ÉCOLE DOCTORALE UNIVERSITÉ PARIS-EST
Sciences, Ingénierie et Environnement
UNIVERSITÉ PARIS-EST
IFSTTAR

Modeling of cement-based materials submitted to sulfate attack

GU yushan, DANGLA Patrick, FEN CHONG Teddy, OMIKRINE-METALSSI Othman, MARTIN Renaud-Pierre

IFSTTAR, Paris-est Université, Champs-sur-Marne, France

Objective

External sulfate attack (ESA) and delayed ettringite formation (DEF) are well-known concrete degradation phenomenon induced by crystallization of ettringite. This paper aims to propose a model, based on the homogeneous paste expansion and surface-controlled ettringite growth mechanism, explaining the both phenomenon in a uniform method. The driving force for this mechanism is the pore pressure from the supersaturated sulfate solution, which leads the ettringite forming from the largest pores to the smallest ones, no matter it is in capillary pores (ESA) or gel pores (DEF).

Modeling

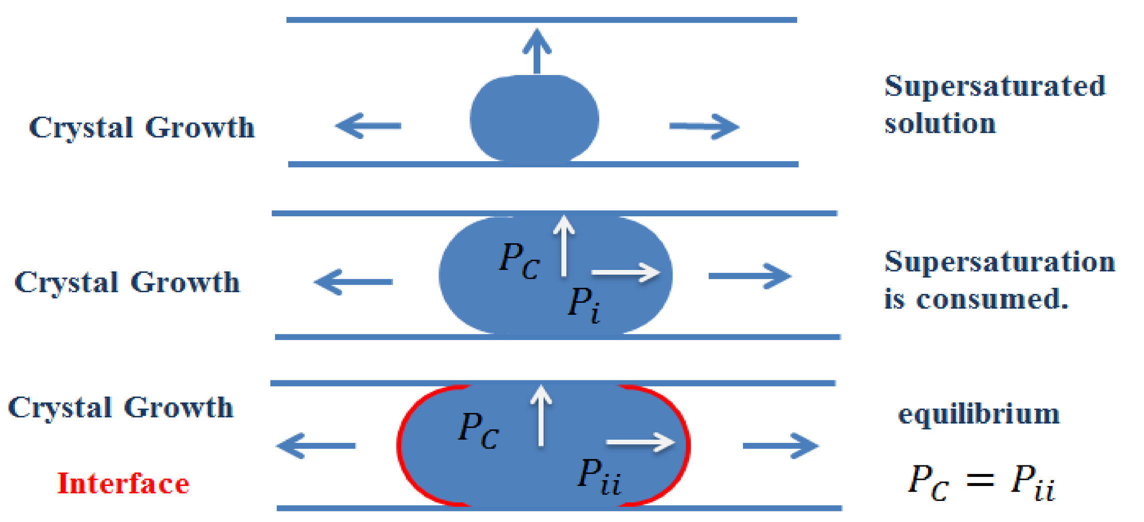


Fig. 1 Crystallization evolution

Poroelasticity theory:

$$\varepsilon_{xx} = \frac{b}{3K} S_C P_C$$

Correns' equation[1]:

$$P_C = \frac{RT}{V_C} \ln(\beta_{AFt})$$

Ostwald-Freundlich Equation:

$$\varepsilon_{xx} = \frac{b}{3K} S_C P_C$$

Growth rate mechanism:

$$\frac{d}{dt}(S_C) = a\left(1 - \exp\left(-\frac{\beta_{AFt}^{\ eq}}{\beta_{AFt}}\right)\right)$$

a: kinetic constant (calibrated)

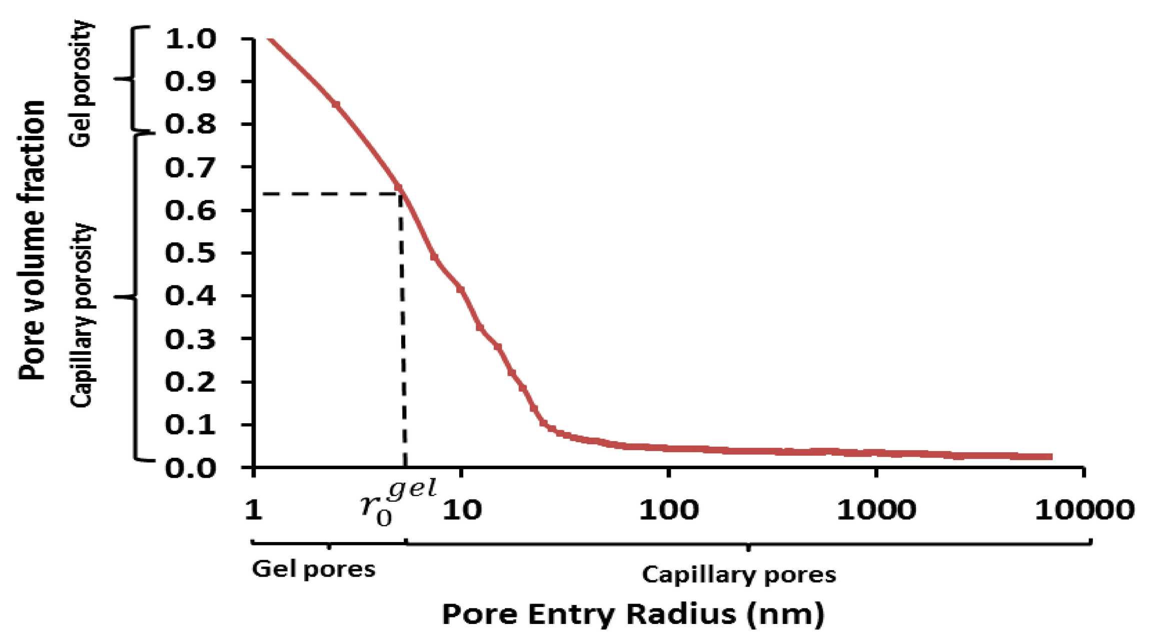


Fig. 2 Evolution of the pore volume fraction with the pore radius

Assumption:

Ettringite (ESA) in capillary pores:

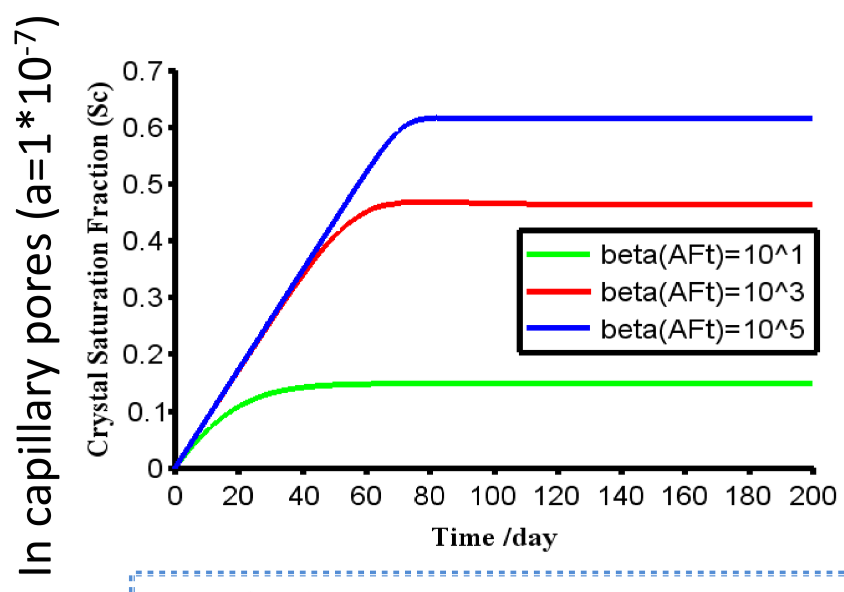
$$S_C^{cap}(r) = 1 - S(r) \qquad r > r^{gel}$$

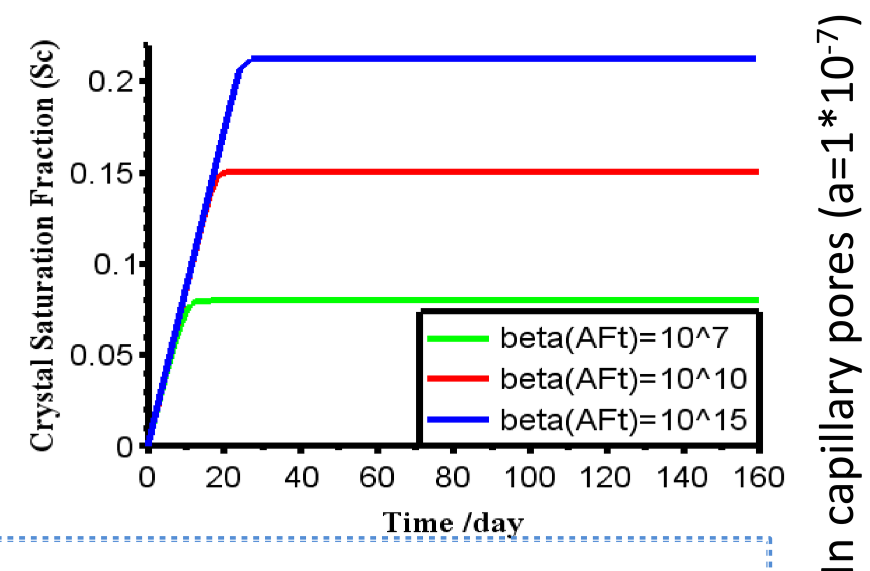
Ettringite (DEF) in gel pores:

$$S_C^{gel}(r) = S(r^{gel}) - S(r) \qquad r < r^{gel}$$

S(r) represents the volume fraction occupied by pores having a pore entry radius lower than r.

Sensitivity analysis

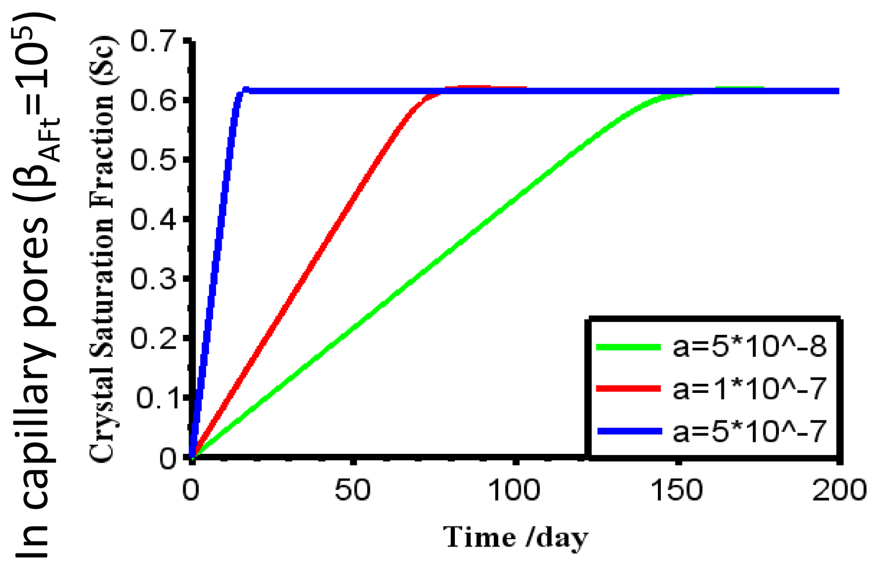


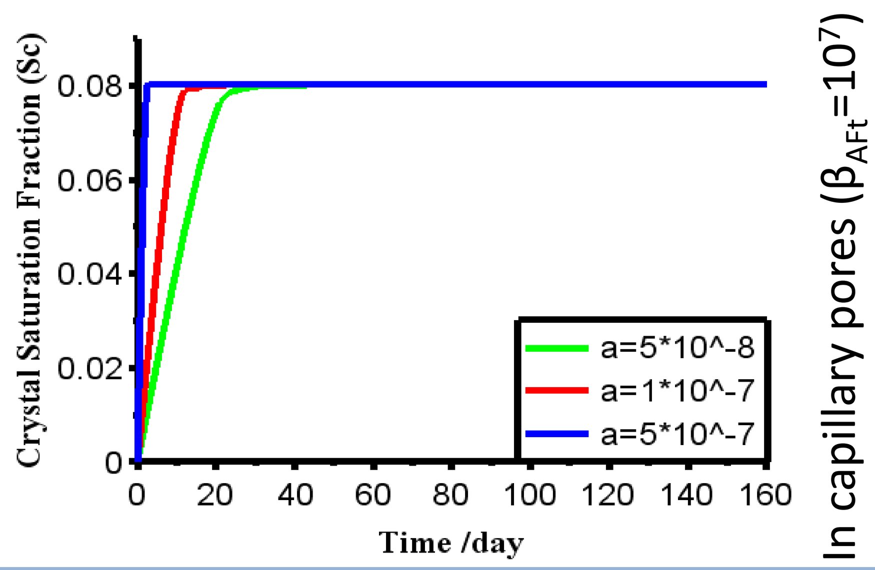


Conclusion:

S_C^{final} is determined by to β_{AFt} only.

In addition to Correns' equation, the β_{AFt} could be calibrated by final swelling.

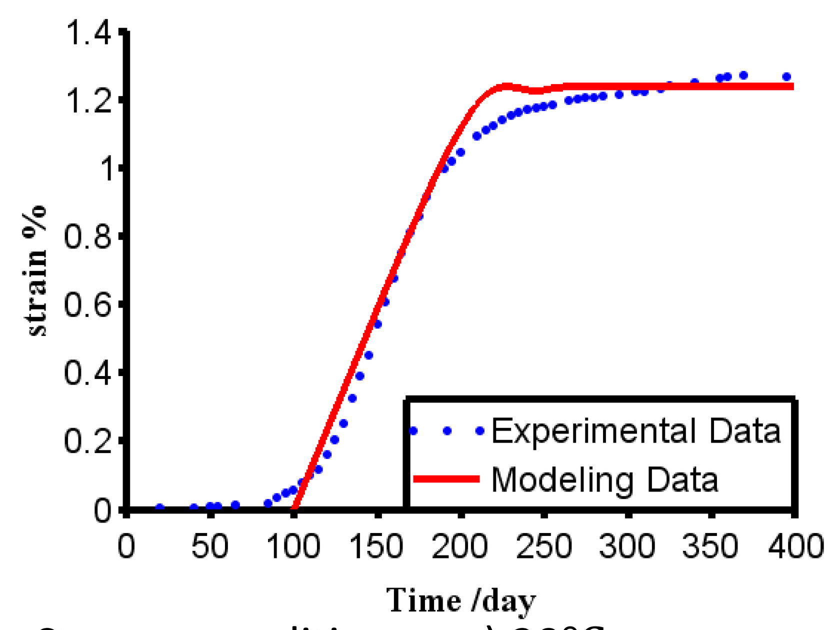


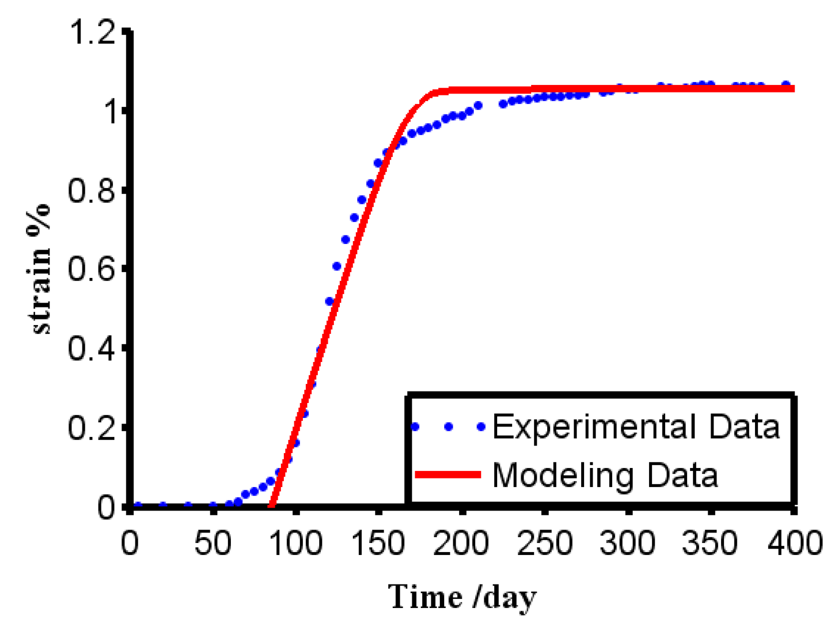


Comparison Results

DEF [2] Mortar bars: 16 *16 * 160mm^3

Preheating: 20 C for 4h, 90 C for 12 h (with heating rates of 30-35 C/h), cool naturally to 20 C over about 5 h and in water afterwards.



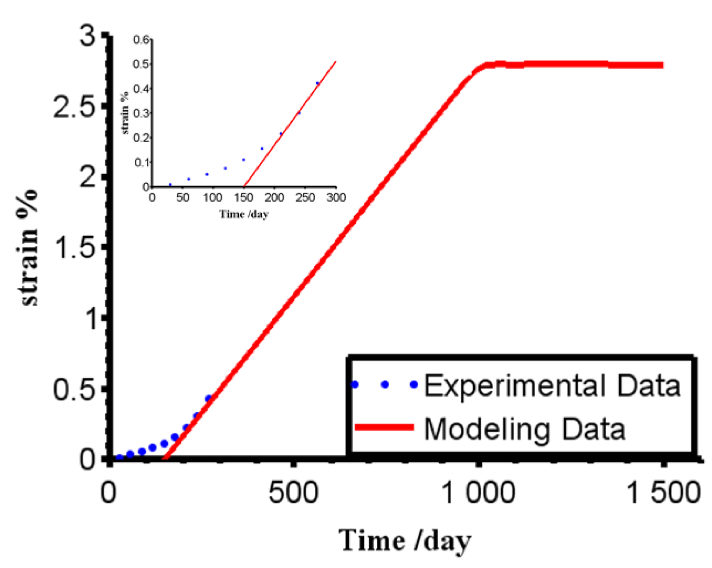


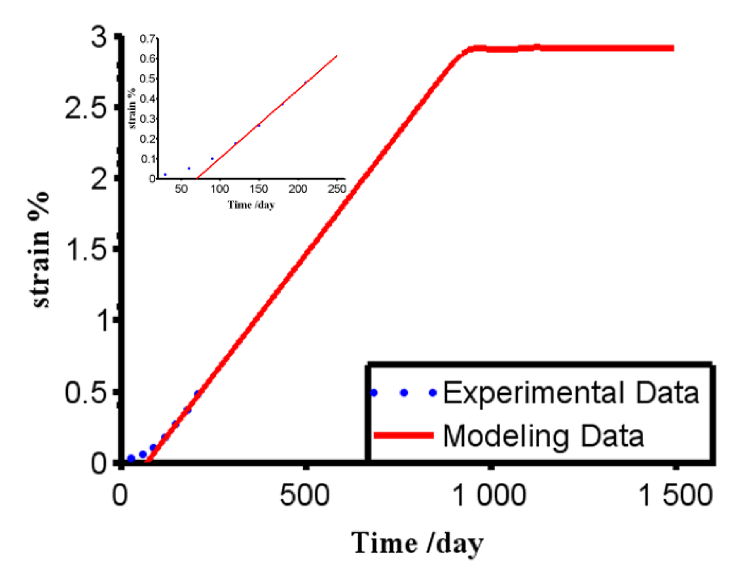
Storage conditions: a) 20°C
a_1 = 1.25*10^{-8}, β_{AFt} = 10$^{8.2}$, K = 0.2GPa, b = 1

b) 20°C 98 days and then 38°C.
a_2 = 1.5*10^{-8}, β_{AFt} = 10$^{7.75}$, K = 0.2GPa, b = 1

ESA [3]

Sulfate solution: 4.3% magnesium sulfate and 2.5% sodium sulfate (by weight)





C_3A content (weight) : 8.8%
a_1 = 1*10^{-8}, β_{AFt}= 10$^{8.8}$, K = 0.6GPa, b = 1

C_3A content (weight) : 12%
a_2 = 1*10^{-8}, β_{AFt}= 10$^{8.8}$, K = 0.6GPa, b = 1

Discussions

- The calibrated β_{AFt} for DEF is between 10$^{7.5}$ to 10$^{8.5}$, and 10$^{8.2}$ to 10$^{8.5}$ for ESA, which are acceptable.
- The bulk modulus used in the model are 0.2 and 0.6GPa, which are smaller than the predicted ones. A plasticity theory is considered to modify this model.
- The diffusing and leaching of the ions contribute to the saturation index of ettringite. This effect will be added into the model in the further step.

References:

[1]Correns, Carl W. "Growth and dissolution of crystals under linear pressure." *Discussions of the Faraday society* 5 (1949): 267-271.

[2] Famy, Charlotte. *Expansion of heat-cured mortars*. Diss. Imperial College London (University of London), 1999.

[3] Ouyang, Chengsheng, Antonio Nanni, and Wen F. Chang. "Internal and external sources of sulfate ions in Portland cement mortar: two types of chemical attack." *Cement and Concrete Research* 18.5 (1988): 699-709.