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MICROMECHANICAL MODELING OF VOID GROWTH IN DUCTILE AND DENSE METALS UNDER HYDROSTATIC LOADING

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During the first microseconds of high velocity impacts, shock waves propagate and reflect on free surfaces as release waves. When such release waves meet together, a nearly hydrodynamic state of tension occurs, and can induce dynamic fracture (spalling) through nucleation, growth and coalescence of microvoids in ductile metals.

The present work aims at modelling ductile spalling via a scale transition approach, in which the voided material is seen as a statistical distribution of mesoscopic cells, each one containing a single microvoid. In this general framework, the first task is to build a mesoscopic cell model. This is being done using the well-known hollow sphere model, to be applied to a high-purity grade of tantalum. This material behaves in a thermo-viscoplastic fashion. In a first approach, however, the effects of rate sensitivity and thermal softening may be neglected as having opposite effects, and elastic-perfectly plastic behaviour is considered here.

Previous studies [Denoual and Diani, 2001 ; Roy, 2003] showed that, under hydrostatic or hydrodynamic loading, a hollow sphere made of an elastic-perfectly plastic material undergoes a three stage deformation process. In the first one, the internal void grows only very slightly, and the hollow sphere stores a very large amount of elastic energy. In a second stage, plasticity develops very rapidly in the sphere, and is accompanied by strong energy release. In this stage, the void grows almost explosively. Finally, quasi-steady state growth occurs in the last part of the process. Hence, neglecting elasticity is equivalent to neglecting the first two stages, and results in a poor prediction of the temporal evolution of void growth [Roy, 2003 ; Dragon and Trumel, 2003].

The present work aims at designing a mesoscopic cell behaviour model accounting explicitly for elasticity and energy restitution effects, in the framework of the Thermodynamics of Irreversible Processes. For this purpose, homogeneous mesoscopic stresses or strains are applied to the hollow sphere external boundary, and the microscopic stress and displacement fields sought in a Lagrangian finite strain context. A closed-form solution is found and validated using the ABAQUS Standard finite element package. This work shows that the finite deformation framework is essential, and that a small strain solution dramatically overestimates small void growth (see the case of a 0.625 mm radius hollow sphere containing an internal void in Figure 1 below).

This analytical solution is then used to determine the overall (mesoscopic) free energy and state variables. In particular, special virtual paths are used to show that the free energy is decomposed into an immediately recoverable part and a stored one, which does not contribute to dissipation. This allows a complete mesoscopic cell model to be derived through (energy release-like) thermodynamic forces, and results in a standard generalized mesoscopic model.

Future work will consist in including the respective effects of inertia and thermal effects, i.e. dissipative heating, thermal softening and heat conduction, prior to proceeding to the statistical assembling of mesoscopic cells and thus to a macroscopic description of the voided material.

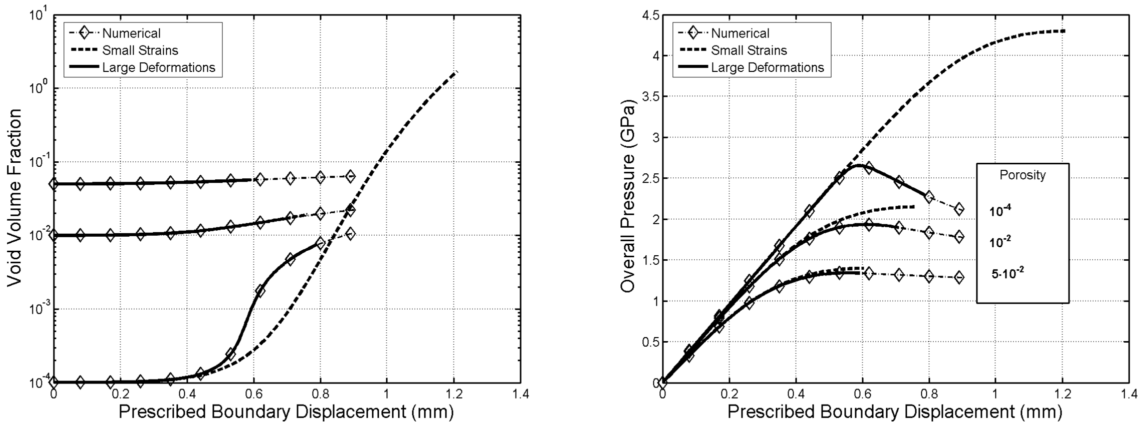

Figure 1 : *Porosity and overall pressure evolutions of a hollow sphere submitted to monotonic hydrostatic tension (prescribed displacement) for three initial porosities - Analytical large strain (continuous lines) and small strain (dashed lines) predictions vs. ABAQUS results (symbols).*

References

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