Frame indifferent elastoplasticity of frictional materials at finite strain

A. Karrech a,b,⇑, K. Regenauer-Lieb a,c, T. Poulet a,c

⇑ Corresponding author at: CSIRO Earth Science and Resource Engineering, 26 Dick Perry Ave, Kensington, WA 6151, Australia.
E-mail address: kar10b@csiro.au (A. Karrech).

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1. Introduction

Large transformations of elasto-plastic materials has been the subject of an extensive research work to describe the behaviour of metals (Lin, 2002; Lin and Brocks, 2004; Lin et al., 2006b), polymers (Nedjar, 2001a,b; Wu et al., 2005), rubber-like materials (Reese and Wriggers, 1997), frictional materials (Betten, 1982; Callari et al., 1998; Meschke and Liu, 1999; Borja, 2004; Rouainia and Wood, 2006), etc. Most of these formulations are based on the pioneering numerical developments of Simo and Pister (1984), Simo and Ortiz (1985), Simo and Taylor (1985), Simo (1985, 1988, 1992), Amero and Simo (1993), etc. These models are derived using the classical thermodynamic framework of generalized standard materials as introduced by Halphen and Nguyen (1975) and its extension to frictional materials’ plasticity using ad hoc dissipation potentials. In addition, these formulations used the classical corotational rates (based on the spin tensor of Jaumann, Green–Naghdi, or Trusdell) which produce aberrant oscillations or hyperbolic responses especially when materials are subjected to large shear stresses (Dienes, 1979; Simo and Pister, 1984; Muhlhaus and Regenauer-Lieb, 2005).

Recent developments by Houlsby and Puzrin (2000, 2006), Nguyen and Houlsby (2007) introduced a framework which describes the behaviour of non-associated materials in accordance with the principles of thermodynamics. In addition, new mathematical formulations by Bruhns (2003), Xiao et al. (2006) suggested new spins which produce stable co-rotational rates based on the principle of frame indifference of deforming bodies. These new formulations as well as the numerical procedures of Simo and co-workers represent a rigorous basis for the development of mathematical models describing the behaviour of fractional materials within the framework of thermodynamics. The scope of this approach can be useful for geo-materials inside shear zones where strains can be excessively high (Regenauer-Lieb et al., 2001, 2006, 2010) and classical engineering approaches are not designed to predict accurately their deformation modes. Understanding the behaviour of these shear zones is a challenging issue since they represent hosting areas for mineral deposits as proved by structural and seismic studies (Blewett et al., 2010; Davis et al., 2010).

In the current paper, we extend the thermodynamic framework of frictional materials suggested by Houlsby and Puzrin (2006) to the context of large transformations. Within this framework, we develop a frame indifferent finite strain model based on the logarithmic co-rotational rates of Xiao et al. (2006) to describe the elasto-plasticity non-associated materials (the particular case of Drucker–Prager is used for illustration purposes). We also describe the numerical procedure used to implement the current approach in finite element based on existing numerical techniques of return mapping (Simo and Taylor, 1985) and their extension to the multiplicative plasticity (Simo, 1992; Nedjar, 2001a,b).

2. Thermodynamic background at finite strain

In order to describe the kinematics of a deformable body, consider an open bounded domain \( \Omega_0 \subset \mathbb{R}^3 \) representing the reference...