DYNAMIC RESPONSE OF DUCTILE MATERIALS CONTAINING CYLINDRICAL VOIDS : ANALYTICAL MODELING AND FINITE ELEMENT VALIDATION

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1 Introduction

The fracture of ductile materials is often the result of the nucleation, growth and coalescence of microscopic voids. In the present talk, we mainly focus on the growth process of voids. In dynamic loading, micro-voids sustain an extremely rapid expansion which generates strong acceleration of particles in the vicinity of cavities. These micro-inertia effects are thought to play an important role in the development of dynamic damage. To account for these large accelerations in the constitutive behavior, a multi-scale approach has been proposed in [1] and it has been shown that the micro inertia contribution to the macro stress is significant when dynamic loading is considered. Here we are focusing on the description of the behavior of the porous material containing cylindrical voids under dynamic conditions.

2 Modelling and Results

To derive the constitutive model, a multiscale approach is adopted where the acceleration contribution is accounted for. Indeed, under dynamic loading, the static definition for the macrostress (as the volume average of the local stress) does not exist further. The overall macroscopic stress is the sum of two contributions: the static term (micro-inertia independent term) and the dynamic term (micro-inertia dependent term):

$$\Sigma = \Sigma^{stat} + \Sigma^{dyn}$$

In this work, we focused on the material response of porous medium with cylindrical voids. As a consequence, a cylindrical representative volume element for the porous material is considered, similar to the one proposed by Gurson [2]. The radius of the void is a, the length is L. The outer radius of the RVE is b, see Figure 1. The porosity f is therefore given by $f = \left(\frac{a}{b}\right)^2$. The RVE is subjected to transversely isotropic loading.

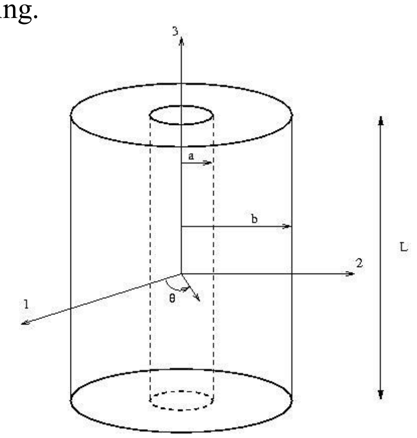

Fig 1: Representative volume element for a porous material containing cylindrical void.

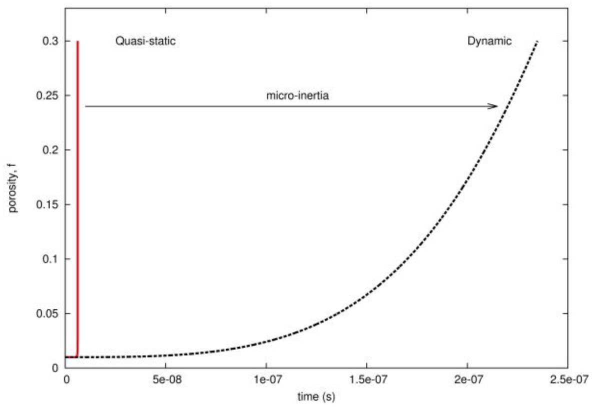

Fig 2: Evolution of the porosity during spherical loading. Quasi-static v/s dynamic results, the delay between dynamic and quasi-static predictions is due to micro-inertia effects.

The static term is derived from the visco-plastic yield function proposed by Gurson [2]. As a consequence, the present work is an extension to dynamic loading of the Gurson's model (cylindrical voids). The dynamic stress Σ^{dyn}needs to be evaluated analytically. Following the formalism proposed in [1], a trial velocity field is adopted to reproduce the velocity field which may prevail during the dynamic expansion of the RVE. Based on the Gurson's velocity field, it is shown, as for spherical voids, that the dynamic stress is scaled by the mass density, the size of the voids, the porosity, the strain rate tensor and the time derivative of the strain rate tensor. An important outcome of the model is the differential lengthscale effect which exists between in plane and out of plane components of the macrostress. Namely, it is observed that for the in plane stress components Σ_{11}^{dyn} and Σ_{22}^{dyn} are only related to the radius *a* while Σ_{33}^{dyn} is linked to the radius *a* and the length of the RVE *L*:

$$\Sigma_{11}^{dyn} = \rho a^2 F\left(f, D, \acute{D}\right) \Sigma_{22}^{dyn} = \rho a^2 G\left(f, D, \acute{D}\right) \wedge \Sigma_{33}^{dyn} = \rho a^2 H\left(f, D, \acute{D}\right) + \rho L^2 J\left(f, D, \acute{D}\right)$$

where D is the overall strain rate tensor.

In this talk, we will propose predictions of damage evolution when the RVE is subjected to spherical and axisymmetric plane strain loadings; here ramps at constant stress rate are considered. While for plane strain loading in quasi static condition, Σ_{33} is the half sum of the in plane components, in dynamic conditions, the inertia contribution reveals a difference. An important result of the proposed theory is the length effect of the RVE, which does not exist in quasi static conditions. A parametric study on the aspect ratio of the RVE will clarify this length scale effect. Next, the analytical model is validated based on comparisons with finite element calculations (Abaqus/Explicit) [3].

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