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# MESOMECHANICAL ANALYSIS OF CONCRETE DETERIORATION INCLUDING TIME DEPENDENCE

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**Key words:** Meso-mechacnics, Drying Shrinkage, Concrete, Staggered Strategy.

**Summary.** *A mesomechanical analysis approach using interface elements with a constitutive law with aging previously developed by the authors, is being extended to diffusion-driven phenomena such as concrete drying shrinkage. Moisture distributions are obtained from a non-linear diffusion analysis carried out on the same meshes. Shrinkage results are obtained by means of an H-M coupled staggered strategy. Application results are presented that agree well with both intuitive understanding and recent experimental observations.*

## 1 INTRODUCTION

Time-dependent behavior of concrete has been traditionally formulated macroscopically in terms of stress and strain of a homogeneous continuum material. This has led to useful models for engineering practice. However, as materials research go deeper into the details of the observed phenomena, influence of composition, physics and chemistry aspects, etc., and as numerical methods and computer resources advance quickly, micromechanical analysis is emerging as a powerful technique for scientific studies. The discretization of the concrete components separately makes it possible to obtain complex material behavior as a “structural” result of the combination of much simpler behavior for each individual component.

## 2 MESO-MECHANICAL MODEL

Three concrete components are represented in the FE discretization: the larger aggregates with randomly generated shapes and locations, the mortar (plus smaller aggregates) matrix, and the interface between them represented with “zero-thickness” interface elements. These interfaces are also inserted in between matrix elements, in order to represent all major potential cracks. For the matrix, aging viscoelasticity is assumed through a Maxwell chain model equivalent to a Dirichlet series expansion of the relaxation function *R(t,t´)*. Because the aggregates are assumed linear elastic, the determination of the matrix visco-elastic parameters from the overall concrete compliance function *J(t,t´)* becomes an inverse problem [1]. Interface behavior is formulated in terms of the normal and shear components of stress on the interface plane, $\boldsymbol{\sigma} = [\sigma_N, \sigma_T]^t$, and dual relative displacements $\mathbf{u} = [u_N, u_T]^t$ (t = transposed). A detailed description and comparison to experimental tests on developing cracks can be found in [2]. Also, a constitutive law for interface elements is presented that is able to represent two competing aspects of the material strength: the strength reduction due to dissipative processes, as well as the increase of strength due to aging processes (Fig.1, *left*). A more detailed description can be found in [3].

## 3 DRYING SHRINKAGE

Drying shrinkage is a complex phenomenon in which various physical mechanisms and coupled interactions are involved. As already described, moisture movements are driven by non-linear diffusion based on the well-known differential equation in terms of relative humidity $H$ [4] (Eqn(1)), where diffusivity coefficient $D_H$ is assumed to depend on $H$ through an hyperbolic function $f(\beta,H)$ ,being $\beta$ a shape parameter.

$$\frac{\partial}{\partial x_i}\left[D_H\,\frac{\partial H}{\partial x_i}\right]+h(x)=\frac{\partial H}{\partial t} \quad ;\ D_H\ (H) = D_0 + (D_1 - D_0)\, f(\beta,H) \qquad (1)$$

From the value of $H$ at each point of the domain, the water loss per unit volume of concrete, $w_e$, can be calculated *a posteriori* using the desorption isotherm expression proposed by Norling[5]. Water loss causes volume reductions in the cement paste, which in a first approach may be assumed linear. This in turn causes strains and stresses, which may create cracks. These cracks may represent easier ways for moisture to migrate out of the specimen, thus accelerating water loss and therefore cracking again. The model developed tries to capture all this using two independent codes for mechanical and moisture diffusion analysis linked through a *staggered* strategy, and using the same FE mesh for both diffusion and mechanical calculations. This requires interface elements with double nodes also for diffusion analysis, as proposed in [6]. After a crack starts to open, the “cubic law” [7] combined with an expression similar to (1b) is used to estimate its discrete diffusivity coefficient. Time is discretized using a backward- Euler finite difference algorithm and, for each time step, iterations between mechanical and moisture diffusion codes are repeated until a certain tolerance for the coupled procedure is satisfied.

## 4 PRELIMINARY RESULTS

A first example of application consists of the drying shrinkage simulation of a 14x14cm concrete specimen with a 6x6 aggregates arrangement, with a volume fraction of 28%. Initial conditions are $H$=1 throughout the specimen. At $t_0$=7 days, boundary conditions become $H$=0.5 on left and right edges, and no moisture flow is allowed through top and bottom surfaces. Calculations are repeated under visco-elastic uncoupled and coupled assumptions, both for aging and non-aging interfaces. Resulting moisture distributions are shown in Fig. 1 *(right)*, arranged in horizontal rows representing the three cases (uncoupled cases lead to the same $H$ distribution), and in vertical columns for three drying times (20, 200 and 10000 days). Weight loss in grams is also indicated. For all cases, the drying front advances towards the specimen center with time, although this happens a bit faster for the coupled analyses, especially with non-aging interface elements, in which more pronounced cracking could be expected. Fig. 2 and 3 depict some mechanical results of the same calculations.

Fig. 2 includes results from the aging coupled visco-elastic case, for 20, 200, 2000, and 10000 days on the left, left-center, right-center and right images, respectively. The cracks

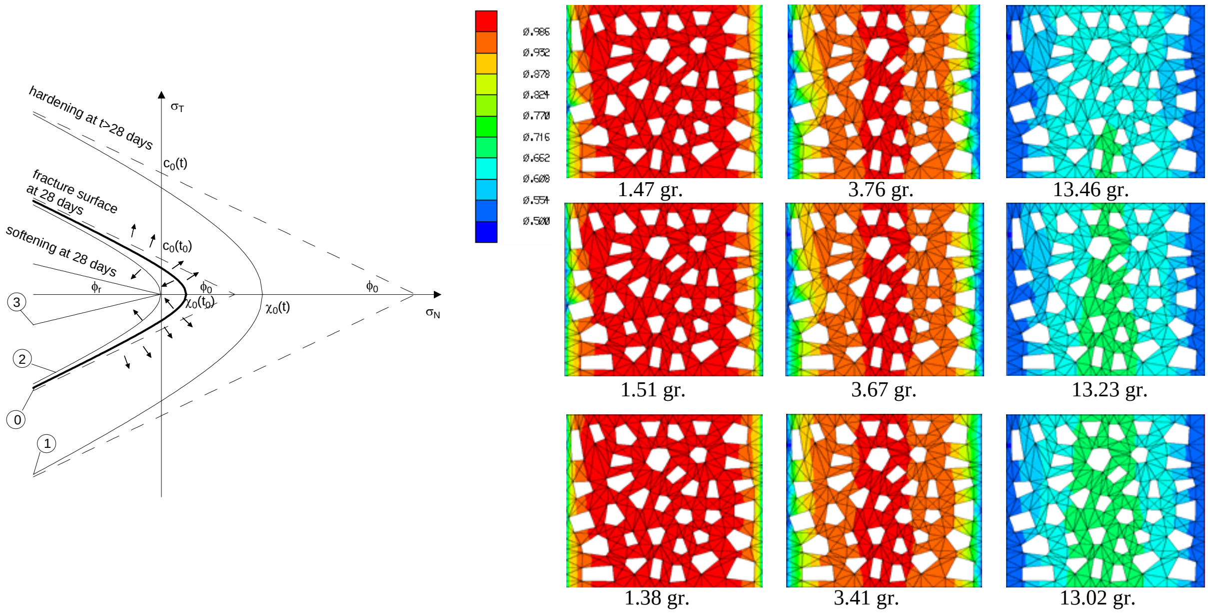


**Figure 1.** Fracture surface evolution ruled by dissipation (softening) or aging (hardening) *(left)*; RH distributions and total weight losses for 20, 200 and 10000 days left to right; coupled (top), aging coupled (middle) and uncoupled (bottom) *(right)*.

openings are highlighted, with thickness representing the energy spent in fracture. Most cracks develop perpendicular to the lateral edges, although at advanced drying times some interfaces are also activated in the interior in directions radial to the aggregates, in consistence with recent experimental results on drying shrinkage [8]. In Fig. 3, deformed meshes at 10000 days for the remaining 3 cases are presented. Two competing effects have to be considered regarding cracking: on the one hand, the coupling effect tends to increase the drying and therefore the opening of cracks; on the other, viscoelasticity in the mortar induces a relaxation effect which leads to an alleviation of the stress field, thus reducing cracking. The results obtained are consistent with these basic considerations.

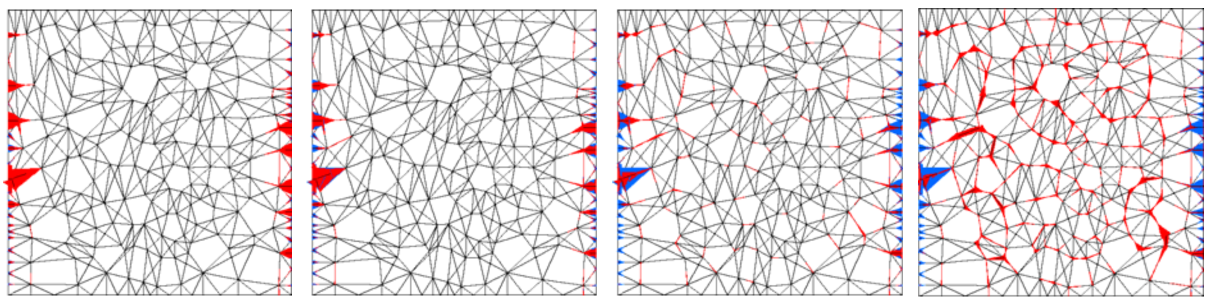

**Fig. 2.** *Visco-elastic coupled case: fracture energy, dissipated along interfaces at 20, 200, 2000 and 10000 days (magnification factor 2).*

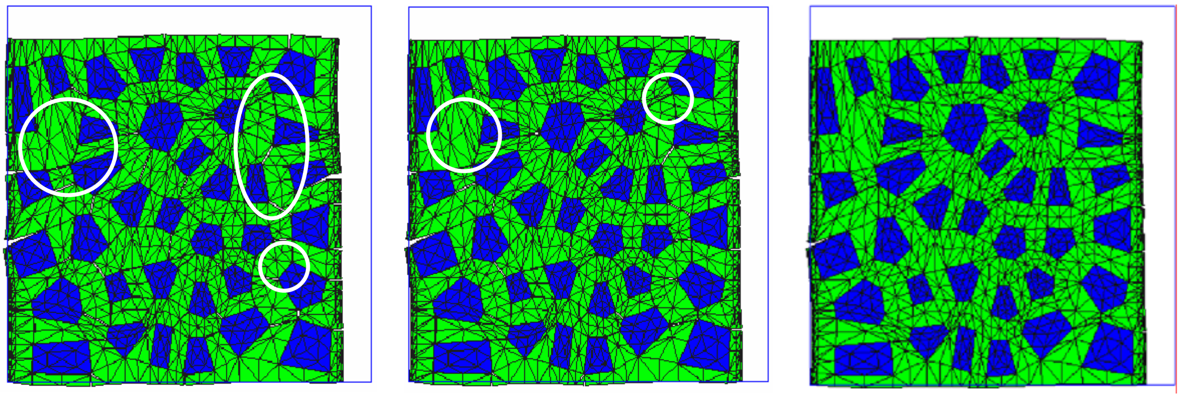

**Figure 3.** *Deformed meshes at 10000 days: (left) non-aging coupled, (middle) non-aging uncoupled and (right) aging uncoupled (magnification factor 150). Circles indicate internal cracks in the specimen.*

## 5 CONCLUDING REMARKS

Some aspects of the on-going research on meso-level analysis of concrete have been described. In this approach, relatively simple, well understood models can be used for each material component. Overall concrete material is obtained as the outcome of the numerical analysis, in which the influence of individual ingredients/parameters may be evaluated and compared. Preliminary results presented of drying shrinkage are consistent with physical and intuitive considerations, and also with experimental results. On-going work aims at improving the model including among others 3D time-dependent calculations, temperature effects, etc.

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## REFERENCES

[1] C. M. Lopez, I. Carol, J. Murcia: Mesostructural modeling of basic creep at various stress levels; In Ulm, F.J., Bazant, Z.P. and Wittmann, F.H. editors, *Creep, Shrinkage and Durability Mechanics of Concrete and other Quasi-Brittle materials*, pp 101-106. John Wiley, New York (2001).

[2] I. Carol, C.M. Lopez, O. Roa : Micromechanical analysis of quasi-brittle materials using fracture-based interface elements; International Journal for Numerical Methods in Eng. , Vol. 52, pp 193-215 (2001).

[3] D. Ciancio, C.M. Lopez and I. Carol. "Mesomechanical investigation of concrete basic creep and shrinkage by using interface elements". In 16th AIMETA Congress of Theoretical and Applied Mechanics (2003).

[4] Z.P. Bazant and L.J. Najjar. "Drying of concrete as a nonlinear diffusion problem". *Cement and Concrete Research, vol.1, pp. 461-473* (1972).

[5] K. Norling: Self-desiccation in concrete; Licenciate Thesis, Chalmers University of Technology, Goteborg, Sweden (1994)

[6] J.M. Segura and I. Carol. "On zero-Thickness Interface Elements for Diffusion Problems"; *International Journal for Numerical and Analytical Methods in Geomechanics*, 28(9), 947-962 (2004)

[7] J.G.M. van Mier, J. Bisschop, T. Shiotani : Experimental and Numerical Analysis of Drying Shrinkage at the Meso-Level: Preliminaries to Numerical Modelling and Analyses. In NSF Advanced Workshop on 'Model-Based Simulation of Durability of Materials and Structures', Czech Tech. Univ., Prague, p.45 (2002).

[8] D. Snow. A parallel plate model of fractured permeable media. *Ph.d* Dissertation, Univ. of California, Berkeley (1965).