Modelling of Chloride Diffusion in RAC

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Why recycling concrete

About 70 million tonnes of demolition construction wastes is produced annually in the UK, but only 10% is converted into aggregate

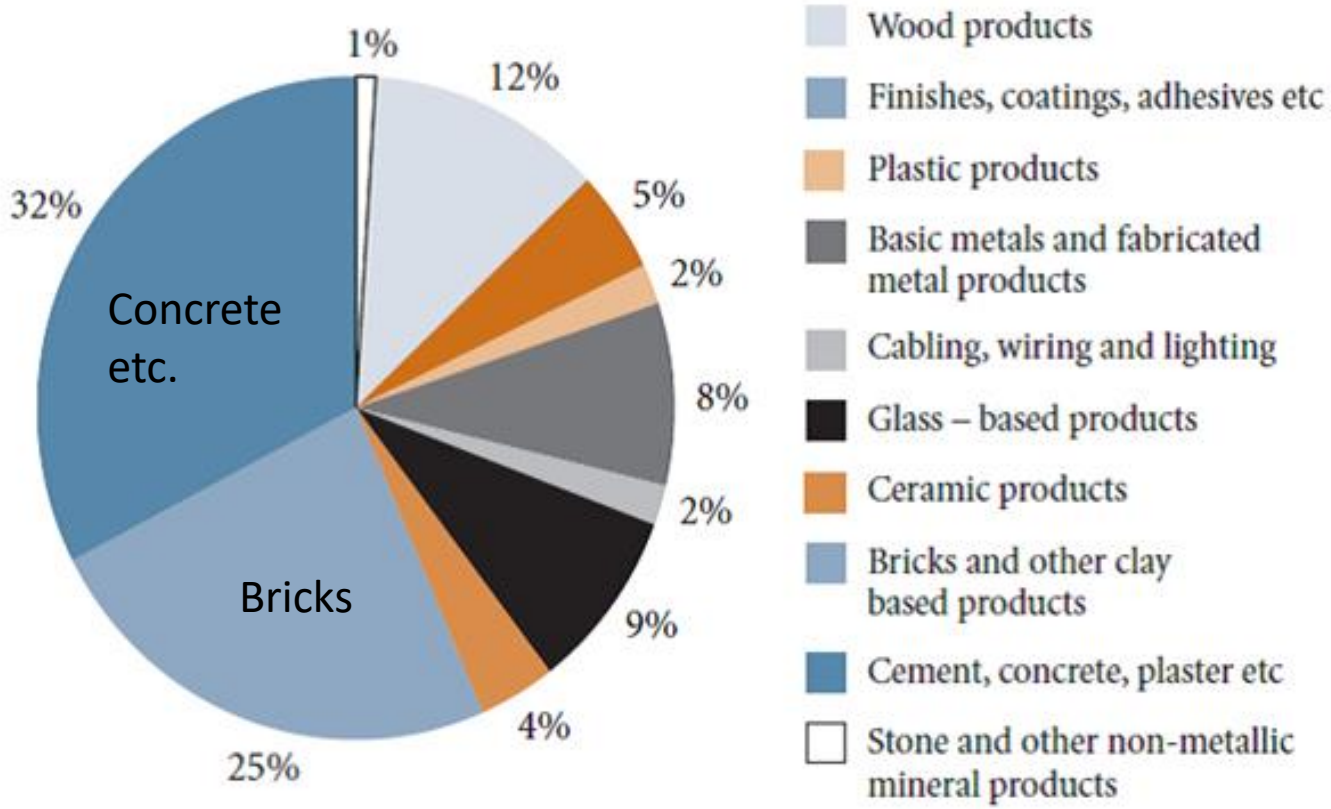


Figure: Wastes from construction materials in the UK (sourced from ORBEE)

Types of recycled aggregate

- Recycled concrete aggregate (RCA) derived from crushed concrete
- Recycled masonry aggregate (RMA) derived from masonry rubble
- Mixed recycled aggregate (MRA), which is the mixture of RCA and RMA, and
- Construction and demolition recycled aggregate (CDRA), which is unsorted RA containing high content of contaminants such as glass, timber and plastics.

Weakness of RCA

- Higher water absorption capacity
- Lower density
- Lower Los Angeles abrasion coefficient
- Higher ITZs volume fractions
- Chemical contaminants

Mixing of NAC and RAC

Cement

Sand

Water

Aggregates

Natural Aggregate Concrete

Cement

Sand

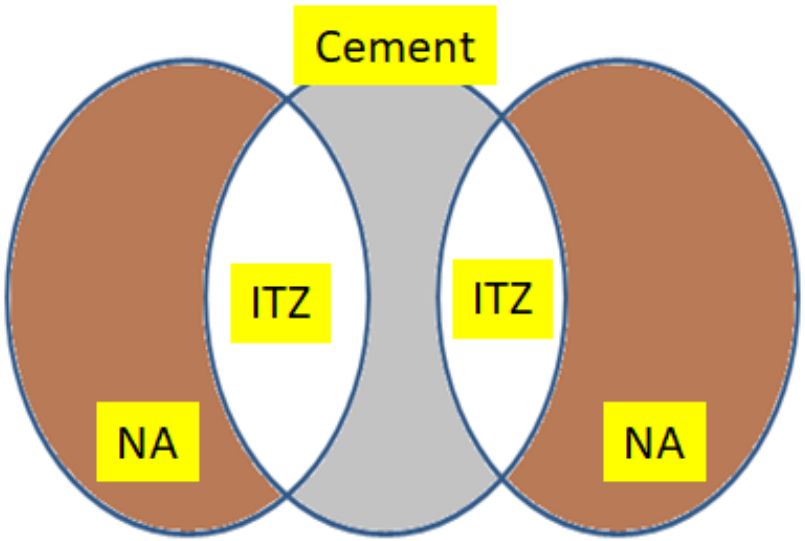
Water

Aggregates

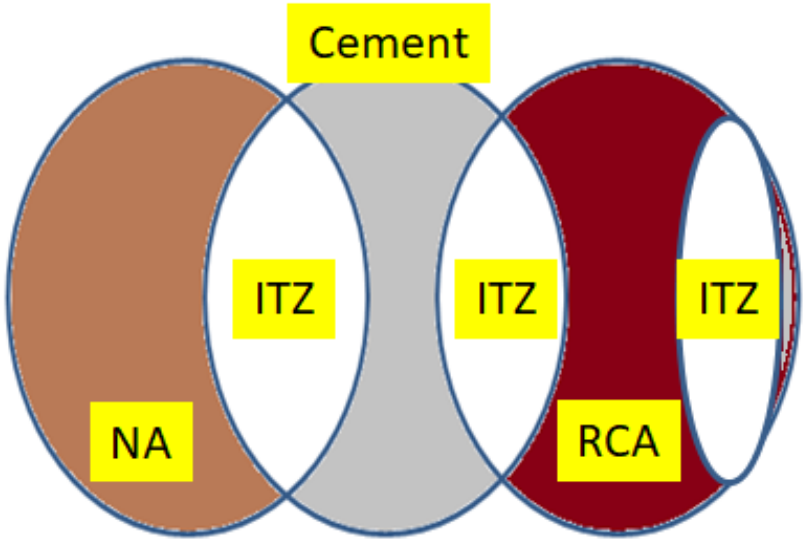
RCA

Recycled Aggregate Concrete

Microstructure of NAC and RAC

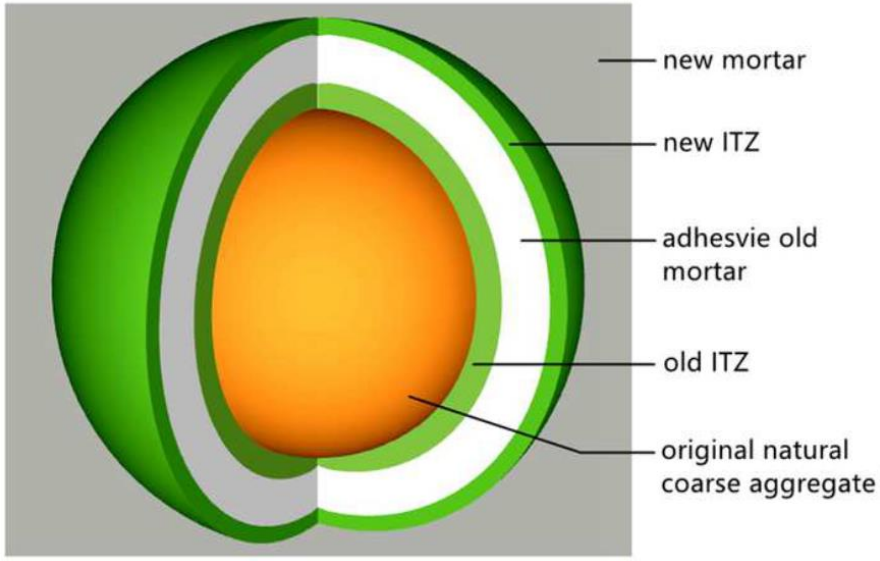


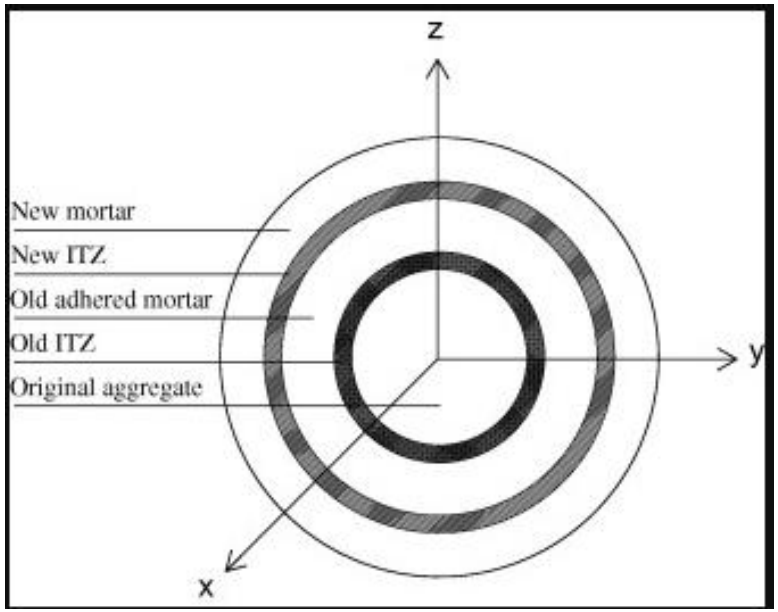
Natural aggregate concrete

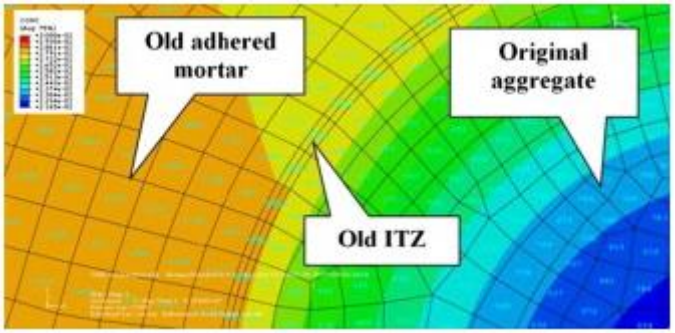


Recycled aggregate concrete

Phases in RAC (coarse RCA)







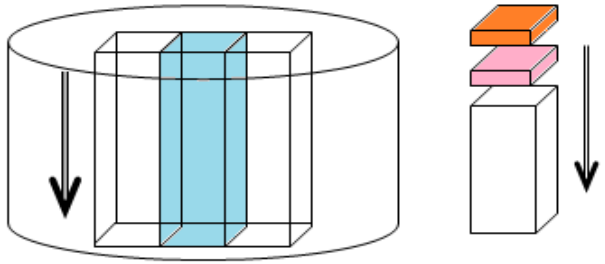
Volumetric fraction of old adhered mortar in RCA is not known !!!

Chloride diffusion in RAC

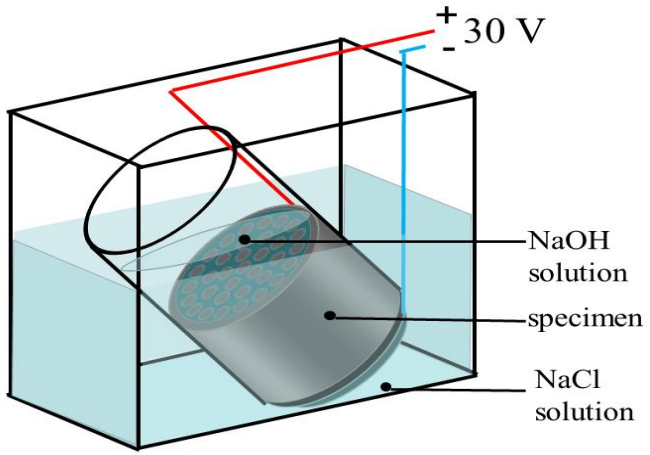
- Experimental method
- Numerical method
- Approximate model

Experiment of chloride diffusion

- Transient state tests
  - *Ponding test (Fick 2nd law,* measure concentration*)*
  - *RCM test (Nernst-Planck Eq., measure penetration depth)*



$$C(x,t) = C_s erfc\left(\frac{x}{2\sqrt{Dt}}\right)$$

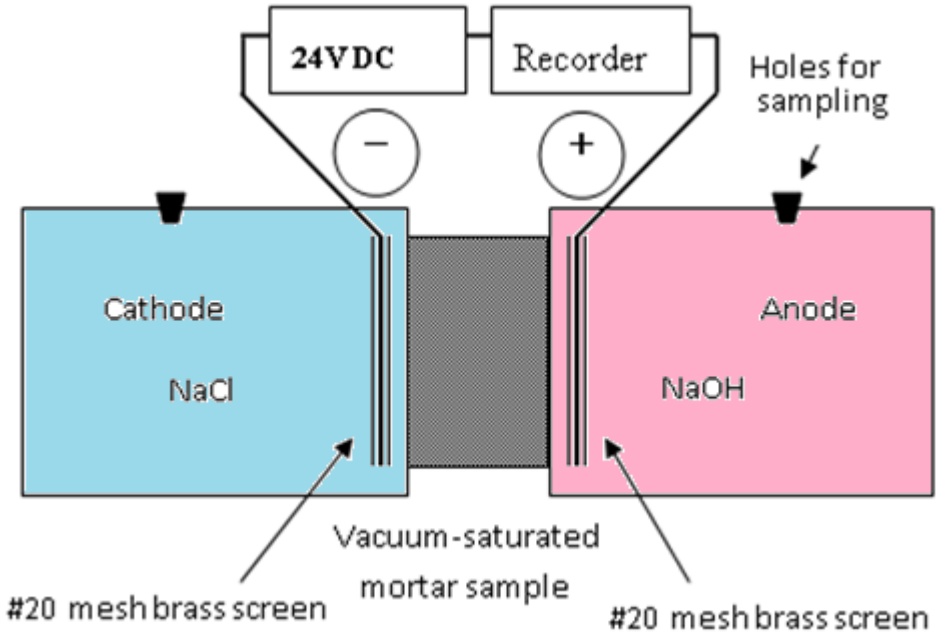


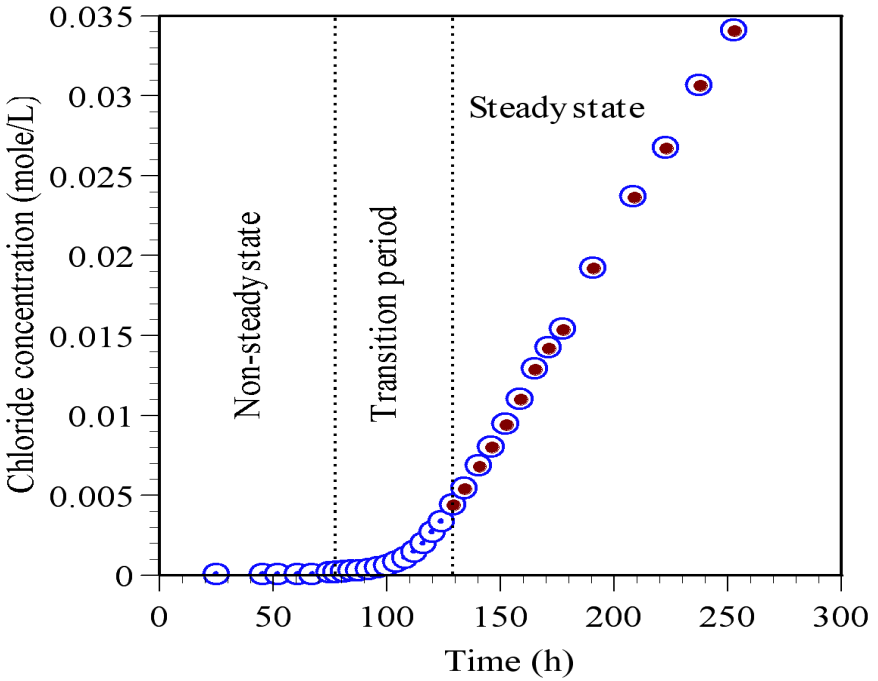
→ They cannot be applied if RCA contains chlorides. Normally test paste or mortar, not concrete !!!

Experiment of chloride diffusion (cont.)

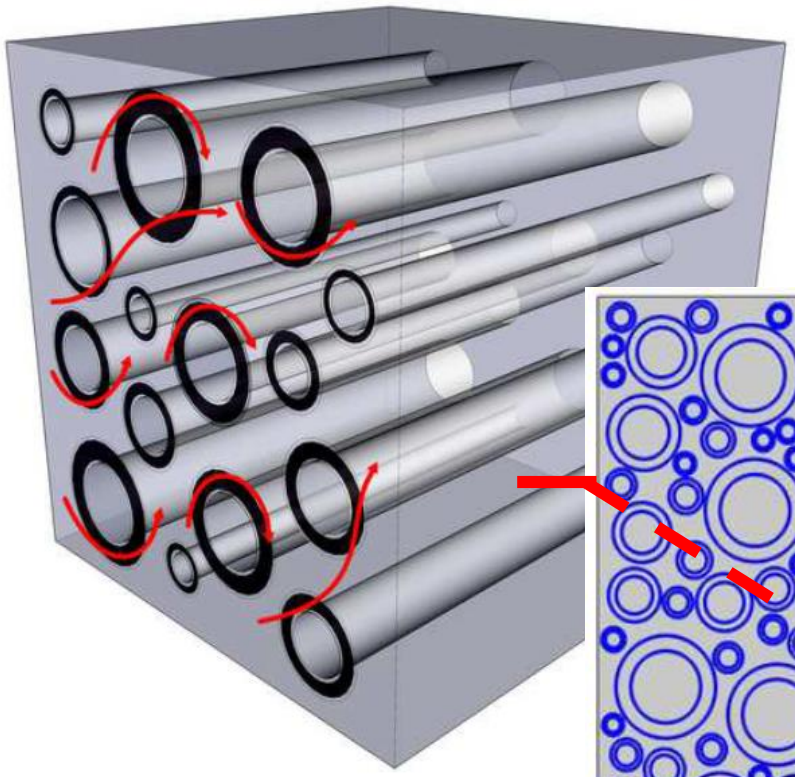
- Steady state tests (measure flux)
  - *Diffusion (Fick 1st law)*
  - *Migration (Nernst-Planck Eq.)*

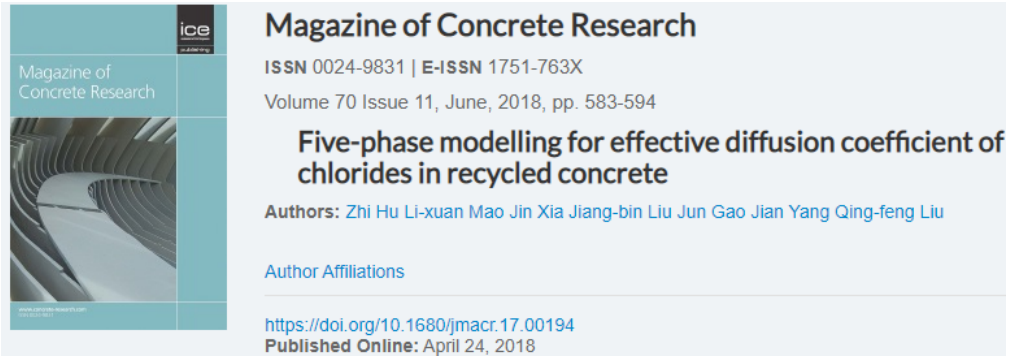
$$J = -D_{eff}\left(\nabla C - \frac{CF}{RT}\nabla\Phi\right)$$
$$= D_{eff}\frac{CF}{RT}\nabla\Phi$$





Five-phase diffusion model of RAC





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Five-phase modelling for effective diffusion coefficient of chlorides in recycled concrete

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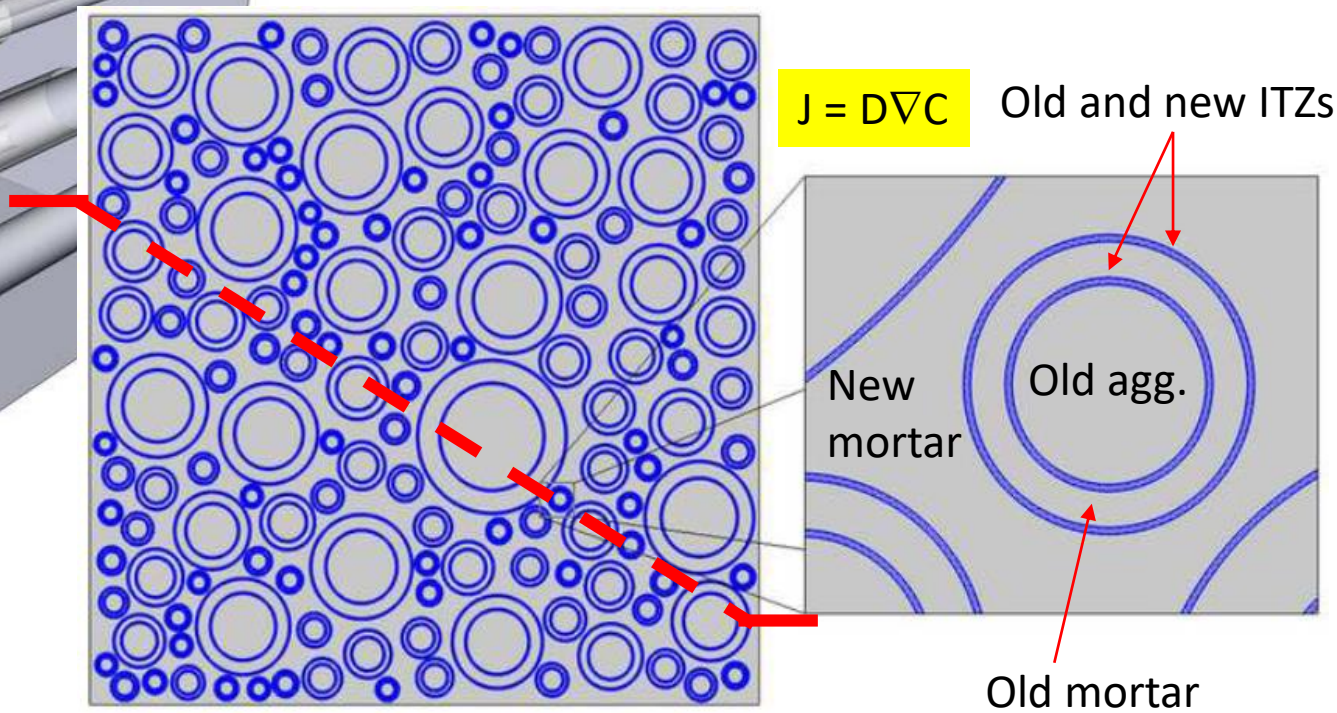
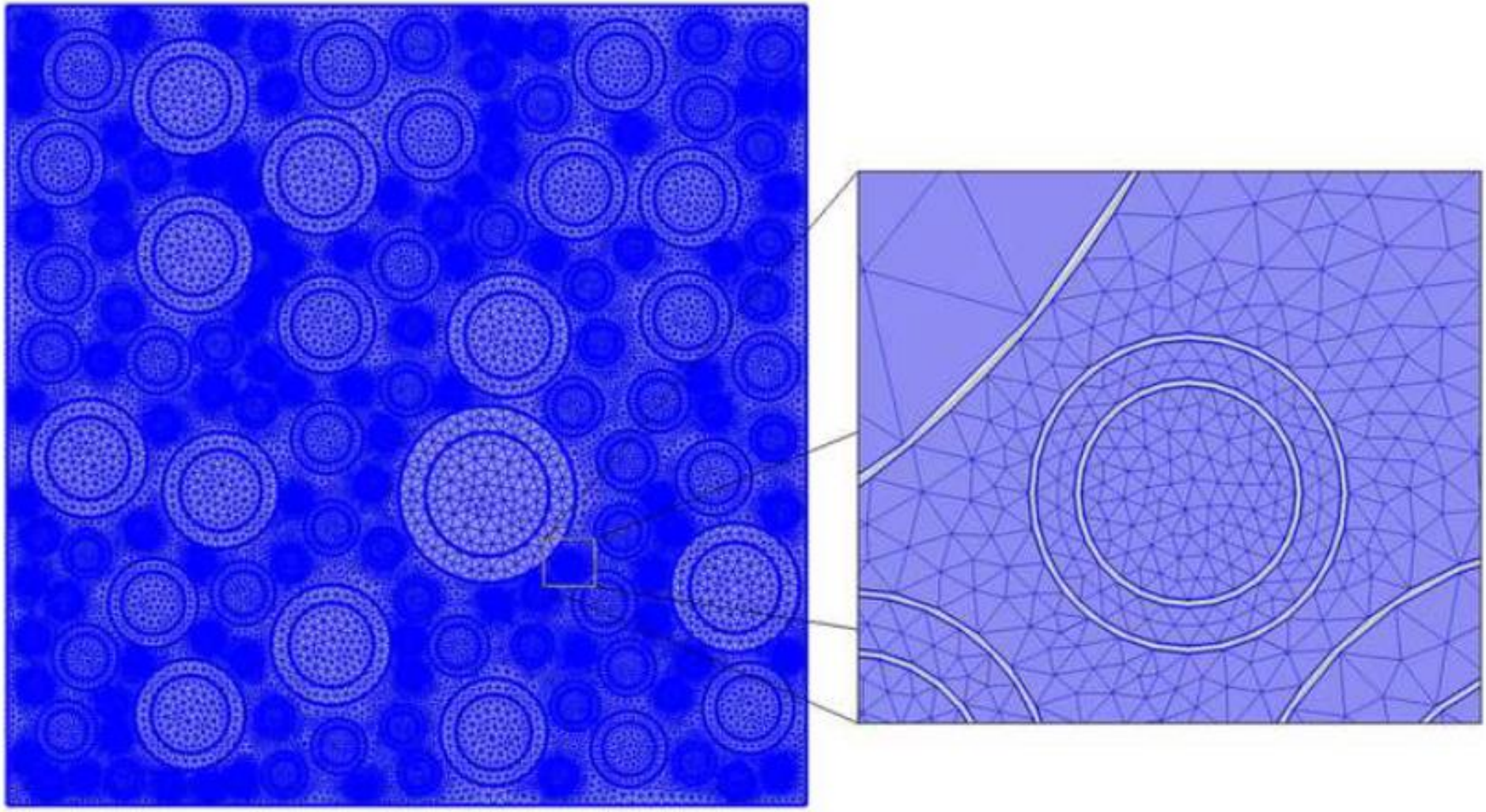
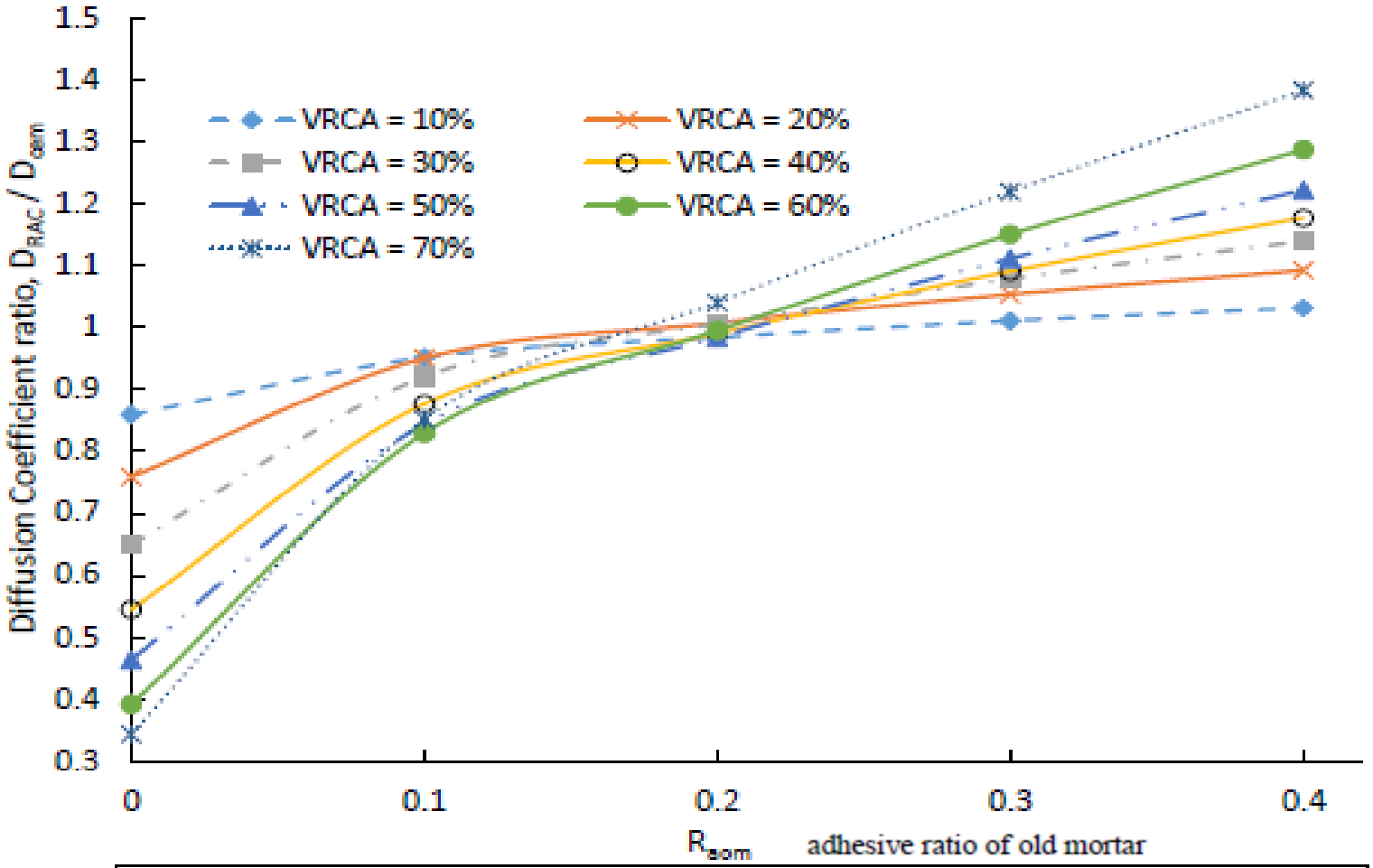


Finite element mesh

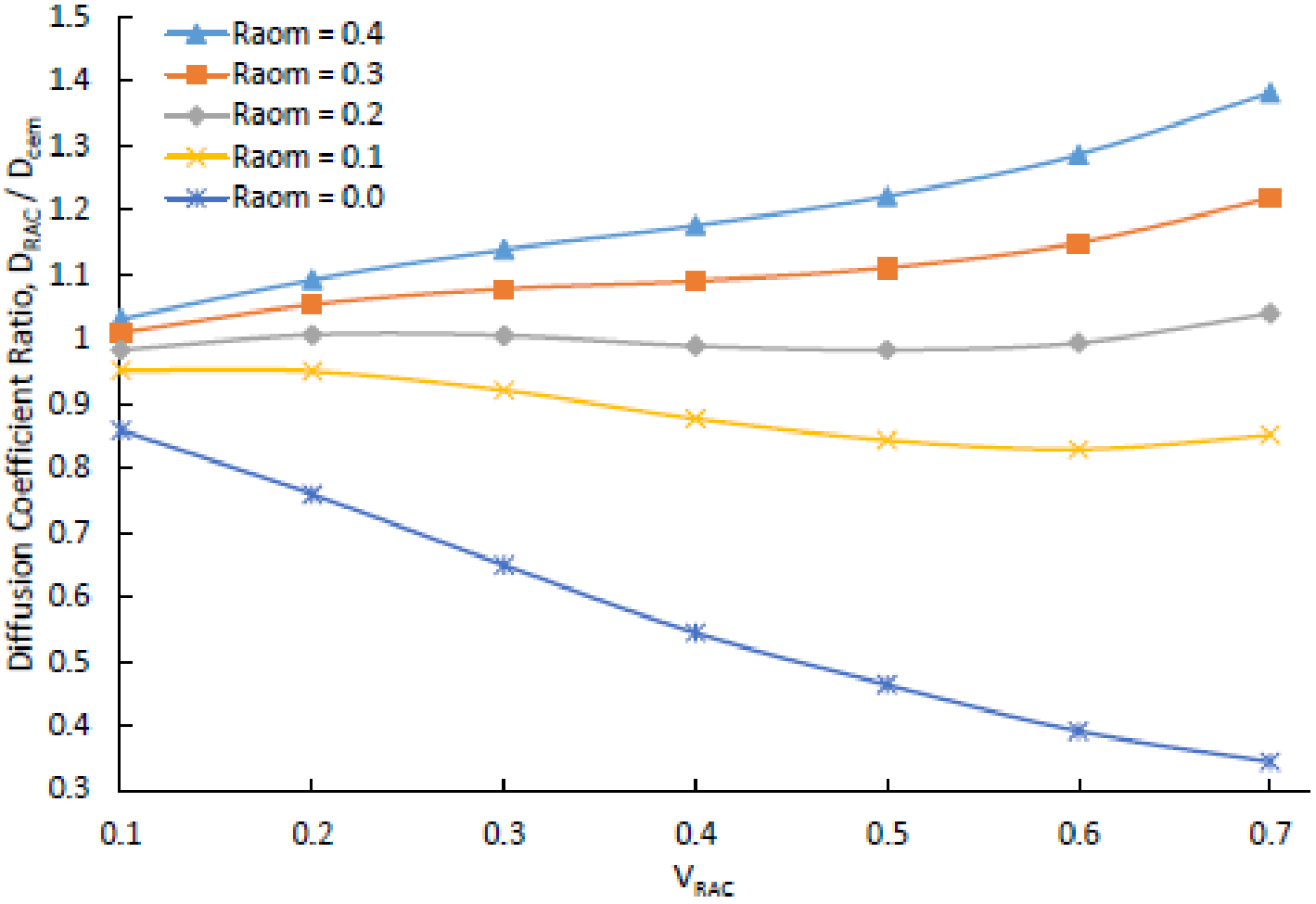


FEA results



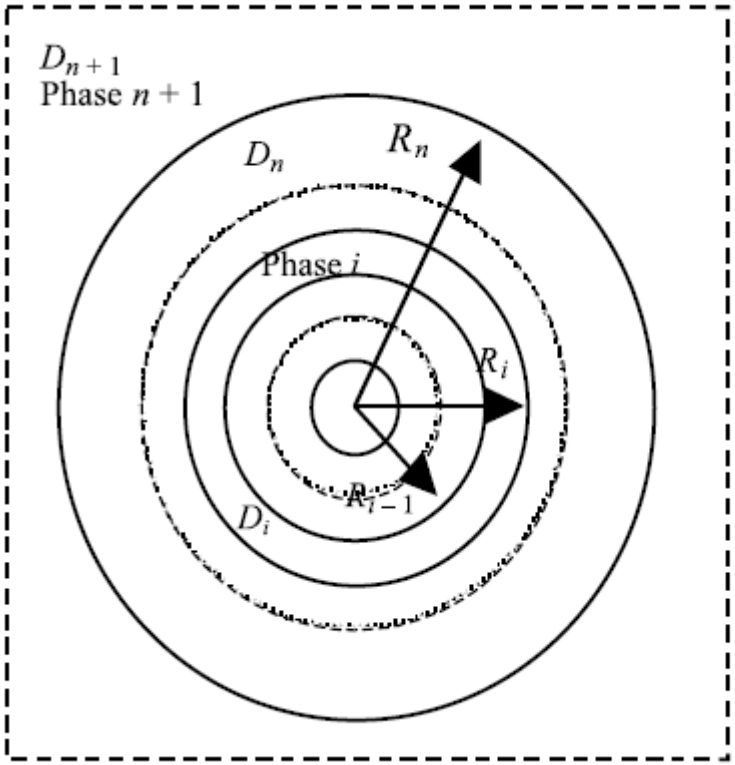
T_{ITZ} = 40 μm; $D_{new,mor}$ = 2x10^{-6} mm^2/s; $M_1 = D_{old,mor} / D_{new,mor}$ = 2; $M_2 = D_{new,ITZ} / D_{new,mor} = D_{old,ITZ} / D_{old,mor}$ = 10; D_{agg} = 1x10^{-12} mm^2/s

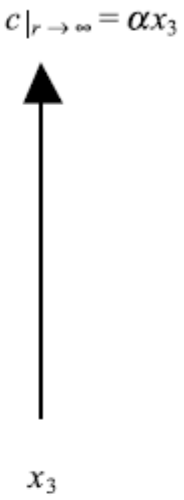
FEA results (cont.)



T_{ITZ} = 40 μm; $D_{new,mor}$ = 2x10^{-6} mm^2/s; M_1 = $D_{old,mor}$ / $D_{new,mor}$ = 2; M_2 = $D_{new,ITZ}$ / $D_{new,mor}$ = $D_{old,ITZ}$ / $D_{old,mor}$ = 10; D_{agg} = 1x10^{-12} mm^2/s

Approximate method – spherical model



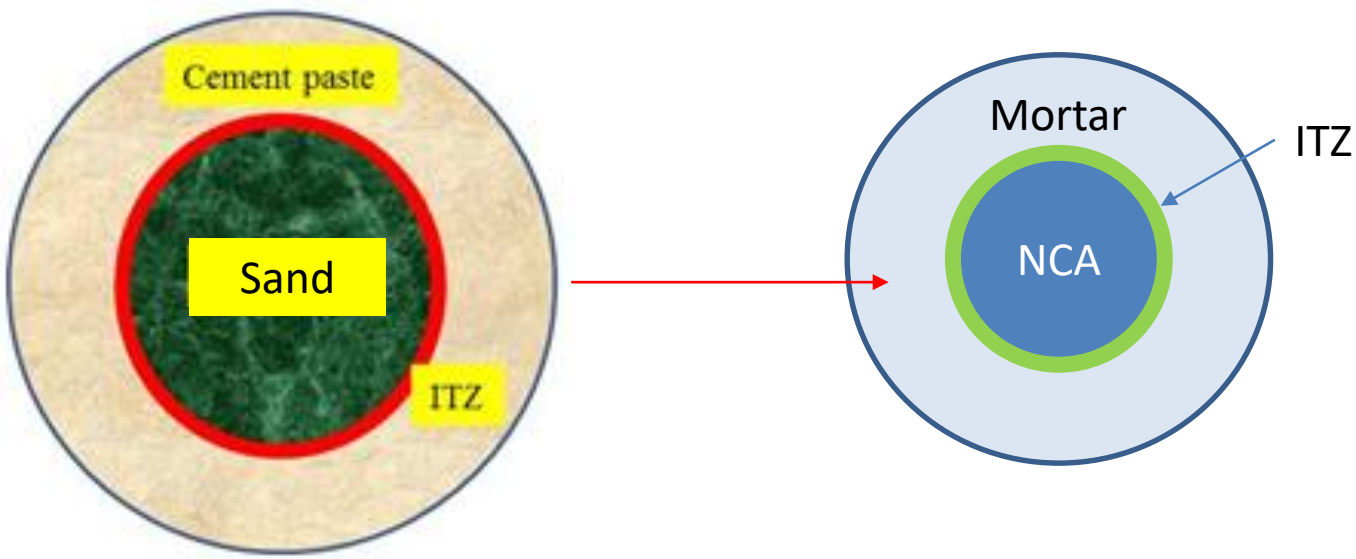


$$D^{\text{eff}}_{(1)} = D_1$$

$$D^{\text{eff}}_{(i)} = D_i + \frac{D_i(R^3_{i-1}/R^3_i)}{(D_i/(D^{\text{eff}}_{(i-1)} - D_i)) + (1/3)((R^3_i - R^3_{i-1})/R^3_i)}$$

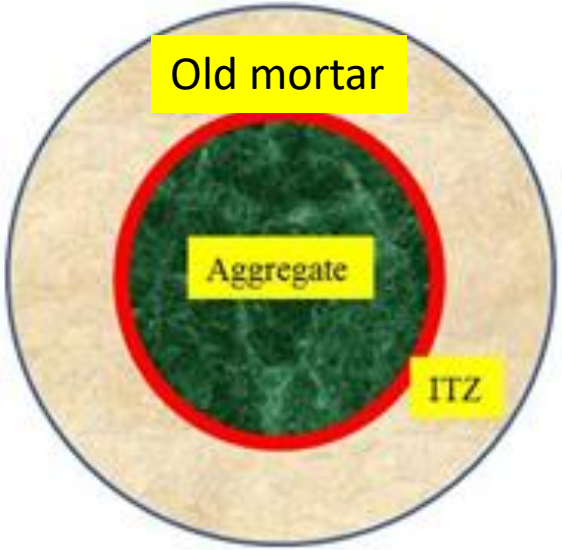
Caré, S. & Hervé, E. (2004). *Transport Porous Media*, 56(2), 119–135

Chloride diffusion in NAC



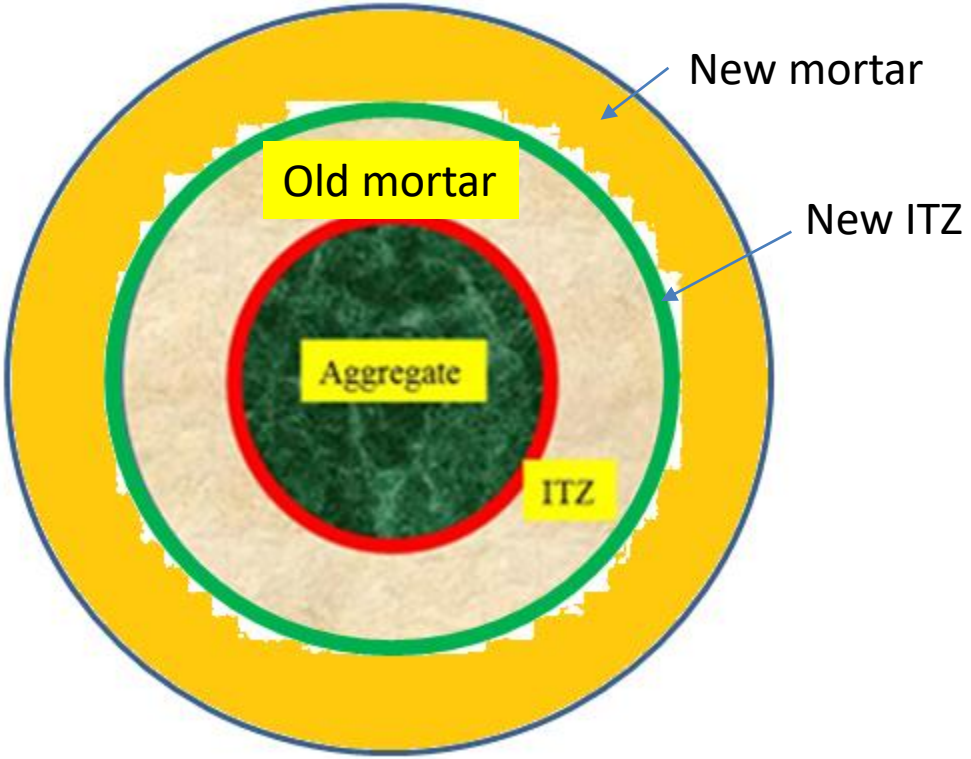
$$D_{con} = D_{cem}\frac{6D_{cem}(1-V_{agg})(V_{agg}+V_{ITZ})+2(D_{ITZ}-D_{cem})V_{ITZ}(1+2V_{agg}+2V_{ITZ})}{3D_{cem}(2+V_{agg})(V_{agg}+V_{ITZ})+2(D_{ITZ}-D_{cem})V_{ITZ}(1-V_{agg}-V_{ITZ})}$$

Chloride diffusion in RCA



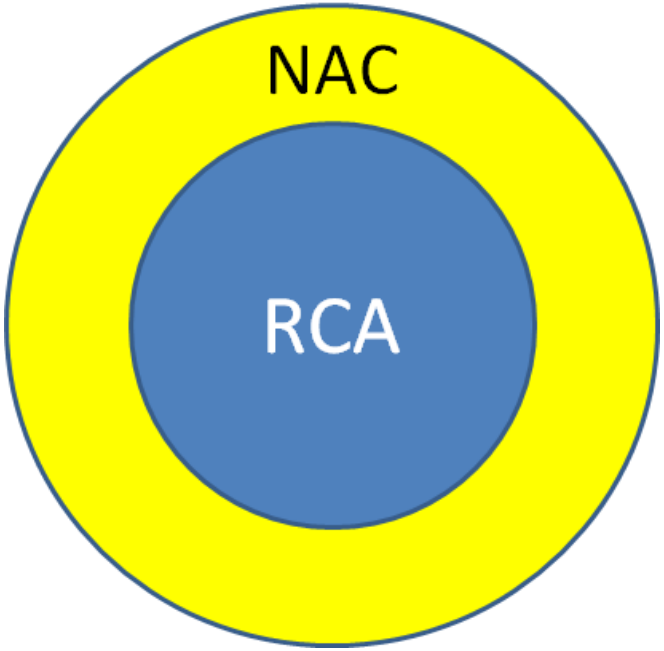
$$D_{con} = D_{cem}\frac{6D_{cem}(1-V_{agg})(V_{agg}+V_{ITZ})+2(D_{ITZ}-D_{cem})V_{ITZ}(1+2V_{agg}+2V_{ITZ})}{3D_{cem}(2+V_{agg})(V_{agg}+V_{ITZ})+2(D_{ITZ}-D_{cem})V_{ITZ}(1-V_{agg}-V_{ITZ})}$$

Chloride diffusion in RAC



$$D_{(i)}^{\text{eff}} = D_i + \frac{D_i(R_{i-1}^3/R_i^3)}{(D_i/(D_{(i-1)}^{\text{eff}} - D_i)) + (1/3)((R_i^3 - R_{i-1}^3)/R_i^3)}$$

Chloride diffusion in RAC with NA



$$D_{(i)}^{\text{eff}} = D_i + \frac{D_i(R_{i-1}^3/R_i^3)}{(D_i/(D_{(i-1)}^{\text{eff}} - D_i)) + (1/3)((R_i^3 - R_{i-1}^3)/R_i^3)}$$

Conclusions

- Prediction of chloride diffusion in RAC is much complicated than that in NAC. It is heavily dependent on the type of RCA.
- Transient diffusion tests can be applied only for the concrete in which the RCA has no chloride contaminant.
- The use of numerical method or approximate model requires volumetric fractions of each individual components, which is often not available or difficult to obtain.
- More work/study is required in order to make concrete 100% recyclable.