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An Eulerian method for finite deformation anisotropic damage with application to high strain-rate problems

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Abstract

This paper is dedicated to establishing a thermodynamically compatible Eulerian theoretical framework for elastoplastic anisotropically damaging materials, that is applicable to high strain rate and strongly compressible problems. The proposed model comprises a system of thermodynamically compatible balance laws based upon hyperelastic-inelastic theory: the mechanical conservation laws are supplemented by kinematic evolution equations for material deformation gradients, which can be written in conservative form. The formulation is rotationally invariant and hyperbolic, with a determinable characteristic structure. An operator split approach is proposed for integrating the governing constitutive models for three-dimensional Cauchy problems, in conjunction with a ghost material numerical method to resolve internal Dirichlet boundaries. Such methods naturally allow the generation of new internal boundaries making them ideal for simulating fragmenting materials and macroscale fracture. A remarkable feature of the proposed approach is that the overall complexity compares favourably with that of the model for elastoplastic deformations only. The simulation of expanding ring and flyer plate experiments are chosen to demonstrate the effectiveness of the proposed approach.

Keywords: dynamic fracture, finite strain, rate-dependent material, numerical algorithms, finite differences

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1. Introduction

Problems in solid dynamics such as high-velocity impacts involve high strain-rate loading and finite strain elastoplastic deformations. Subjected to such extreme conditions the material can fail through the accumulation of non-spherical states of damage. Accurate predictions of these behaviours requires comprehensive constitutive models, and numerical methods that are capable of resolving complex non-smooth flows, large material distortions, and internal tearing as a result of ultimate failure. Eulerian approaches, which employ fixed meshes and feature the ability to resolve internal material boundaries, avoid the unacceptable and potentially catastrophic errors that can plague conventional fixed connectivity Lagrangian methods subjected to such conditions. Historically, many of the Eulerian methods for solid dynamics reported in the open literature solve hypoelastic systems on staggered grids and rely on explicit artificial viscosity terms to resolve shocks. However, in recent years it has been demonstrated that cell centred Godunov type methods applied to hyperelastic-plastic models can effectuate better resolved simulations (Barton et al., 2009, 2010, 2013; Favrie et al., 2009; Gavrilyuk et al., 2008; Hill et al., 2010; López et al., 2014; Miller and Colella, 2001, 2002; Stoch et al., 2013; Titarev et al., 2008; Trangenstein and Colella, 1991). Godunov methods are based upon solving local Riemann problems to approximate numerical flux functions – and by doing so implicitly introducing the required numerical viscosity – in order to resolve non-linear Cauchy problems. In many of these previous works the numerical methods have, at least in part, been

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