8th. World Congress on Computational Mechanics (WCCM8)
5th European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 –July 5, 2008
Venice, Italy

DUCTILE FAILURE OF HETEROGENEOUS MATERIALS: A COHESIVE-VOLUMETRIC APPROACH COUPLING ANALYTICAL AND NUMERICAL HOMOGENIZATION MODELS

Y. Monerie[(1,2)], F. Perales[(1,2)], P.-G. Vincent[(1)]

[(1)] Institut de Radioprotection et de Sûreté Nucléaire (IRSN), and
[(2)]Laboratoire de Micromécanique et d'Intégrité des STructures (MIST), IRSN - CNRS - UM2,
CE Cadarache, BP3, F-13115 Saint-Paul-lez-Durance, Cedex, France.
yann.monerie@irsn.fr

Key Words: *Micromechanics, Heterogeneous Materials, Non Smooth Fracture Dynamics.*

ABSTRACT

In the frame of the nuclear safety research programs of the French "Institut de Radioprotection et de Sûreté Nucléaire" (IRSN), a new approach was developed in order to predict the ductile fracture of heterogeneous materials during transient loadings. This approach is based on the so-called cohesive-volumetric finite element (CVFE) method in the periodic homogenization framework [1]. The coupling of this numerical approach to some analytical homogenization models allows to predict the behavior of heterogeneous materials from elasticity to ductile damage up to failure.

The present paper shows the ability of this coupling in the case of two materials from the nuclear industry: (1) the uranium dioxide UO_2 nuclear fuel, and (2) its cladding. The first example deals with the way to a posteriori enrich some homogenization estimates or bounds devoted to the ductile damage of porous materials in order to take into account the coalescence of cavities leading to failure. The second example illustrates a more coupled approach where the overall hardening behavior of a composite material (as elastoplasticity) is incorporated into the bulk behavior and the overall softening behavior (as damage and fracture) is incorporated into some cohesive zone models.

Example (1). The highly irradiated UO_2 is a polycrystalline material which exhibits a microstructure with two populations of voids of rather different sizes and shapes. With the help of two up-scalings, a Gurson-like ductile damage model can be obtained for this material [2]. However, since no coalescence is taken into account in this type of model, the proposed periodic CVFE method can be used to identify a Gurson-Tvergaard-Needleman-like acceleration of the porosity at the onset of the coalescence. This identification is performed on periodic Voronoï tessellations incorporating penny-shape voids along the grain boundaries [3]. The accuracy of the obtained overall ductile fracture model is illustrated in Figure 1.

Example (2). The highly irradiated Zircaloy cladding is a functionally graded material composed of a metal matrix and aligned brittle hydride inclusions (Figure 2). The overall elastoplastic and damageable behavior of this material is obtained using the CVFE method where both the mean volumetric and

cohesive properties arise from homogenization techniques at the microscale. The volumetric hardening behavior is obtained with the help of an homogenization model based on a variationnal approach, and the cohesive softening behavior comes from a periodic CVFE modeling [4].

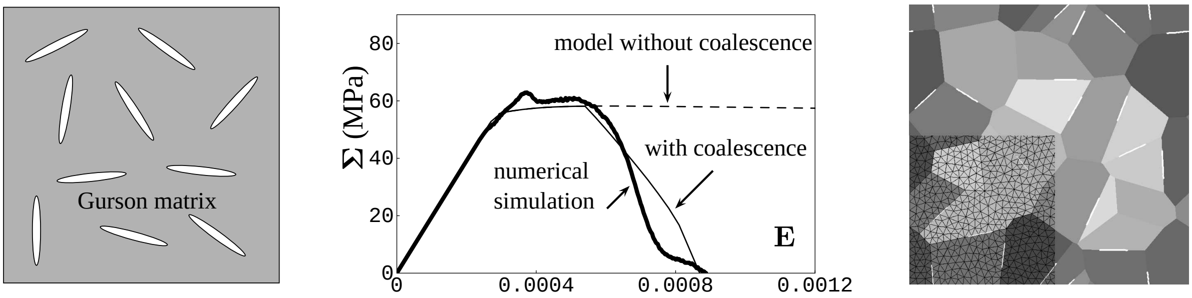

Figure 1: *Modelling of the ductile damage of a biporous nuclear ceramic. A two-scale homogenization model (left) is enriched at the macroscale by a coalescence model derived from numerical simulations incorporating cohesive zone models in a periodic Voronoï tessellation (right).*

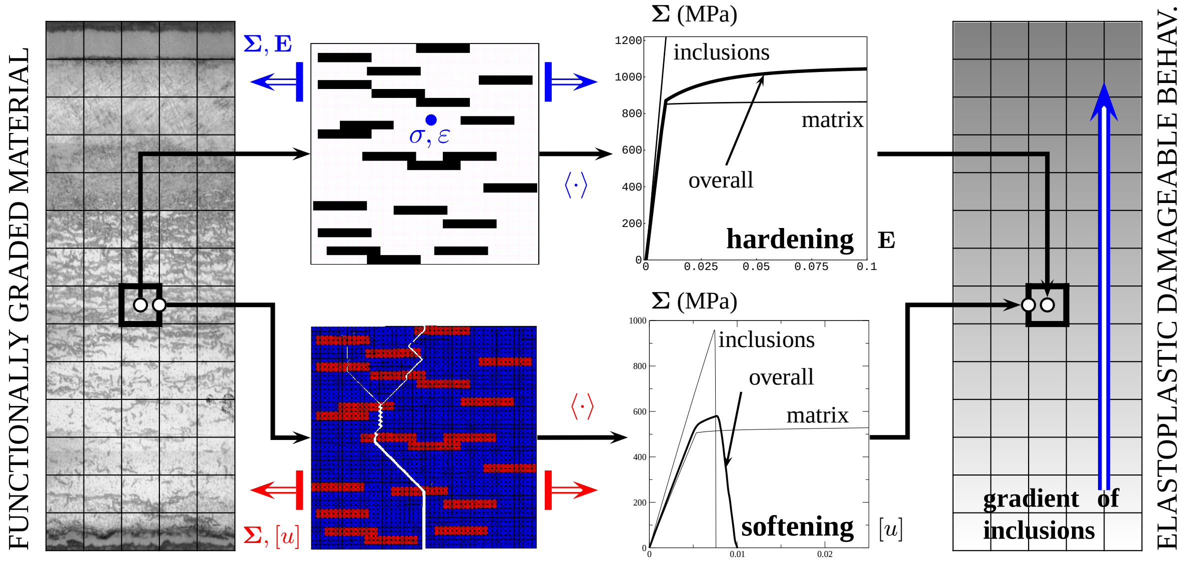

Figure 2: *Principle and partial results of the multiscale cohesive-volumetric approach for the study of the overall elastoplastic and damageable behavior of a functionally graded material.*

REFERENCES

[1] F. Perales, S. Bourgeois, A. Chrysochoos, Y. Monerie. "Two field multibody method for periodic homogenization in fracture mechanics of nonlinear heterogeneous materials". *Engng Fracture Mech.*, to appear.

[2] P.-G. Vincent, Y. Monerie, P. Suquet. "Ductile damage of porous materials with two populations of voids". *C. R. Mécanique*, to appear.

[3] P.-G. Vincent. "Modélisation micromécanique de la croissance et de la percolation de pores sous pression dans une matrice céramique à haute température", PhD Thesis, Aix-Marseille I University, 2007.

[4] F. Perales, Y. Monerie, A. Chrysochoos. "Nonsmooth fracture dynamics of functionally graded materials". *J. Phys. IV*, Vol. **134**, 367–372, 2006.