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An Adaptive Multiscale Resolution Strategy for the Analysis of Microheterogeneous Structures

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ABSTRACT

This work is concerned with the adaptive multiscale resolution analysis of microheterogeneous structures that exhibit localization zones where standard homogenization techniques may fail. Localization is observed ahead of stress concentration points, near shear bands, within the process zone ahead of crack tips and at boundary layers near contact interfaces. These zones are typically accompanied by high gradients of the macroscopic deformation gradient tensor such that the variation of the macroscopic deformation gradient over microstructural length scales becomes significant, in disagreement with fundamental volumetric homogenization assumptions. A central goal of this study, therefore, is to adaptively identify multiple regions of macroscale structural resolution in order to improve the accuracy and the reliability of macrostructural analyses. These regions of resolution will vary from zones where homogenization techniques are employed to zones with an explicit microstructural representation and analysis where homogenization assumptions fail.

For this purpose, sample microstructures that sustain finite deformation damage are considered. The method of enforcing appropriate boundary conditions at finite deformations will be discussed in the context of penalty formulations [1]. Subsequently, the macroscopic tangent that is consistent with this enforcement technique is derived, using tangent matrix condensation strategies [2]. An analytical argument based on the micro-macro energy balance [1] will be demonstrated for infinitesimal and finite deformation regimes which demonstrates that the macroscopic constitutive behavior displays pure damage if solely damage is allowed on the microscale. The computational results will be shown to be consistent with this conclusion, and as such these methods comprise a robust methodology for extracting the macroscopic constitutive behavior of the microstructure without recourse to explicit constitutive modeling. However, the underlying condensation procedure for the macroscopic tangent computation is a computer memory intensive application that is not practical for large micromechanical test samples. It will be demonstrated that the macroscopic tangent may alternatively be extracted to high accuracy

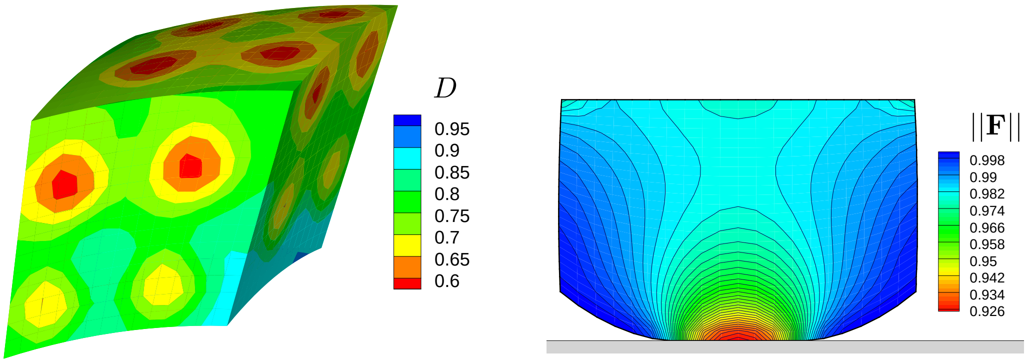

Figure 1: *(LEFT) Homogenization boundary conditions are applied with a superimposed gradient of the macroscopic deformation gradient on a periodic test sample with eight unit-cells and the nonlinear isotropic damage parameter D is plotted. (RIGHT) A macroscopic, homogeneous, frictionless contact problem that demonstrates the strong gradients of the macroscopic deformation gradient tensor ($\mathbf{F}$) near the contact interface.*

with perturbation techniques for the class of inelastic problems considered with a minimal number of micromechanical tests [3].

Based on the presented micromechanical framework, sample macroscale problems will be analyzed using the multilevel finite element technology without any recourse to explicit constitutive formulations for the microheterogeneous structure. Of particular importance is the construction of indication functions that correctly identify localization effects (Fig 1) and that can predict the size of the *critical region* where such effects are predominant. For this purpose, it is demonstrated (Fig 1) that the degradation of standard homogenization results is strongly coupled to the gradient of the macroscopic deformation gradient tensor [4]. Subsequently, based on the magnitude of this gradient with respect to the microstructural length scale, a criterion is built to automatically identify the critical region where an alternative strategy must be pursued to overcome the shortcoming of the inaccuracy induced by the homogenization process. This alternative strategy is proposed to be an explicit microstructural representation and analysis in the critical region. Of critical importance is an efficient numerical resolution of the localization zone, which requires mesh refinement techniques that are appropriate for the class of finite deformation problems considered. Accordingly, the proposed methodology admits refinement in the material modeling space as well as in the numerical discretization space.

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