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# FINITE ELEMENT SIMULATION OF DUCTILE DAMAGE USING A THREE FIELD FORMULATION BASED NONLOCAL MODEL

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## ABSTRACT

Ductile fracture prediction and control remain pivotal topics in many industrial situations such as gas and oil transportation by pipelines, airplanes maintenance. . . In these applications, installations cost and size render full-scale experiments difficult or even impracticable. Predictive, robust and reliable numerical analyses are thus of great importance to model crack nucleation, growth and path. Continuum Damage Mechanics based models [1, 2] are promising tools to simulate ductile crack initiation and extension as they rely on a description of actual damage processes (i.e. void nucleation, growth and coalescence). They, however, lead to a strong mesh dependency when used within standard displacement based finite element formulations [3]. In order to solve this problem, nonlocal formulations considering either gradient of state variables [4] or high order continua [5] can be used. In addition, high strain levels may be reached before ductile damage becomes high so that the material can be considered as quasi-incompressible during a significant part of the loading history. When damage is high, plastic volume change then becomes significant. This requires the use of mixed finite elements [6, 7] which can deal with quasi-incompressibility and also provide a much more reliable evaluation of hydrostatic pressure which largely controls damage growth.

In this work three-field (displacement, pressure, volumetric strain) finite elements are used to simulate growth of ductile damage in cracked specimens. This first allows a better calculation of hydrostatic stresses and therefore of damage growth. Volumetric strain, $\theta$, being a nodal variable, its gradient (either Eulerian or Lagrangian), $\vec{\nabla}\theta$, can easily be computed. In the case of ductile damage controlled by void growth, volumetric strain is directly related to porosity which is the damage variable. A penalty term function of $\vec{\nabla}\theta$ is added to the finite element variational (consequently weak) formulation so as to avoid strong damage localization. The corresponding strong form is derived and it is shown that it corresponds to a microdilatation theory of a high order continua [5]. Different element formulations are compared: (i) quadratic displacement interpolation, linear pressure and volumetric strain interpolation, (ii) quadratic displacement and pressure interpolation, linear volumetric strain interpolation, (iii) linear interpolation for all fields using mixed-enhanced elements [7].

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