A NEW PLASTICITY CRITERION FOR POROUS SINGLE CRYSTALS

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Summary A new procedure is developed to estimate the effective behaviour of a rigid-ideal-plastic metallic matrix containing spherical voids. The proposed new plasticity criterion, which is based on variational homogenization method, allows predicting the yield criterion for a given nonlinear porous single crystal. The analytical results are compared with 3-D FE simulations of a unit cell made of a single crystal containing a single void, to study the effect of crystallographic orientation, triaxial stress state and porosity on the yield surfaces of a porous single crystal.

INTRODUCTION

Since the last forty years, much effort has been made to predict damage evolution and fracture of ductile materials at macro and mesoscopic scales (see [1, 2, 3]), by taking into account different characteristic features (*e.g.* void shape, porosity, plastic anisotropy of the matrix, etc.). Recent progress of the homogenization methods allows to determine the effective response of a multi-phase polycrystalline aggregate with intergranular cavities [4, 5]. However, so far, very few analytical studies have been done to predict in particular the effective behaviour of porous single crystals. The development of micro- and nano-technologies required a better mastery of void damage within a single crystal, via both constitutive [6] and numerical modeling [7, 8].

The objective of this work is to propose a new constitutive model to estimate the effective response of a single crystal containing spherical voids, which will be compared to the numerical results obtained by 3-dimensional finite element unit cell analysis. The influence of stress triaxiality, crystallographic orientation as well as porosity on evolution of the yield surface is then discussed. The developed damage model will be later applied for the study of the influence of cavity swelling on mechanical properties of the irradiated austenitic stainless steels used in nuclear reactor core. These tiny cavities, formed during irradiation, are observed at the nanometer scale and located within the austenitic grains. The cavity swelling phenomenon is regarded as one of the potential limiting factors for plant life extension beyond 40 years.

CONSTITUTIVE MODEL DEVELOPMENT AND VALIDATION

Motivated by the variational approach proposed by Ponte Castañeda [9], the stress potential of a porous nonlinear viscous single crystal is compared with the Hashin-Shtrikman lower bound of the estimated effective stress potential of the corresponding linear comparison single crystal. Hence, an approximate effective stress potential of the porous single crystal is derived. According to this expression, the effective shear stress of each slip system can be transformed to get the yield criterion of a porous single crystal, as illustrated by the 3-dimensional yield surface in Figure 1 (for the $[\bar{1}25] - [1\bar{2}1] - [210]$ triaxial loading direction).

A three-dimensional unit cell containing one single central void is meshed using the Zebulon finite element code (see Figure 2) and a series of numerical simulations including a face-centered cubic (FCC) crystal plasticity behaviour have been performed, in order to identify model parameters. Ten levels of stress triaxiality from 0 to infinity, 8 representative crystallographic orientations and 5 void volume fractions ranging between 0.5% and 10% are chosen to investigate the effect of various microstructural features on the shape of the yield surface in the porous single crystal.

CONCLUSIONS AND OUTLOOK

According to the comparison between constitutive model results and above-mentioned numerical simulation results, the proposed yield criterion is able to give a very good prediction of the yield surfaces of the given single crystal. The triaxial stress state strongly affects the elastic limit of the porous single crystal. For the low level of triaxiality, the shape of the yield surface mainly depends on the crystallographic orientation. However for high triaxiality level, its shape is mainly controlled by porosity.

The present work has focused on the prediction of the yield criterion of voided single crystals, with the proposed constitutive model. To enrich our single crystalline damage model, further work will be needed to develop a corresponding void growth rule, allowing to model the effective response of porous single crystal under triaxial loads, with help of 3-D unit cell simulations.

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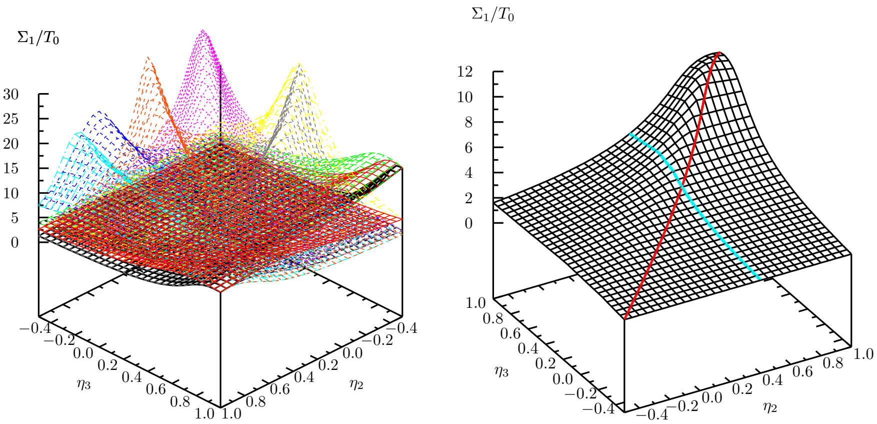
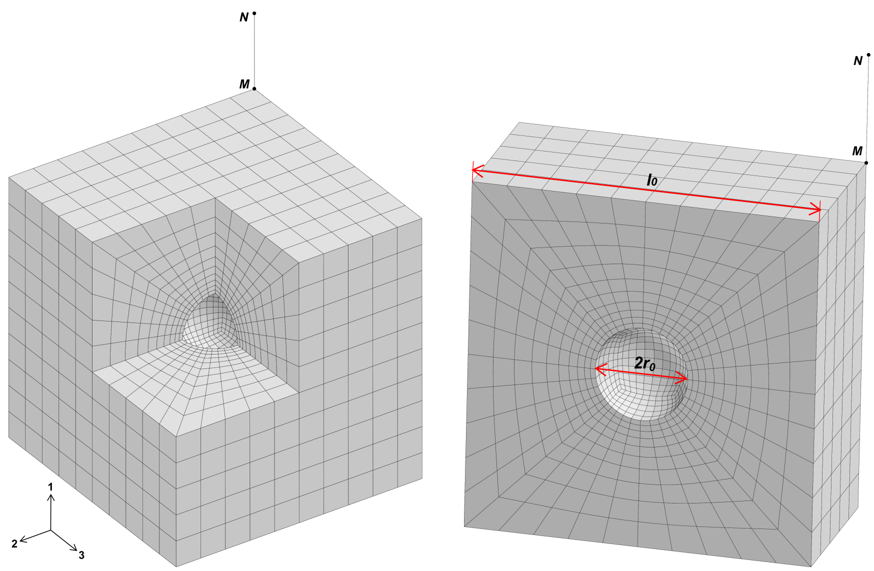


(a) (b)

Figure 1: 3-dimensional yield surfaces for $[\bar{1}25] - [1\bar{2}1] - [210]$ triaxial loading direction: (1a) yield surfaces for all 12 slip systems; (1b) yield surface of the overall porous single crystal.



(a) (b)

Figure 2: Unit cell containing one single void: (2a) FE mesh of $f = 0.01$, with cut of $1/8$ of the full geometry; (2b) half of the full geometry to describe dimensions of the voided cell.

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