ANISOTROPIC DAMAGE MODEL FOR CONCRETE INCLUDING UNILATERAL EFFECTS

Godard V.*,**, Leblond J.-B.*, Badel P.-B.**
* LMM, Université Paris 6, 4 Place de Jussieu, 75005 Paris , France
** EDF R&D Département AMA, 1 avenue du général de Gaulle, 92141 Clamart, France

Summary

The complexity of microscopic mechanisms, which occur in concrete during the damage process, including notably the formation of cracks in tension and the closure of cracks in compression, with possible friction between the crack lips, seems to preclude any other approach than a phenomenological one. Furthermore, concrete exhibits an essentially elastic-brittle behaviour, which is the preferred domain of application of the damage theory, as initiated by Kachanov.

The aim of the present work is to propose a thermodynamically consistent model, which accounts for some anisotropy induced by damage, and which includes unilateral effects related to crack closure. Attention is paid to limiting the complexity of the model, and especially the number of parameters, in order to make the model a viable candidate for practical engineering computations.

The present work is an extension of the model developed by Badel [1] and Leblond. The model meets the 5 following features:

(i) It accounts for the anisotropy induced by damage.
(ii) It exhibits the asymmetry between tension and compression.
(iii) The stress varies continuously with respect to strain and damage in spite of the asymmetry between tension and compression.
(iv) A complete loss of stress-bearing capacity is possible for a totally damaged material.
(v) It fits within the framework of "generalized standard materials", as defined by Halphen and Nguyen [2].

Except for point (v), which is motivated by mathematical and numerical considerations, points (i) to (iv) are clearly desirable from a physical point of view. None of the models proposed up to now meets all 5 requirements. Many satisfy (i) and (ii) but fail to satisfy (iii), (iv) or (v).

The model in [1] satisfies all 5 requirements but fails to describe properly the mechanical behaviour of concrete in compression, and in particular shows no peak of stress. The main improvement of the present work is the introduction of a scalar damage variable representing the damage process that occurs in compression, in addition to the damage tensor representing the anisotropic damage (point (i)) induced by the formation of cracks perpendicularly to the direction of major tension already present in [1]. The use of two damage variables is motivated by the fact that the damage process seems to be different between tension and compression (see Mazars [3], Comi and Perego [4]). The evolution of both damage variables is coupled in only one criterion and one evolution law for physical and numerical reasons. Besides, unilateral effects (point (ii)) are taken into account by treating positive and negative principal strains (or eigenvalues of a combination of strain and damage) on a different footing in the thermodynamic potential. Moreover, the threshold in the criterion, formerly taken constant in [1], now depends on the confinement state, assimilated here to the negative part of the strain, in order to take into account the confinement effect (Kupfer et al. [5]). Point (iv) is adressed by using a free energy as the thermodynamic potential, instead of a free enthalpy; this leads to expressing the stress as a function of strain rather than vice versa. Finally, point (iii) and (v) are satisfied, thanks to the expressions of the free energy, the dissipation potential and the stress.

The model involves only 5 parameters (in addition to usual elastic moduli), what makes it very simple in comparison to other anisotropic models for concrete. The simplicity of the model and the demanding constraints placed on the model induce some defects, among which the absence of residual strains and of volumetric dilatancy in compression. However, numerical simulations show that in many situations, these defects should be acceptable, and that the model yields relatively good results. For instance, figure 1 shows the numerical simulation of a uniaxial tension followed by compression on one element:

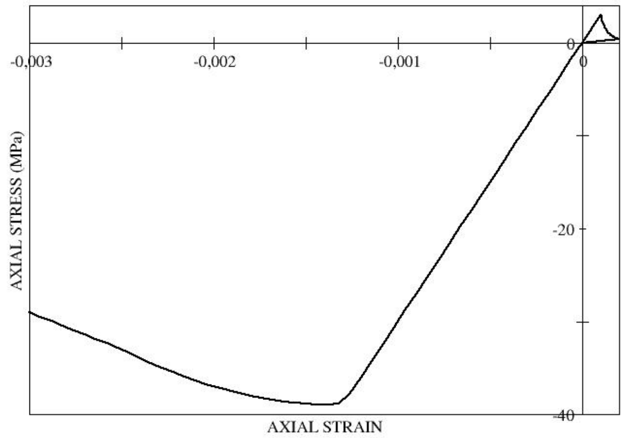

Figure-1: Axial stress/ axial strain for a uniaxial test of tension followed by compression

Finally, a non local model, based on the use of regularised deformations in the evolution equation of damage variables, which has been developed from the model proposed by Peerlings et al. [6], can be adapted to the present anisotropic damage model, in order to overcome the problem of mesh dependence induced by the softening regime.

References

1. Badel, P.-B., Contributions à la simulation numérique de structures en béton armé, *Thèse de doctorat de l'université Paris VI* , Paris, France, 2001.
2. Halphen, B., Nguyen, Q.S., Sur les matériaux standards généralisés, *J . de Mécanique*, **14**, pp 39-63, 1975.
3. Mazars, J., Application de la mécanique de l'endommagement au comportement non linéaire et à la rupture du béton de structure, *Thèse d'Etat* , UPMC, Paris, France, 1984.
4. Comi, C., Perego, U., Fracture energy based bi-dissipative damage model for concrete, *Int. J. Solids Struct.*, **38**, 6427-6454, 2001.
5. Kupfer, H.B., Hilsdorf, H.K., Rusch, H., Behaviour of concrete under biaxial stresses, *J. ACI 66 (8)*, 656-666, 1969.
6. Peerlings R.H.J., de Borst R., Brekelmans W.A.M., Geers M.G.D., Gradient-enhanced damage modelling of concrete fracture, *Mech. Cohesive-Frictional Mat.*, 3, 323-342, 1998.