Nanovoids coalescence by internal necking

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NANOVOIDS COALESCENCE BY INTERNAL NECKING

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Abstract: Theoretical estimates for the onset of coalescence of nanoscale voids in anisotropic plastic material are obtained based on limit analysis and homogenization. Both axisymmetric and combined tension and shear loading conditions are considered. These analytical criteria are shown to be in good agreement with exact results obtained with finite-element simulations, and therefore can be used to model coalescence of nanoporous ductile materials.

1. Introduction

Nanoscale voids can be observed in metallic materials, for example on those used in nuclear power plants. Subjected to (neutron) irradiation, nanometric defects are formed due to ballistic interactions between particles and crystallographic structure, and under particular conditions, nanovoids are observed [1]. Example of such nanovoid in an irradiated material is shown on Fig. 1a. Molecular dynamics simulations have been used extensively to assess the deformation of nanovoids (see e.g. [2]), showing size effects (the smaller the void, the less the deformation) but a complete macroscopic model for the mechanical behavior of nanoporous metallic material is still lacking. Recently, homogenized models have been proposed to describe nanoporous isotropic materials in the growth regime (non-interacting voids with diffuse plastic flow) [3, 4] accounting for interface stresses, leading to extensions of the well-known Gurson model. No homogenized model is available so far to describe nanoporous materials in the coalescence regime (where voids strongly interact with each other). The aim of this study is thus to obtain, for nanoporous metallic materials, homogenized criteria for the onset of coalescence, i.e. to describe the transition from diffuse plastic flow to localized plastic flow in the intervoid ligament.

2. Results

Following the pioneering work of Thomason [5], limit analysis along with homogenization is used to describe the onset of coalescence of nanoporous material and to obtain coalescence stress as the limit load of a cylindrical unit-cell containing a cylindrical void (Fig. 1b). Matrix material is assumed to be rigid-perfectly plastic (of yield stress σ_0), obeying von Mises isotropic or Hill anisotropic plasticity criteria. Isotropic interface stresses are considered following [3, 4] with an interface strength *k*, and extended to the anisotropic case. Theoretical estimates for the coalescence stress obtained through limit analysis are evaluated with comparisons to exact coalescence stress obtained through numerical limit-analysis with finite elements simulations [6]. Under axisymmetric loading conditions, for both isotropic and anisotropic matric materials, simple analytical formulas are obtained to account for the increase of stress required for the onset of coalescence due to interface stresses, as a function of the dimensionless ratio $\Gamma=k/(\sigma_0 R)$. These formulas are in very good agreement with numerical results in the relevant case of elongated voids, as shown on Fig. 2 for the isotropic case. Under

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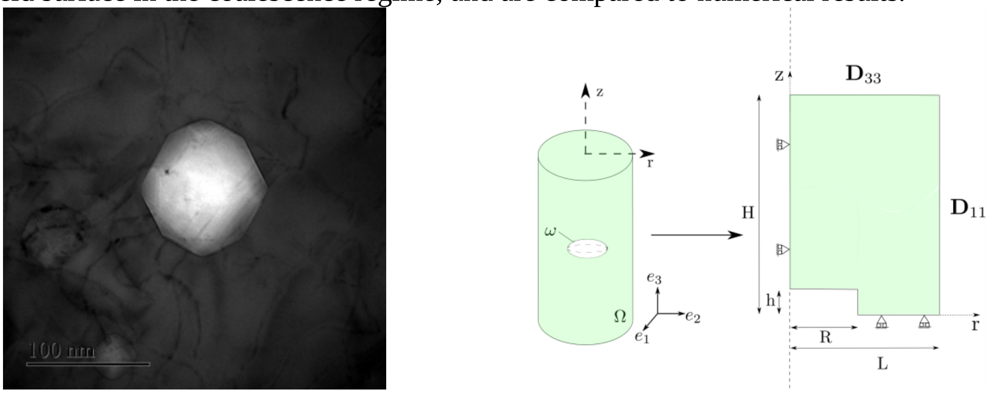
combined tension and shear loading conditions, parametric equations are obtained to describe the yield surface in the coalescence regime, and are compared to numerical results.



(a) (b)

Figure 1. (a) Nano-void observed in Iron-irradiated austenitic stainless steel. (b) Cylindrical unit-cell considered as an approximation of a unit-cell of a periodic array of voids of hexagonal lattice under periodic boundary conditions

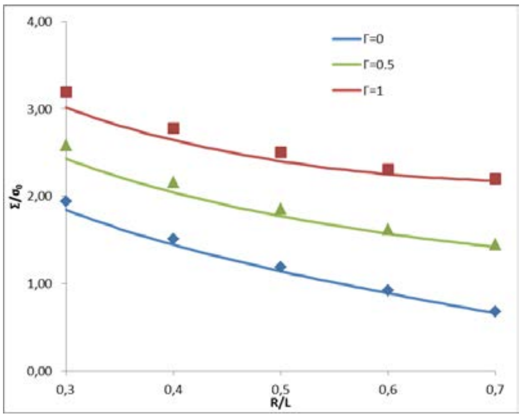


Figure 2. Coalescence stress (normalized by the yield stress of the von Mises matrix) as a function of the size of the void (normalized by the size of the unit-cell), as a function of the parameter Γ. Lines correspond to the analytical model, points to numerical results.

3. Conclusions

Theoretical estimates for the onset of coalescence of nanoscale voids in anisotropic plastic matrix have been obtained based on limit analysis and homogenization, under both axisymmetric and combined tension and shear loading conditions. Good agreement observed between the analytical estimates and exact numerical results makes these estimates suitable to provide an analytical yield surface for nanoporous materials in the coalescence regime.

References

[1] G. Was (2007), *Fundamentals of Radiation materials Science*, Springer.
[2] S. Brach, L. Dormieux, D. Kondo, G. Vairo. A computational insight into void-size effects on strength properties of nanoporous materials, *Mech. Mat*. 2016:101:102-117.
[3] L. Dormieux, D. Kondo. Non linear homogenization approach of strength of nanoporous materials with interface effects, *Int. J. Eng. Sci*. 2013:71:102-110.
[4] V. Monchiet, D. Kondo. Combined voids size and shape effects on the macroscopic criterion of ductile nanoporous materials. *Int. J. Plasticity*. 2013:43:20-41.
[5] P.F.Thomason, (1990). *Ductile Fracture of Metals*. Oxford, Pergamon Press
[6] L. Morin, J.B. Leblond, A.A. Benzerga. Coalescence of voids by internal necking: theoretical estimates and numerical results. *J. Phys. Mech. Solids*. 2015:75:140-158.