A Computational Linear Elastic Fracture Mechanics-based Model for Alkali-Silica Reaction - poster MPPS

Laurent Charpin, Alain Ehrlacher

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Laurent Charpin - laurent.charpin@enpc.fr, Alain Ehrlacher

Université Paris-Est, Laboratoire Navier (ENPC/IFSTTAR/CNRS), École des Ponts ParisTech,
6-8 avenue Blaise Pascal, 77455 Marne-la-Vallée, France

Abstract: This poster presents a fracture mechanics model for Alkali-Silica Reaction. The model deals with the case of a concrete made up of dense aggregates submitted to chemical attack. The chemistry and diffusion (of ions and gel) are not modeled. The focus is put on the mechanical consequences of the progressive replacement of the outer layer of the aggregate by a less dense gel. A schematic cracking pattern is assumed: a ring-shaped crack appears in the cement paste surrounding the spherical aggregate depending on the pressure build-up. The onset of cracking is determined using an incremental energy criterion. The stored elastic energy and deformation of a given configuration are determined assuming that each aggregate behaves as if it was embedded in an infinite cement paste matrix. The calculations are performed by Finite Element Analysis. We note a very different behavior of aggregates of different sizes. Adding the contributions of different aggregate sizes leads to an estimation of the global free expansion of a concrete of given aggregate size distribution. An optimized rate of attack is found that leads to recover the usual sigmoid ASR expansion curve.

Problem set up

- A spherical and homogeneous aggregate of radius R_p (Fig. 1)
- surrounded by an infinite cement paste matrix
- the spherical attack of the aggregate, described by the loading parameter α, which is replaced by gel of volume δ times that of the aggregate
- the cracking of the cement paste is studied. The relative crack size is x
- the volumetric expansion due to each aggregate, and summation for multiple aggregate sizes

Cracked configuration

The volume variation of the cavity $V_{lib}(\alpha, x) = \frac{4}{3}\pi R_p^3 \frac{P(\alpha,x)}{E_c} \Delta v(x, \nu_c)$ due to the deformation of the cement paste under pressure, as well as the stored elastic energy $E_c^{el}(\alpha, x) = \frac{P(\alpha,x) V_{lib}(\alpha,x)}{2}$ are computed numerically (Fig. 2, Fig. 3). The other elastic energies are evaluated analytically. The pressure is found using volume compatibility.

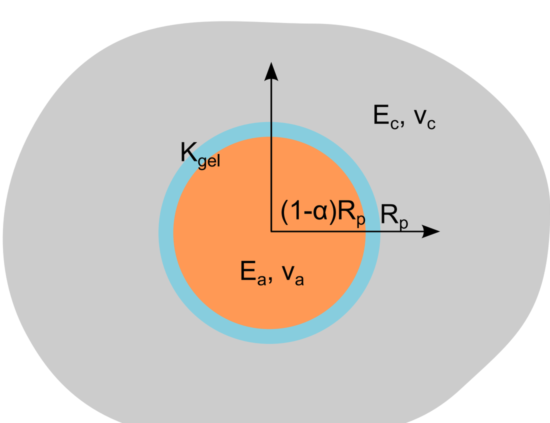

Fig. 1: Aggregate and surrounding cement paste

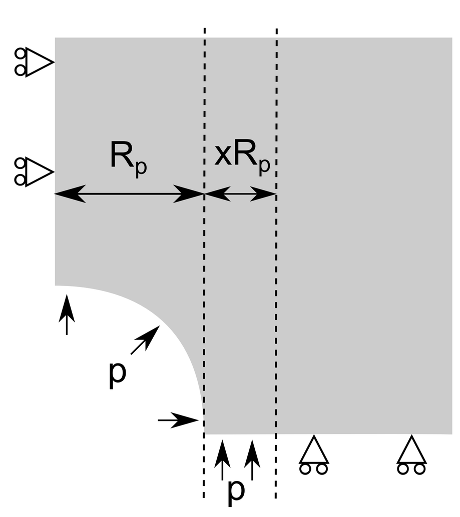

Fig. 2: Studied crack

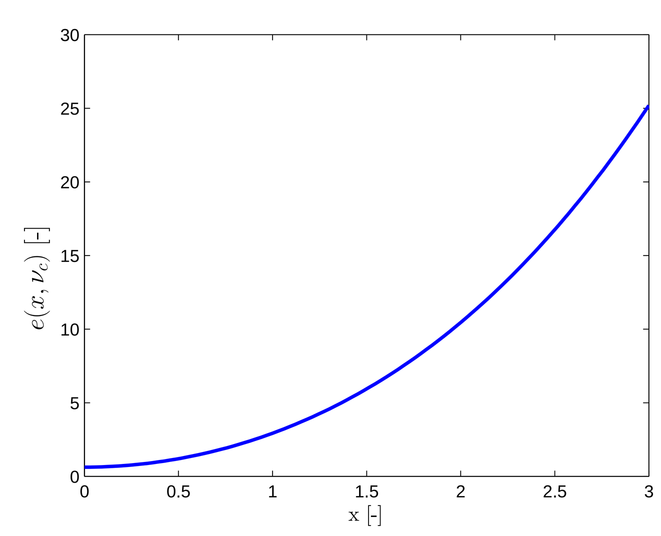

Fig. 3: Dimensionless stored elastic energy in the cement paste

Crack initiation and propagation

$E^{Rel}(\alpha, x)$ is the release of elastic energy when a crack of size x is created at the attack degree α, $E^{diss}(x)$ is the dissipated energy in the creation of a crack of size x, proportional in our model to the surface of the crack.

The initiation of a crack occurs when there is enough stored elastic energy to create a new surface:

$$E^{Rel}(\alpha, x) = E^{diss}(x)$$

Then, the crack propagates according to the energy rate equation (Fig. 4):

$$\frac{\partial E^{Rel}}{\partial x}(\alpha, x) = \frac{dE^{diss}}{dx}(x)$$

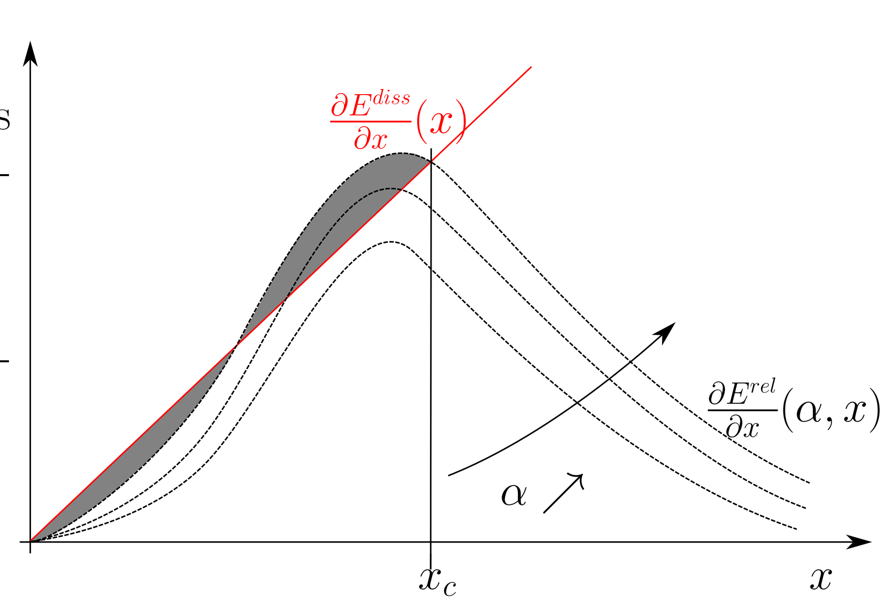

Fig. 4: Energy rates

Average deformation

To compute the average deformation, we add the individual contribution of each aggregate sizes, which are computed assuming that each aggregate behaves as if it was embedded in a infinite cement paste matrix.

Application of the model to a $0 - 4$ mm Seine Sand

- 22.5 % mass of the concrete is made of this Seine sand (Fig. 5)
- two cases are shown: no initial crack around each aggregate, and the case where each aggregate is initially surrounded by a crack of size $x = 0.5$
- we look at the results in terms of absolute attack depth (equal to $\alpha(t, R_p)R_p$ for each aggregate)
- pressure (Fig. 7) and crack size (Fig. 6) around different aggregate sizes are shown in both cases

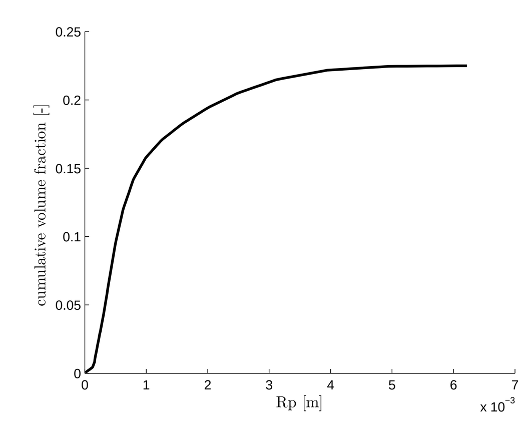

Fig. 5: Granulometry

- cracking first occurs in the biggest aggregates
- the smallest aggregates are not able to crack the cement paste even at full attack
- influence of assumptions about the presence of original flaws around aggregates: they allow a greater expansion at the beginning of the attack, but also at full consumption of the aggregates (here the degree of attack reaches $\alpha = 1/8$ for the biggest aggregate).

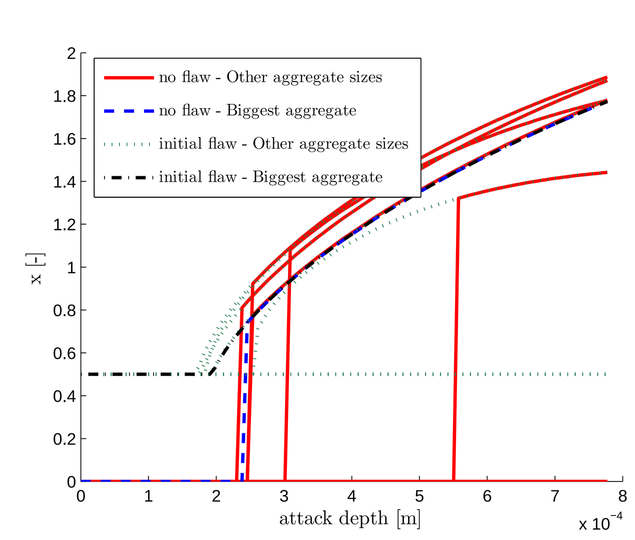

Fig. 6: Crack size

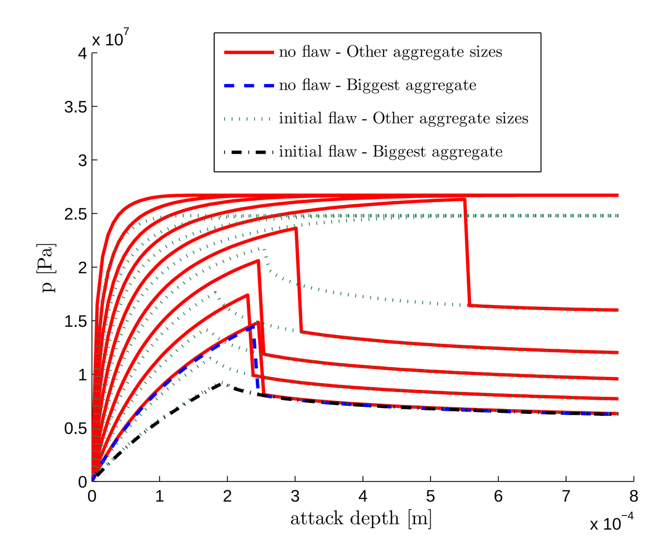

Fig. 7: Pressure

- Usual ASR expansion curves are sigmoids
- we need to link the absolute attack depth, common to all aggregates, to physical time
- the absolute attack depth is optimized so that the expansion curve sticks to experimental ASR data (Fig. 8)

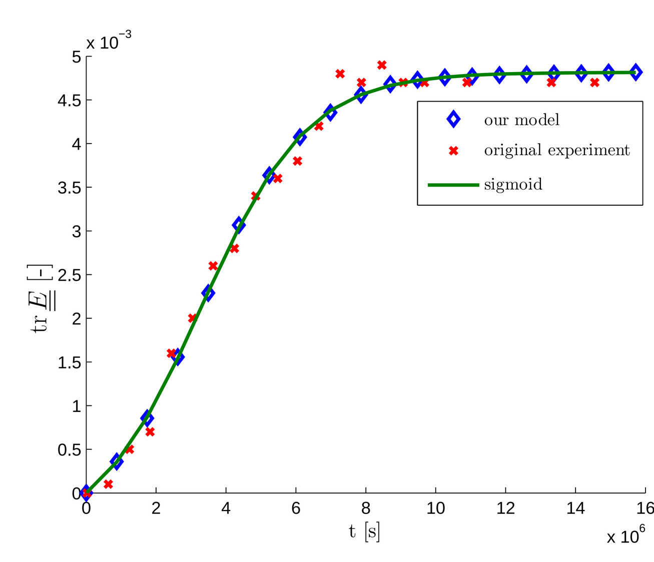

Fig. 8: Sigmoid expansion curve

Conclusion

We have built a very schematic model of aggregate attack and subsequent cracking. The poor knowledge of some of its parameters limits its possibilities.
It doesn't take into account :

- the high aggregate volume fraction
- gel permeation into the cement paste
- external mechanical loadings
- ion diffusion
- chemical reactions