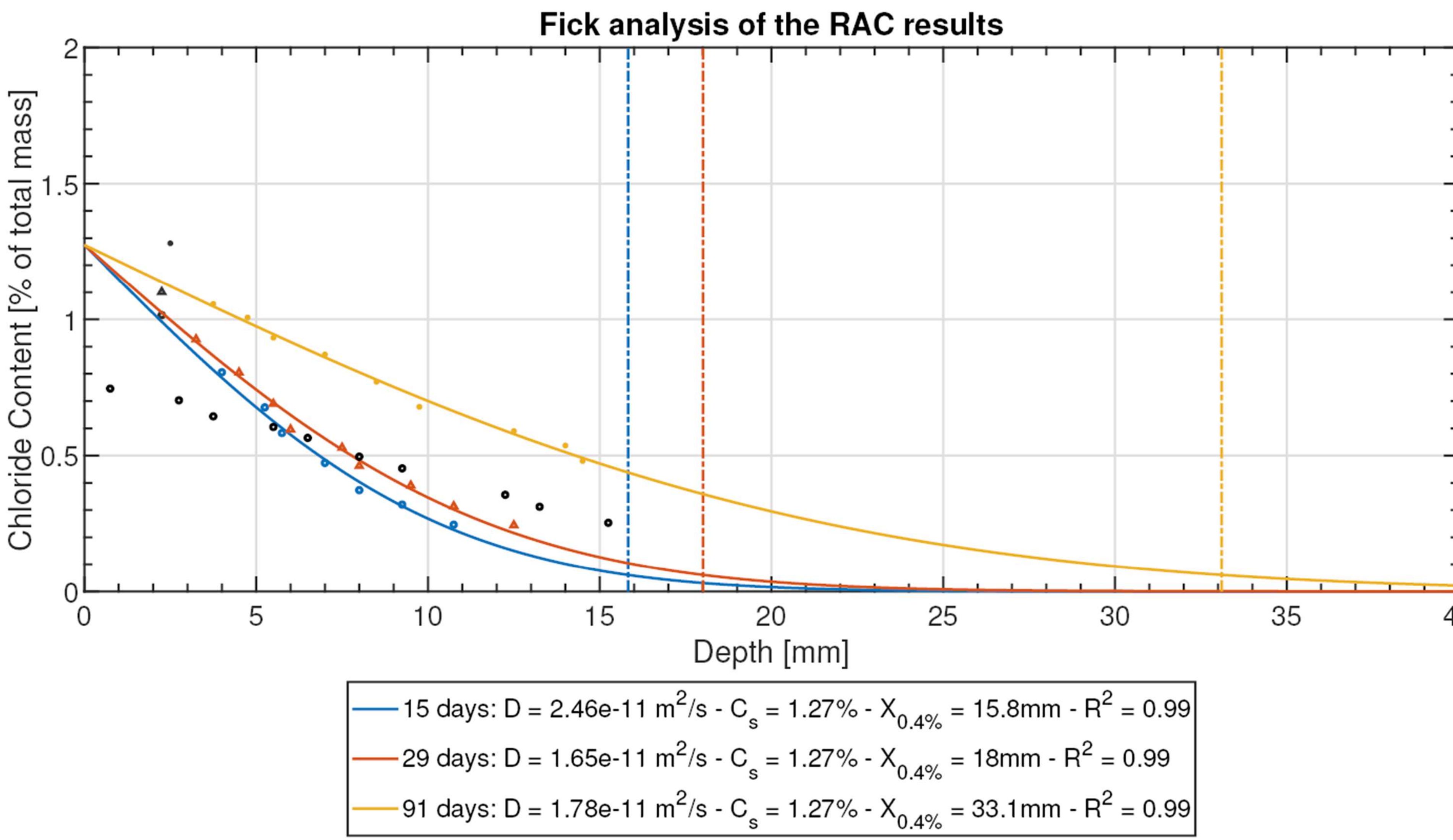


Experimental results



Corrosion process

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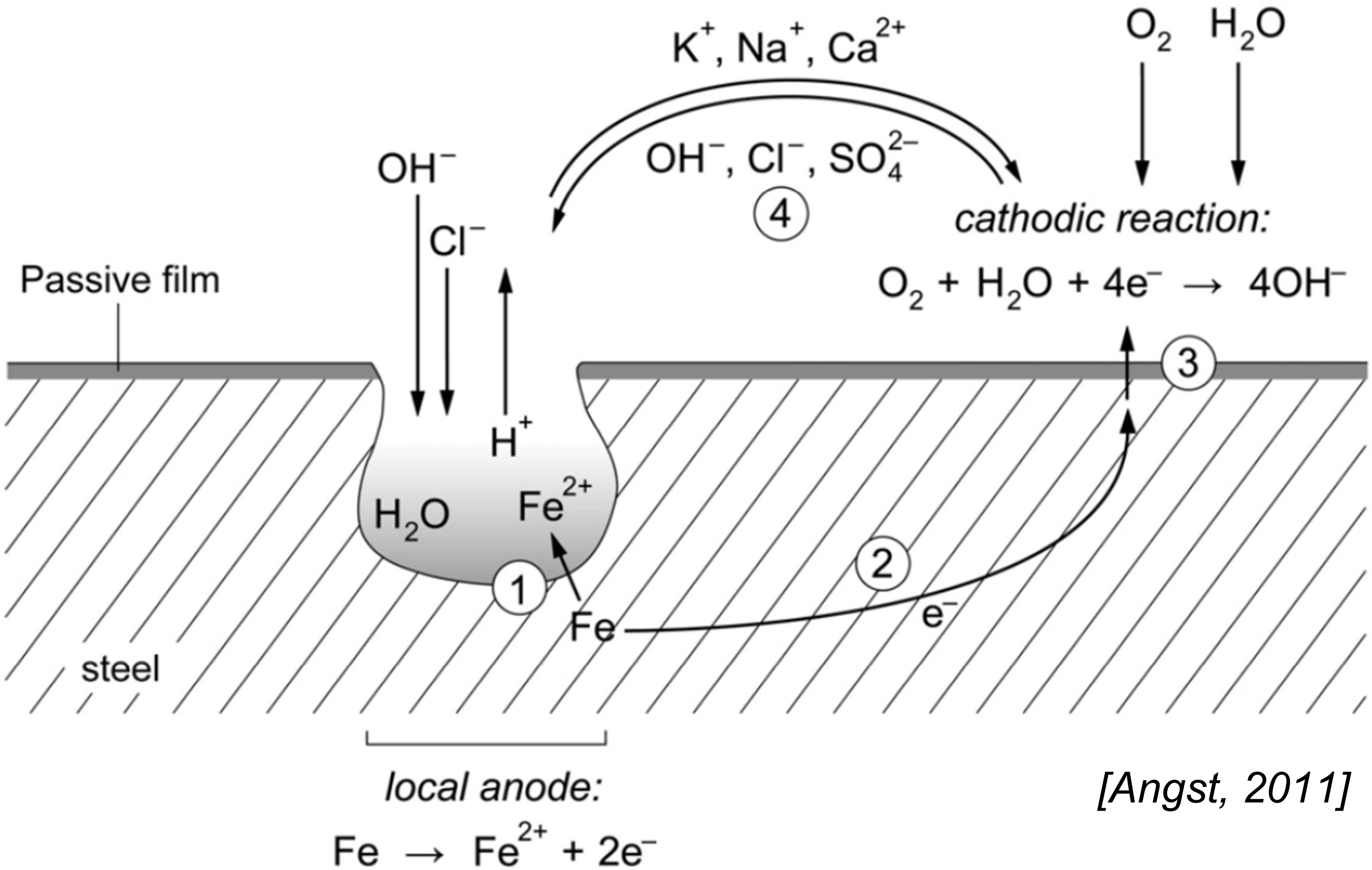

[Angst, 2011]

Chloride threshold

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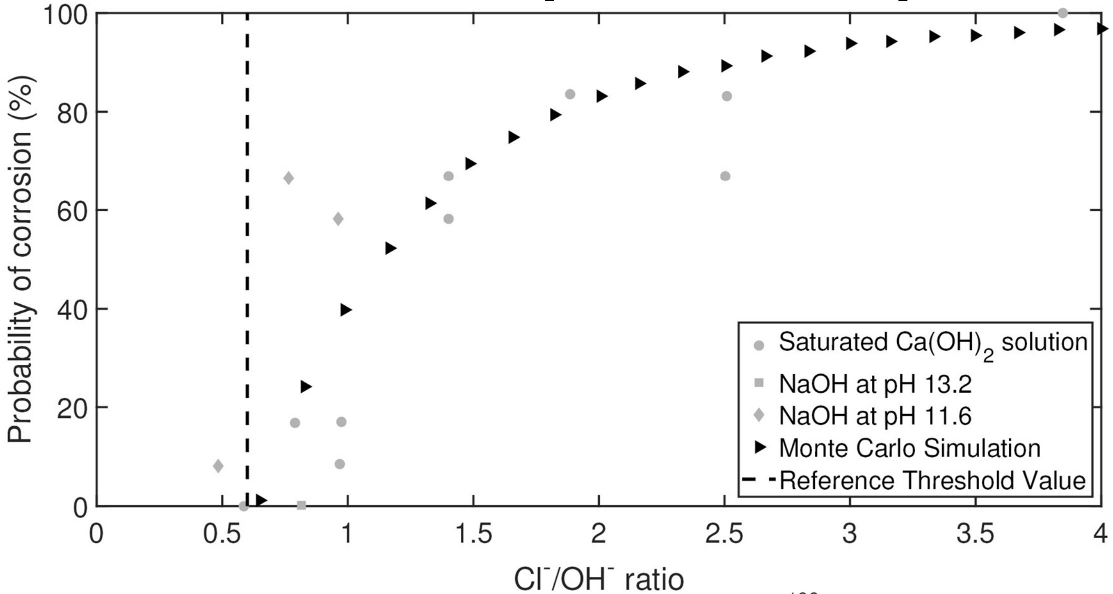
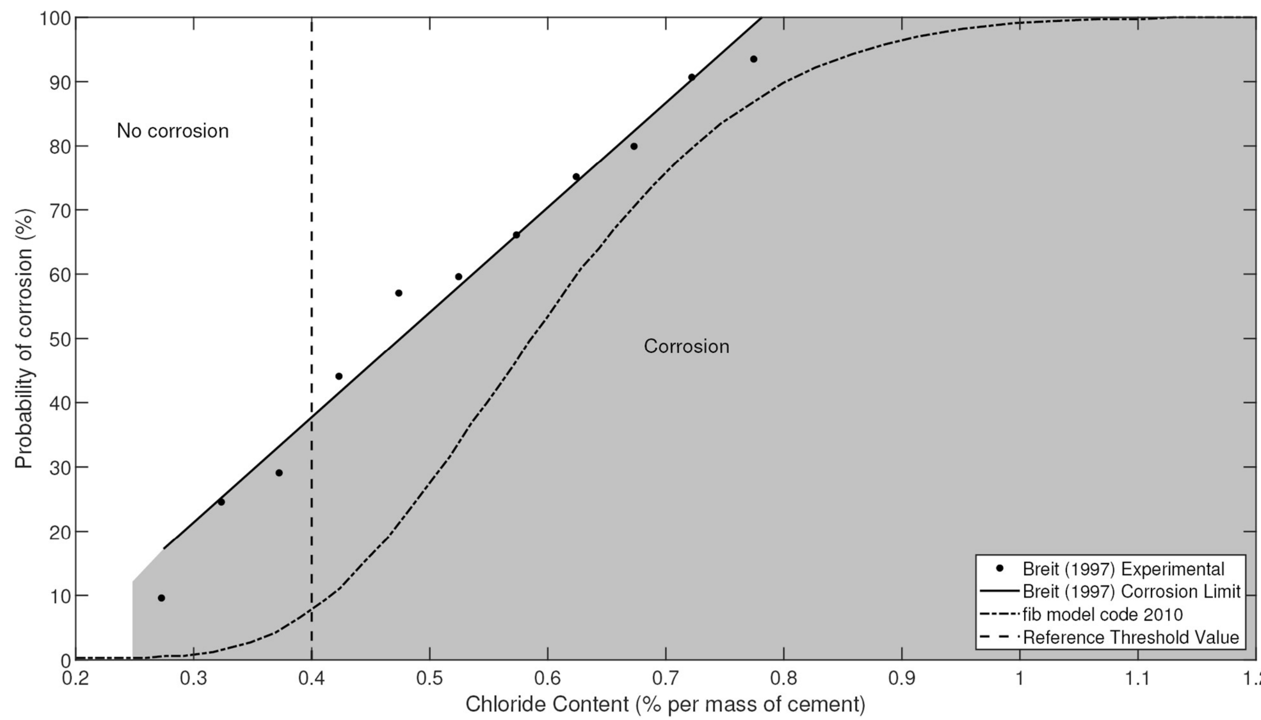
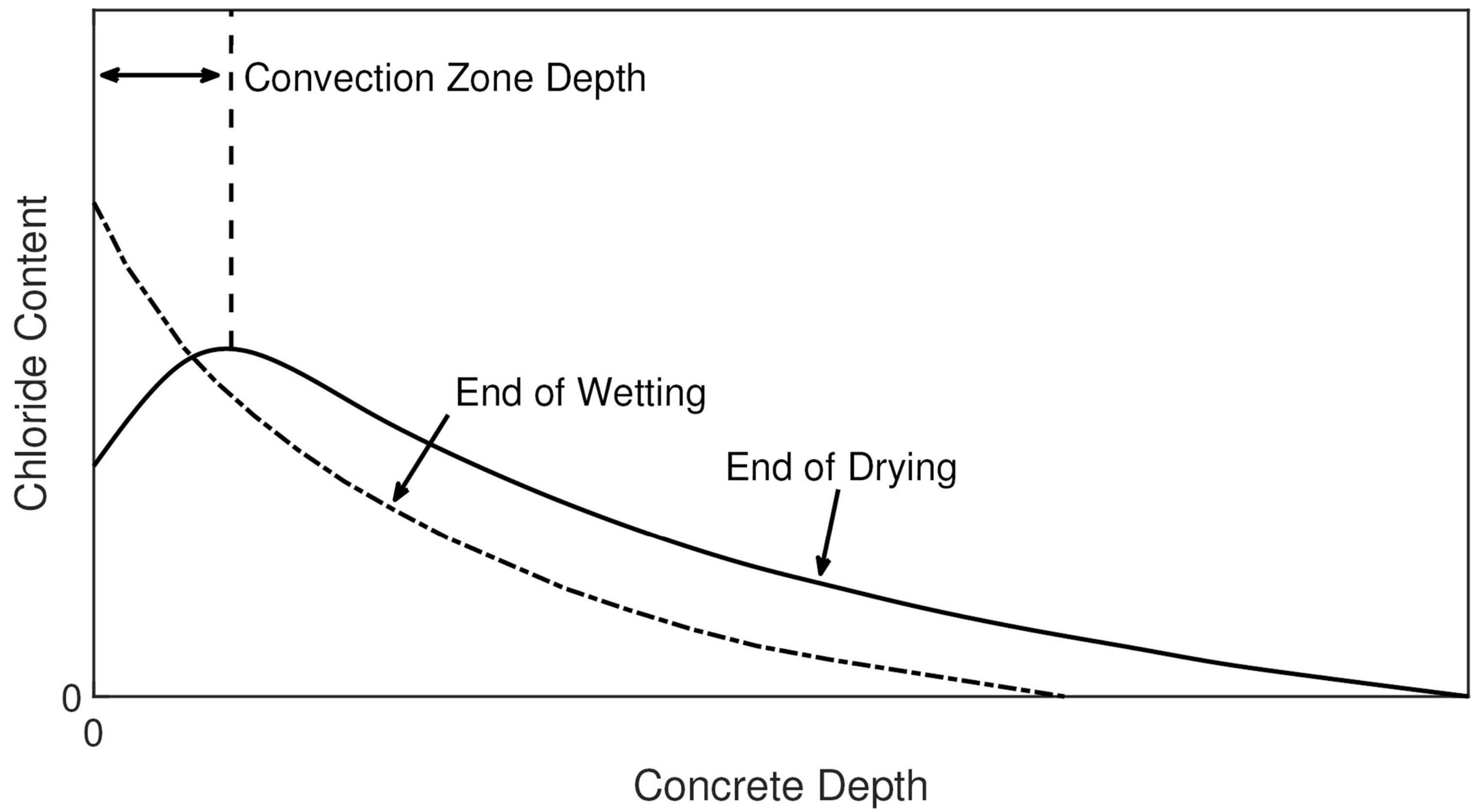
[Broomfield, 2007]



[Raupach & Büttner, 2014]



Influence of convection



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