11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20–25, 2014, Barcelona, Spain

# A BIPHASE MODEL FOR CONCRETE SUBJECT TO SULFATE ATTACK

**N. Cefis[1] and C. Comi[2*]**

[1] Politecnico di Milano, Piazza Leonardo da Vinci 32, 20133 Milano, nicola.cefis@polimi.it
[2] Politecnico di Milano, Piazza Leonardo da Vinci 32, 20133 Milano, claudia.comi@polimi.it

**Key words:** *Concrete, Damage, Porous Media, Sulfate attack*

The sulphate attack is one of the phenomena which may cause expansion and severe microcracking in concrete. The durability analysis of concrete structures in contact to external sulphate solutions requires the definition of a proper diffusion-reaction model, for the computation of the varying sulphate concentration and of the consequent ettringite formation, coupled to a chemo-mechanical model for the prediction of swelling and material damage. In this paper we propose a chemo-elastic damage model aimed to simulate the mechanical response of concrete subject to sulphate attack. In the framework of the Biot's theory [2], the material is represented as a two-phase medium: the solid skeleton and the reaction products. The total stress $\boldsymbol{\sigma}$ is then given by the sum of the effective stress $\boldsymbol{\sigma}'$ acting on the solid skeleton and the pressure $p$ exerted by the expansive products

$$\boldsymbol{\sigma} = \boldsymbol{\sigma}' - bp\mathbf{1} \tag{1}$$

The mechanical response of concrete skeleton is described by an elastic model with isotropic damage $D$ relating the effective stress to the total strain $\boldsymbol{\varepsilon}$ . The internal pressure is linked via the Biot's modulus $M$ and the Biot's coefficient $b$ to the total volumetric deformation $\varepsilon_V$ and to the volumetric expansion of the reaction products $\zeta$

$$\boldsymbol{\sigma}' = (1-D)\boldsymbol{d} : \boldsymbol{\varepsilon}; \qquad p = (1-D)[-bM\varepsilon_V + M\zeta] \tag{2}$$

The time evolution of the internal expansion $\zeta$ is computed through the diffusion-reaction model proposed in [4]. As in [3], the activation of the damage in concrete depends on the macroscopic stress tensor and on the pressure through an "inelastic effective stress" defined as $\boldsymbol{\sigma}'' = \boldsymbol{\sigma} + \beta p\mathbf{1}$ with $\beta \leq b$. The damage activation function $f_D$ depends on the first invariant of the inelastic effective stress tensor $I_1$ and on the second invariant of the inelastic effective deviatoric stress tensor $J_2$

$$f_D(\boldsymbol{\sigma}'') = J_2 - a \cdot I_1^2 + bI_1 h(D) - kh(D)^2 \leq 0; \qquad h(D) = (1-D^c)^{0.75} \tag{3}$$

where $h(D)$ is the softening function and $a,\ b,\ k,\ c$ are non-negative parameters to be calibrated through experimental data. The preliminary validation of the model was done simulating the experimental tests presented in [1]. Those tests were performed on mortar prism in which 3.1% of $Na_2SO_4$ was added to the mixture water. The specimens where cured at high temperature to allow for DEF; then some of them were placed in restraint devices in order to compare the expansion under stress-free and loaded conditions. In this case an internal sulphate attack occurs and there is no need to perform a diffusion analysis to compute the distribution of the sulphate concentration. Assuming a first order reaction, the evolution of $\zeta$ is described by a sigmoidal function which can be calibrated using the expansion curves under stress-free conditions. The comparison between the experimental curves and numerical simulations is shown in figure 1 (blue: free expansion, red: restrain bars $\oslash = 2mm$, black: restrain bars $\oslash = 5mm$). A good agreement is observed.

The model is currently being applied to structural problems of external sulfate attack where the mechanical response is function of the local concentration of ionic species.

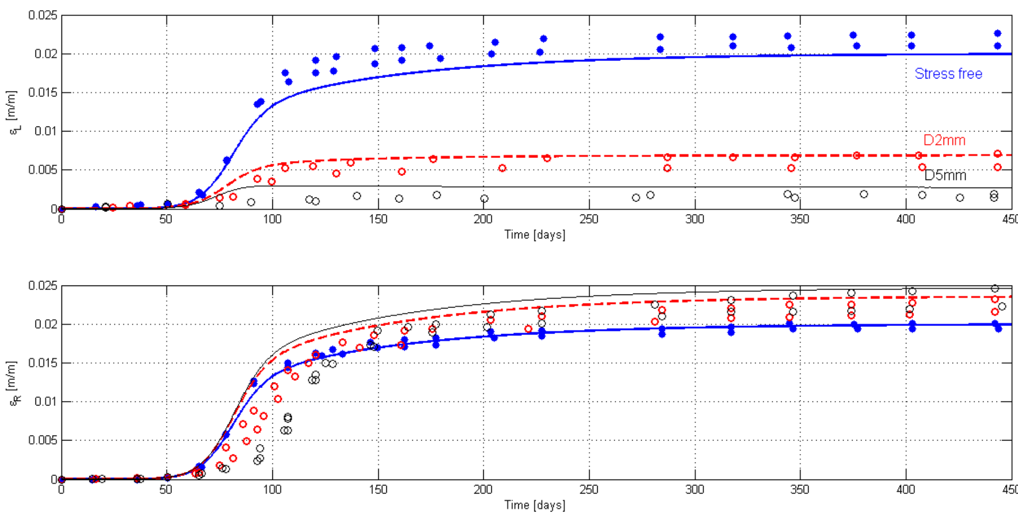


**Figure 1**: Longitudinal and radial deformation in stress-free and restrained conditions

## REFERENCES

[1] H. Bouzabata, S. Multon, A. Sellier, H. Houari. Effects of restraint on expansion due to delayed ettringite formation. *Cement and Concrete Research 42*, 1024-1031, 2012.

[2] O. Coussy. Poromechanics. *John Wiley Sons*, 2004.

[3] C. Comi, R. Fedele, U. Perego. A chemo-thermo-damage model for the analysis of concrete dams affected by alkali-silica reaction. *Mechanics of Materials 41*, 210-230, 2009.

[4] R. Tixier, B. Mobasher. Modeling of damage in cement-based materials subjected to external sulfate attack. *J. Mater. Civ. Eng. 15*, 305-313,2003