Modelling of chemo-mechanical coupling in porous cement paste

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ABSTRACT

This work is devoted to constitutive modelling of elastoplastic damage in porous cement paste subjected to compression-dominated stresses and chemical degradation. The basic mechanism of chemical degradation is the dissolution of calcium ions from solid skeleton. The kinetics of chemical degradation is essentially governed by the diffusion process if calcium ions inside interstitial solution. Based on the thermodynamics equilibrium curve established from experimental data relating calcium content in solid and calcium concentration in interstitial solution (Berner, 1992), a phenomenological chemistry model is adopted (Gerard, 1996). The chemical degradation is characterized by a scalar chemical damage variable related to the change of porosity. Triaxial compression tests have been performed on both sound and chemically degraded materials. The basic mechanical behaviour of the cement paste strongly depends on confining pressure, and may be characterized by a coupled elastoplastic damage model. The chemical degradation affects elastic and plastic properties. In Fig. 1, the failure surfaces in $I_1 - \overline{\sigma}$ plane are shown respectively for sound and degraded materials. We can see that the mechanical strength is significantly affected by chemical damage.

An elastoplastic model coupled with mechanical and chemical damage is then formulated. The principal state variables used are: elastic strains ε_{ij}^{e}; plastic strains ε_{ij}^{p}, mechanical damage d_m and chemical damage d_c. Based on the general framework of thermodynamics, the constitutive equation is derived:

$$\boldsymbol{\sigma} = \frac{\partial \Psi}{\partial \boldsymbol{\varepsilon}^{e}} = \mathbb{C}(d_m, d_c) : (\boldsymbol{\varepsilon} - \boldsymbol{\varepsilon}^{p})$$

The plastic deformation takes into account two mechanisms: deviatoric shearing and pore collapses. The deviatoric mechanism is characterized by a quadratic yield function, non-associated flow rule and isotropic hardening law. The pore collapse mechanism is described by a cap yield surface, an associated flow rule and isotropic hardening law. The both plastic mechanisms are coupled with mechanical and chemical damage. An appropriate damage criterion is proposed for the description mechanical damage due to microcracks, while the chemical damage is determined by chemistry model.

In order to validate the proposed chemo-mechanical model, a series of coupled tests have been performed. In these ones, the sample is first subjected to triaxial stress state with given confining pressure and deviatoric stress. Then nitrate ammonium solution is injected from the bottom of the sample, and variation of axial strain with injection time is measured. The finite element method is used to simulate such coupled boundary values problems. In Fig. 2, an example is shown. We can observe good concordance between numerical predictions and experimental data.

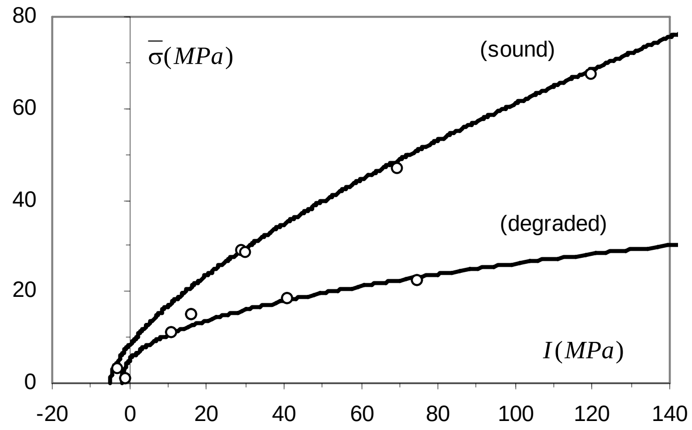

Figure 1: Failure surfaces of sound and chemical degraded materials

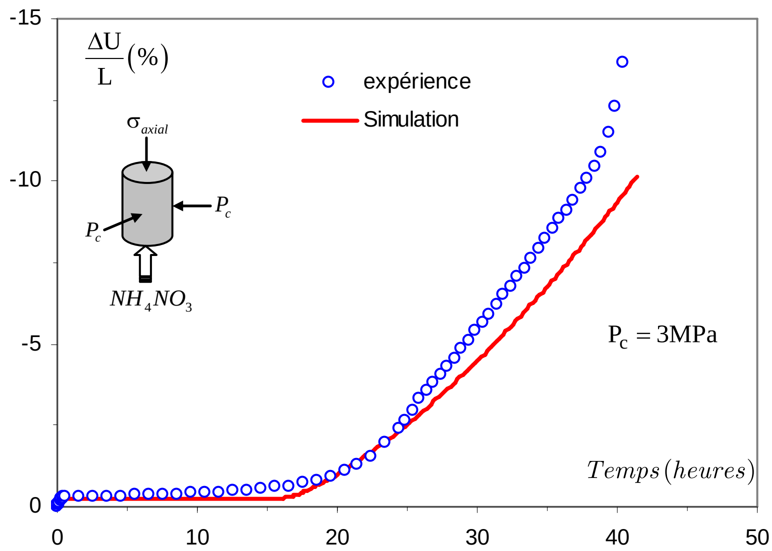

Figure 2: Variation of axial strain with chemical degradation during coupled chemo-mechanical test

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