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Damage evolution and thermal coupled effects in inelastic solids

M. Vaz Jr.*, P.A. Muñoz-Rojas, M.R. Lange

Department of Mechanical Engineering, State University of Santa Catarina, Campus Universitario, 89223-100 Joinville, Brazil

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ABSTRACT

Mechanical degradation and ductile failure in metal forming operations can be successfully modelled using Continuum Damage Mechanics. In addition to elastic–plastic deformations, heat transfer affects material behaviour, imposing further effects upon damage evolution. This paper addresses modelling aspects and presents a numerical discussion of the coupled effects between ductile damage and temperature evolution. The heat transfer problem is formulated based on a transient heat conduction approximation, in which heat transfer at the free surfaces and heating due to dissipation of the inelastic work are accounted for. Damage is modelled using an elastic–plastic fully coupled approximation, in which differences in tensile and compressive stress states are included.

1. Introduction

The constant pursuit of improvement in products and manufacturing processes has prompted industries to using numerical simulation in an increasing scale. This effort has raised greater expectation of new computational developments, creating the environment to foster expansion of commercial packages. Most such codes can simulate intricate geometries and coupled problems, however, the development of new materials and simulation of complex multiphysics behaviour still require further interaction between industries and academia. For instance, constitutive models able to simulate mechanical degradation in metal forming operations subject to general stress–strain deformation paths are still very limited in commercial codes. In this case, in addition to a robust large deformation formulation, the successful approach must account for a damage model capable to describe different effects owing to tensile and compressive stress states. Furthermore, in several metal forming processes, temperature evolution plays an important role thereby requiring inclusion of heat transfer effects. The heat transfer factor is important, not only to temperature-dependent properties, but also to evolution of the mechanical degradation itself. The latter imposes a high nonlinearity to the problem, which in turn, requires a careful attention to the thermal and mechanical coupling scheme.

This work is placed within the framework described above, in which aspects of mechanical degradation and temperature evolution are addressed. Mechanical degradation is modelled using concepts of Continuum Damage Mechanics (CDM), in which a new damage function was defined aiming at modelling void nucleation, growth and coalescence under tension and void closure under compression. Inclusion of such effects is accomplished by a modification of the damage strain energy release rate. Temperature variations are obtained by solving a transient, conjugated heat conduction problem that includes dissipation of the inelastic work and heat transfer at the free surfaces.

2. Mechanical degradation and damage evolution

2.1. Modelling approaches

The literature has shown an increasing number of works on modelling mechanical degradation and failure of fracture-free ductile materials. In spite of so many strategies, one could divide such formulations into three general approaches: (i) post-processed damage assessment, (ii) porous materials formulations and (iii) thermodynamic-based modelling, also referred as continuum damage mechanics.

Post-processing damage evaluation consists of computing a material degradation indicator based on the solution of the mechanical problem, i.e. this strategy does not couple damage growth to inelastic deformation history. Post-processing techniques have been frequently associated to modelling ductile failure prediction, being very attractive due to implementation simplicity. However, accuracy is affected when mechanical degradation is decoupled from the material model. The criteria are generally based on energy dissipation (e.g. plastic work) and void growth (e.g. void growth mechanisms and void geometry). The literature on ductile failure has shown several comparative works with mixed conclusions [1–5]. Bao and Wierzbicki [4], also in the context of ductile fracture prediction, have extensively discussed application of some post-processed criteria based on numerical

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* Corresponding author.
E-mail address: M.Vaz@joinville.udesc.br (M. Vaz Jr.).

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