PREDICTION OF LOCALIZED NECKING IN POLYCRYSTALLINE AGGREGATES BASED ON PERIODIC HOMOGENIZATION

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Ductile failure is the main mechanism that limits the formability of thin metal sheets during forming processes. In the current contribution, ductile failure is assumed to be solely induced by the occurrence of localized necking within the sheet metal. Hence, other failure scenarios such as damage evolution are excluded in this study. It is well known from a number of previously reported works that the onset of localized necking in thin sheets is strongly dependent on the microstructure-related parameters, such as initial and induced textures, grain morphology and crystallographic structure. To accurately understand and analyze this dependency, several micromechanical constitutive frameworks have been coupled in the literature with various localized necking criteria ([1]). The aim of the current investigation is to contribute to this effort by developing a powerful and efficient numerical tool to predict the onset of localized necking in polycrystalline aggregates, which are assumed to be representative of thin metal sheets. In this tool, the periodic homogenization multiscale scheme is used to accurately derive the mechanical behavior of polycrystalline aggregates from that of their microscopic constituents (the single crystals). Compared to other multiscale schemes, such as the Taylor model or the self-consistent approach, the periodic homogenization technique allows us to acurately consider some important aspects in the modeling of the polycristalline behavior (realistic description of the morphology of the grains, boundary conditions, grain boundaries...). The constitutive framework at the single crystal scale follows a finite strain formulation of rate-independent crystal plasticity. At this scale, the Schmid law is used to model the plastic flow and the hardening is defined by a non-linear power law relating the evolution of the critical shear stresses to the slip rates of the crystallographic slip systems. From a numerical point of view, the periodic homogenization problem is solved by using the finite element method. In the present study, we have used ABAQUS/Implicit finite element code, where the polycrystalline aggregate is discretized by 3D finite elements. Each grain is assigned to one finite element. The periodic boundary conditions as well as the macroscopic loading are applied on the polycrystalline aggregate by using the Homtools developed by Lejeunes and Bourgeois ([2]). As the developed model is used to study the ductility limit of thin sheets, the macroscopic plane stress condition (in the thickness direction of the sheet) is legitimately adopted ([3]). The single crystal constitutive equations are integrated by using a powerful and robust numerical implicit scheme belonging to the family of ultimate algorithms ([4]). This numerical scheme is implemented via a user material subroutine (UMAT) into Abaqus. To predict the incipience of localized necking in polycrystalline aggregates, the developed periodic homogenization scheme is coupled with the bifurcation approach ([5]). With this approach, the localization phenomenon is viewed as a consequence of instability in the constitutive description of uniform deformation. In other words, the occurrence of strain localization is a result of jump in the macroscopic velocity gradient of the deformed solid. It is noteworthy that, besides its sound theoretical foundations, the bifurcation approach does not need the calibration of any additional parameter, such as the geometric imperfection factor required when the M–K analysis is used ([6]). The use of the Schmid law at the single crystal scale allows predicting localized necking at realistic strain levels. To apply the bifurcation approach for the prediction of strain localization, the macroscopic tangent modulus should be determined. In the current work, this tangent modulus is derived by a condensation of the global stiffness matrix ([7]). This global stiffness matrix is determined by coupling a 3D user element (UEL), used to compute the element stiffness matrices, with a Python Script developed to assembly these matrices. We have also developed a set of Python Scripts to condense the global stiffness matrix and then to obtain the macroscopic tangent modulus. Compared to other numerical techniques, such as the fluctuation technique ([8]) and the perturbation technique ([9]), the condensation technique seems to be the most appropriate and the most robust to derive the macroscopic tangent modulus. The performance and accuracy of the proposed computational methods will be demonstrated for representative numerical problems dealing with polycrystals

with microstructures of FCC single crystals. The evolution of the macroscopic tangent modulus during the loading will be particularly analyzed and commented. A sensitivity study will be conducted in order to investigate the effect of some microstructure parameters (initial crystallogrpahic texture, initial morphology of the grains...) on the prediction of localized necking. In order to investigate the effect of the multiscale scheme on the predictions of strain localization, the results obtained with the current model will be compared with the results obtained with other multiscale schemes (the Taylor model and the self-consistent approach).

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